Dear Reader:

Enclosed is a summary of the *Operation of Glen Canyon Dam Final Environmental Impact Statement*. This summary is intended for readers who desire a brief but complete overview of the contents of the environmental impact statement (EIS).

Nine alternatives are presented covering a full range of possible operations of Glen Canyon Dam. Two of the alternative operations evaluated, including no action, would allow unrestricted hourly fluctuations; four would provide various levels of restricted fluctuating flows; and three would provide steady flows. Additional measures are combined with the alternative operations, where appropriate, to provide additional resource protection or enhancement.

The EIS team and cooperating agencies attempted to balance benefits to all resources in identifying a preferred alternative. As a result of comments on the draft EIS and discussions with the U.S. Fish and Wildlife Service, the preferred alternative described in the draft EIS was modified for this final EIS. The preferred alternative is the Modified Low Fluctuating Flow Alternative.

To obtain a copy of the entire final EIS or find out where you can review a copy, please contact:

Bureau of Reclamation
Attention: Colorado River Studies Office
125 South State Street, Room 6107
Salt Lake City UT 84138-1102
Telephone: 801-524-5479

The final EIS will be used by decisionmakers in the Bureau of Reclamation and the Department of the Interior and is provided for public information. A record of decision can be approved 30 days after publication of release of the final EIS in the *Federal Register*. Any decision regarding the operation of Glen Canyon Dam, as well as opportunities for future public involvement, will be well publicized.

Sincerely,

Charles A. Calhoun, Regional Director
Upper Colorado Region
Bureau of Reclamation

The glories and the beauties of form, color, and sound unite in the Grand Canyon—forms unrivaled even by the mountains, colors that vie with sunsets, and sounds that span the diapason from tempest to tinkling raindrop, from cataract to bubbling fountain. . . . A year scarcely suffices to see it all. It has infinite variety, and no part is ever duplicated. Its colors, though many and complex at any instant, change with the ascending and declining sun; lights and shadows appear and vanish with the passing clouds, and the changing seasons mark their passage in changing colors.

JOHN WESLEY POWELL

Overview

This overview briefly describes the need, alternatives, and issues of the Glen Canyon Dam Final Environmental Impact Statement. The summary provides greater detail.

This environmental impact statement (EIS) analyzes a range of alternative Glen Canyon Dam operations designed to protect downstream resources and Native American interests in Glen and Grand Canyons, as well as to produce hydropower.

Glen Canyon Dam—the key feature of the Colorado River Storage Project—was completed by the Bureau of Reclamation in 1963 as a multipurpose facility. The purposes for which the dam was constructed are set forth in the Colorado River Storage Project Act of 1956 and include, among others: regulating the flow of the Colorado River; water storage; reclamation of arid and semiarid lands; flood control; and hydroelectric power generation, "... as an incident of the foregoing purposes."

The Colorado River is the main influence in the dynamic ecosystem of these canyons. Glen Canyon Dam brought about fundamental changes in the river and predam ecosystem. Sediment transport and supply have been reduced, and controlled volumes of cold, clear water annually pass through Glen and Grand Canyons. Both native and non-native fish that cannot tolerate these conditions have declined or disappeared from the canyon. Other species and communities that were rare or nonexistent before the dam now abound.

Alternatives

None of the alternatives presented in this EIS can return the system to predam conditions. However, this EIS considers nine alternate ways to operate the dam to reduce further adverse impacts on or to enhance the valuable ecosystem components that remain or have developed under postdam conditions. These alternatives propose changes in maximum and minimum flows, daily flow fluctuations, and rate of change in fluctuations (ramp rate). The alternatives would change the riverflows below the dam (also called discharges or releases), which are measured in cubic feet per second. Annual or monthly volumes are measured in acre-feet.

The alternatives are variations of dam operations, ranging from unrestricted fluctuations to steady flows. The impacts often vary only slightly among alternatives. The EIS team and cooperating agencies considered the sum total of these sometimes subtle variations in recommending the preferred alternative—the Modified Low Fluctuating Flow Alternative.

Affected Resources

By analyzing public comments, the EIS team refined and evaluated issues of concern, identifying the following resources to be evaluated: water, sediment, fish, vegetation, wildlife and habitat, endangered and other special status species, cultural resources, air quality, recreation, hydropower, and non-use value.

The canyon supports a complex system formed by interactions between communities of organisms and their environment, or an ecosystem. Changes in a single process can affect resources throughout the system. The EIS focuses on two processes that form linkages affected by dam operations.

- **Water release patterns** directly or indirectly affect physical, biological, cultural, recreational, and hydropower resources.
- **Sediment transport** and supply stabilizes archeological sites and camping beaches, develops and maintains backwater habitats, transports nutrients, and provides a foundation for vegetation that in turn provides wildlife habitat.

These two processes affect the complex, linked resources in the Colorado River corridor downstream from the dam. For example:

- **Aquatic resources** form a chain: river conditions created by the dam operations allow a native alga, *Cladophora glomerata*, to flourish. This alga, in turn, provides habitat for diatoms and for insect larvae and crustaceans that feed on diatoms. Together, these are an important food source for non-native trout, native fish, and other organisms. Habitat changes and non-native fish have created problems for native fish.
- **Terrestrial resources** are linked together, as well as to aquatic resources. Water release patterns and sediment affect riparian and emergent marsh vegetation which provide habitat for wildlife.

Environmental Consequences

This EIS evaluates the alternatives' effects on both short-term needs of the environment and long-term requirements to maintain and support the ecological elements of Grand Canyon. These evaluations use indicators for each resource to measure the effects alternatives would have on that resource.

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Purpose of and Need for Action

The Federal action considered in this environmental impact statement (EIS) is the operation of Glen Canyon Dam, Colorado River Storage Project (CRSP), Arizona.

Purpose

On July 27, 1989, the Secretary of the Interior (Secretary) directed the Bureau of Reclamation (Reclamation) to prepare an EIS to reevaluate Glen Canyon Dam operations. The purpose of the reevaluation is to determine specific options that could be implemented to minimize—consistent with law—adverse impacts on the downstream environmental and cultural resources, as well as Native American interests in Glen and Grand Canyons.

Need

The need for this reevaluation stems from concerns about impacts to downstream resources caused by the operation of Glen Canyon Dam. Such impacts have been identified from scientific studies, resulting in significant public concern. Analysis of an array of reasonable alternatives is needed to allow the Secretary to balance and meet statutory responsibilities for protecting downstream resources and producing hydropower, and to protect affected Native American interests.

In addition, the Grand Canyon Protection Act of 1992 was enacted October 30, 1992. Section 1802 (a) of the act requires the Secretary to operate Glen Canyon Dam:

> *. . . in such a manner as to protect, mitigate adverse impacts to, and improve the values for which Grand Canyon National Park and Glen Canyon National Recreational Area were established, including, but not limited to natural and cultural resources and visitor use.*

BACKGROUND

Glen Canyon Dam was completed by Reclamation in 1963 as a feature of the CRSP. The underlying project purposes are defined by section 1 of the Colorado River Storage Project Act of 1956, which authorized the Secretary to construct, operate, and maintain Glen Canyon Dam:

> *. . . for the purposes, among others, of regulating the flow of the Colorado River, storing water for beneficial consumptive use, making it possible for the States of the Upper Basin to*

> *utilize, consistently with the provisions of the Colorado River Compact, the apportionments made to and among them in the Colorado River Compact and the Upper Colorado River Basin Compact, respectively, providing for the reclamation of arid and semiarid land, for the control of floods, and for the generation of hydroelectric power, as an incident of the foregoing purposes. . .*

Since the dam was completed prior to enactment of the National Environmental Policy Act (NEPA), no EIS was filed regarding construction or operation of Glen Canyon Dam.

The "Law of the River"—a collection of Federal and State statutes, compacts, court decisions and decrees, Federal contracts, a treaty with Mexico, and formally determined long-range operating criteria—define the operation and management of the Colorado River.

The powerplant at Glen Canyon Dam has been used primarily for generating power during high demand periods (peaking power). The daily fluctuating releases associated with peaking power operations have caused concern among Federal, State, and Tribal resource management agencies; fishing and rafting interests; and environmental groups concerned about detrimental effects on downstream cultural resources, vegetation, wildlife, and other river resources.

These concerns were expressed most forcefully by the public during two Reclamation studies on possible increases in peaking power generation at Glen Canyon Dam. Although an uprate and rewind of powerplant generators was completed in 1987, Reclamation agreed not to use the increased generating capacity until completing a more comprehensive study of impacts from historic and current dam operations. Maximum releases have been limited to 31,500 cubic feet per second (cfs) instead of the potential 33,200 cfs that resulted from the uprate and rewind.

Glen Canyon Environmental Studies

In December 1982, Reclamation initiated the multiagency Glen Canyon Environmental Studies (GCES) to respond to the concerns of Federal, State, and Tribal agencies and the public. GCES Phase I was completed in 1988. In June 1988, GCES Phase II was initiated to gather additional data on specific operational elements. Agencies and individuals cooperating in the studies include Federal and State resource agencies, Indian Tribes, private consultants, universities, and river guides. CRSP power revenues have funded these studies, which form the basis for the impact assessment presented in the EIS.

Interim Operations

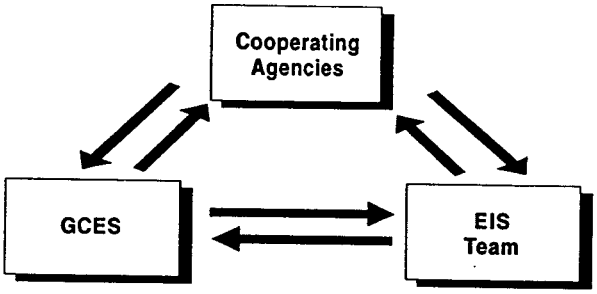
To protect downstream resources until completion of this EIS and the record of decision (ROD), Reclamation began testing interim operations on August 1, 1991. The interim operating criteria and a monitoring program were implemented on November 1, 1991. Although the criteria may be modified based on new information, they will remain in effect until the EIS and ROD are completed. These interim criteria are essentially the same as those described later under the Interim Low Fluctuating Flow Alternative. The interim operating criteria:

- Restrict peak releases to 20,000 cfs
- Limit minimum releases to 5,000 cfs at night and 8,000 cfs during the day
- Limit daily fluctuations to between 5,000 and 8,000 cfs, depending on the monthly release volume
- Limit the rate of change to 2,500 cfs per hour (cfs/hr) during periods of increasing releases and 1,500 cfs/hr during periods of decreasing releases

Cooperating Agencies

The Secretary designated Reclamation as lead agency in preparing the EIS. Cooperating agencies are: Bureau of Indian Affairs (BIA), National Park Service (NPS), U.S. Fish and Wildlife Service (FWS), Western Area Power Administration (Western), Arizona Game and Fish Department (AGFD), Hopi Tribe, Hualapai Tribe, Navajo Nation, San Juan Southern Paiute Tribe, Southern Paiute Consortium, and Zuni Pueblo.

Representatives from Reclamation, NPS, FWS, Western, U.S. Geological Survey, AGFD, Hopi and Hualapai Tribes, Navajo Nation, and a private consulting firm served on the interdisciplinary EIS team charged with formulating the alternatives and assessing their impacts on the human environment.



SCOPE AND SETTING

The affected area encompasses the Colorado River corridor in northern Arizona from Lake Powell through Glen and Grand Canyons to the headwaters of Lake Mead (figure 1). The uppermost 15 miles of the river are within the Glen Canyon National Recreation Area; the remaining 278 miles of the river flow through Grand Canyon National Park. Several Indian Tribes have land resource interests in the area—Navajo Nation, Hopi Tribe, Havasupai Tribe, Hualapai Tribe, Southern Paiute Tribe, and Zuni Pueblo.

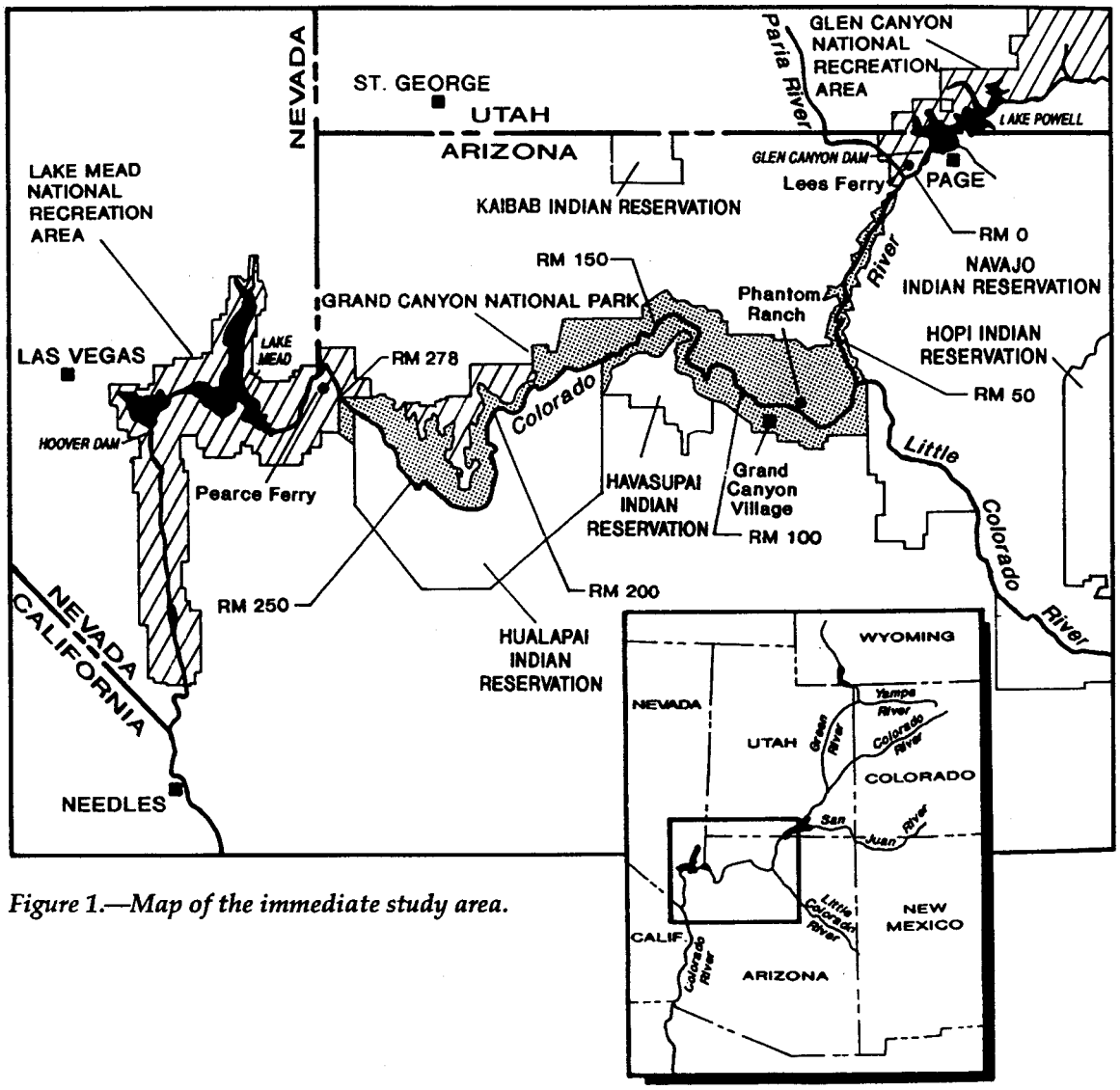


Figure 1.—Map of the immediate study area.

Some impacts would occur outside of the immediate geographic area and were also evaluated. For example, power generated at Glen Canyon Dam is marketed in Wyoming, Utah, Colorado, Arizona, Nevada, and New Mexico.

Glen Canyon Dam stores and releases water from Lake Powell, which has an active capacity of about 24.3 million acre-feet (maf). Water can be released from the dam through the powerplant, the outlet works, or spillways (figure 2). Although the combined release capacity of the facilities is 256,000 cfs, the maximum combined release from Glen Canyon Dam is not expected to exceed a probable maximum flood of 180,000 cfs.

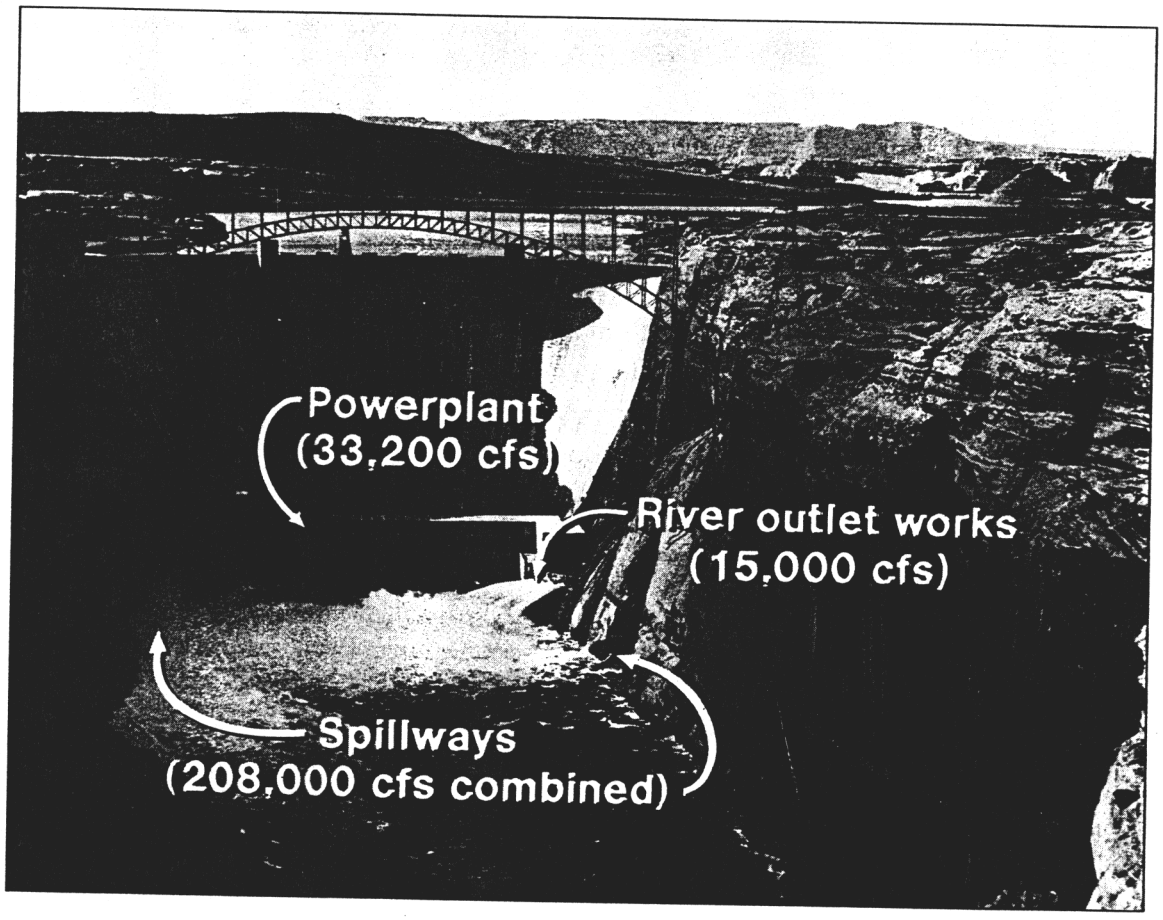


Figure 2.—Photograph of Glen Canyon Dam and Powerplant showing water release capacities of the powerplant, outlet works, and spillways.

PUBLIC INVOLVEMENT

This EIS has received broad interest from water and power users, environmental and conservation groups, Federal and State agencies, Indian Tribes, and private citizens across the country. Information has been disseminated through public meetings and periodic newsletters to about 20,000 people. In addition, interest groups have been invited to observe and participate in the cooperating agency meetings.

The ongoing Glen Canyon Dam EIS scoping process was initiated in early 1990 to receive public comment on and determine the appropriate scope of the EIS. Every effort was made to notify all potentially interested parties about the scoping process and opportunities to provide comment. Reclamation increased opportunities for public participation through public meetings, news releases, mailings, and legal notices, as well as contacts with media, organizations, and individuals.

The *Federal Register* notice of environmental scoping meetings was published on February 23, 1990, with a corresponding news release announcing the opening of the scoping process. The scoping comment period initially established for March 12 through April 16, 1990, was extended to May 4, 1990, in response to public comment. Public meetings were held in Salt Lake City, Utah; Denver, Colorado; Phoenix and Flagstaff, Arizona; Los Angeles and San Francisco, California; and Washington, DC. More than 17,000 comments were received during the scoping period, reflecting national attention and intense interest in the EIS.

Issues of Concern

As a result of the analysis of the oral and written scoping comments, the following were determined to be resources or issues of public concern: beaches, endangered species, ecosystem, fish, power costs, power production, sediment, water conservation, rafting/boating, air quality, the Grand Canyon wilderness, and a category designated as "other" for remaining concerns. Comments regarding interests and values were categorized as: expressions about the Grand Canyon, economics, nonquantifiable values, nature versus human use, and the complexity of Glen Canyon Dam issues.

The EIS team consolidated and refined the public issues of concern, identifying the resources and their significant issues to be analyzed in detail. These resources are: water, sediment, fish, vegetation, wildlife and habitat, endangered and other special status species, cultural resources, air quality, recreation, hydropower, and non-use value.

Public Review of Draft EIS

On January 4, 1994, the draft EIS was filed with the Environmental Protection Agency. The official public comment period began with a *Federal Register* notice on January 7 and concluded on April 11, 1994.

The three-volume draft EIS was distributed to over 1,000 names on the distribution list soliciting public comment. In addition, over 17,000 interested parties on the newsletter mailing list received the summary volume by itself. After the initial distribution, Reclamation received over 1,000 additional requests for either the entire draft EIS or its summary.

To provide the public an opportunity to learn more about the draft EIS, members of the EIS team conducted information sessions in Salt Lake City, Utah, and Phoenix and Flagstaff, Arizona, in March 1994. These sessions were informational only; public comments were not taken. In addition, two briefings were conducted in Washington, DC. Public hearings were held in the same seven cities as the scoping meetings to receive oral comments on the draft EIS.

Over 33,000 written comments were received. More than 2,300 separate issues and concerns were extracted from the analysis of oral and written comments. The "Comments and Responses" volume of the final EIS summarizes the public comments and the EIS team's responses to them.

As a result of comments on the draft EIS and discussions with FWS, the preferred alternative described in the draft EIS was modified for the final EIS. The cooperating agencies broadly supported this modification.

All public comments, responses prepared by the EIS team, the public hearing transcripts, and the *Public Comment Analysis Report* prepared by Bear West Consulting Team are filed with the Bureau of Reclamation, Upper Colorado Regional Office, Salt Lake City, Utah, as part of the official record.

Description of Alternatives

The nine alternatives considered in detail are described below, beginning with the No Action Alternative (historical operations) to provide a baseline for comparison. Figure 3 summarizes the alternatives and their descriptions.

UNRESTRICTED FLUCTUATING FLOWS	
No Action	Maintain fluctuating releases and provide a baseline for impact comparison
Maximum Power-plant Capacity	Permit use of full powerplant capacity
RESTRICTED FLUCTUATING FLOWS	
High	Slightly reduce daily fluctuations from historic no action levels
Moderate	Moderately reduce daily fluctuations from historic no action levels; includes habitat maintenance flows
Modified Low (*Preferred Alternative*)	Substantially reduce daily fluctuations from historic no action levels; includes habitat maintenance flows
Interim Low	Substantially reduce daily fluctuations from historic no action levels; same as interim operations
STEADY FLOWS	
Existing Monthly Volume	Provide steady flows that use historic monthly release strategies
Seasonally Adjusted	Provide steady flows on a seasonal or monthly basis; includes habitat maintenance flows
Year-Round	Provide steady flows throughout the year

Figure 3.—Glen Canyon Dam EIS alternatives.

The eight action alternatives were designed to provide a broad spectrum of options. One alternative would allow unrestricted fluctuations in flow (within the physical constraints of the powerplant) to maximize power production, four would impose varying restrictions on fluctuations, and three others would provide steady flows on a monthly, seasonal, or annual basis. The names of the alternatives reflect the operational regimes they represent. In addition, the restricted fluctuating flow and steady flow alternatives include common elements, which are discussed in the next section. The EIS team and the cooperating agencies attempted to balance benefits to all resources (physical, biological, cultural, and consumable) in identifying the preferred alternative—the Modified Low Fluctuating Flow Alternative.

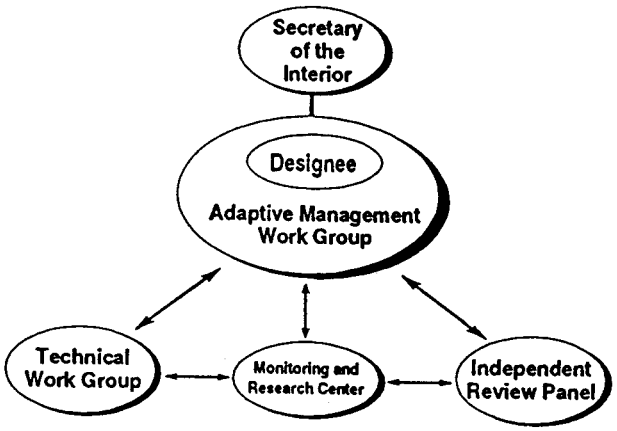
COMMON ELEMENTS

The elements common to all restricted fluctuating flow and steady flow alternatives were designed to provide additional resource protection or enhancement. Impact analyses took these common elements into account.

Adaptive Management

Many uncertainties still exist regarding downstream impacts of water releases from Glen Canyon Dam. The concept of adaptive management is based on the recognized need for ongoing operational flexibility to respond to future monitoring and research findings and varying resource conditions.

The purpose of the Adaptive Management Program would be to develop modifications to dam operations and exercise other authorities under existing law as provided in the Grand Canyon Protection Act to protect, mitigate adverse impacts to, and improve the values for which the Glen Canyon National Recreation Area and Grand Canyon National Park were established. Long-term monitoring and research are essential to adaptive management and would measure how well the selected alternative meets resource management objectives.



Consultation would be maintained with appropriate agencies of the Department of the Interior, including the FWS, NPS, Reclamation, and BIA; the Secretary of Energy; Governors of Arizona, California, Colorado,

Nevada, New Mexico, Utah, and Wyoming; cooperating Indian Tribes; and the general public, including representatives of academic and scientific communities, environmental organizations, the recreation industry, and contractors purchasing Federal power produced at Glen Canyon Dam.

The Adaptive Management Program, under the direction of the Secretary of the Interior, would be facilitated through an Adaptive Management Work Group (AMWG), organized as a Federal advisory committee.

Adaptive Management Work Group

The AMWG membership would be appointed by the Secretary with representation from each of the EIS cooperating agencies, Basin States, and two representatives each from environmental groups, recreation interests, and contractors for the purchase of Federal power from Glen Canyon Powerplant.

The AMWG would:

- Provide the framework for adaptive management policy, goals, and direction
- Develop recommendations for modifying operating criteria and for other resource management actions
- Facilitate coordination and input from interested parties

Recommendations formulated by the AMWG would be forwarded to the Secretary or his designee. If one or more entities did not support a recommendation, the views or concerns of the nonconcurring interests would accompany the recommendation for consideration in the decision.

The AMWG would be supported by a monitoring and research center and a technical work group with overview and evaluation by an independent review panel(s) .

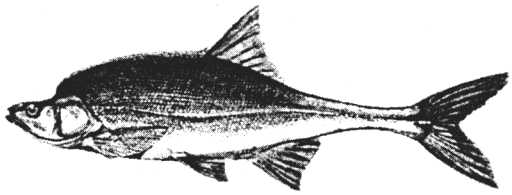
Monitoring and Research Center. To support the AMWG, it is recommended that the Secretary establish a research center within the U.S. Geological Survey and/or National Biological Service with a small permanent staff in Flagstaff, Arizona. The center would manage and coordinate adaptive management research programs and all data collected as part of those programs.

Technical Work Group. This work group would be comprised of technical representatives from Federal, State, and Tribal Governments and other interests represented on the AMWG. This work group would translate AMWG policy and goals into resource management objectives and establish criteria and standards for long-term monitoring and research.

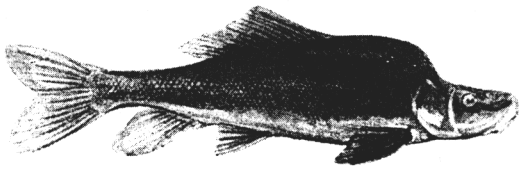
Independent Review Panel(s). The review panel(s) would be comprised of qualified individuals not otherwise participating in the long-term monitoring and research studies. Responsibilities would include reviewing resource-specific technical studies and providing technical advice. The review panel(s) would be established by the Secretary in consultation with the National Academy of Sciences, the tribes, and other AMWG entities.

Endangered Fish Research

Further studies of the linkages among endangered fish, their habitat, and Colorado River flows would be undertaken as part of the Adaptive Management Program. Included in these studies would be an initial phase of hypotheses building and risk assessment which could lead to reopening Endangered Species Act consultation with FWS.



Humpback Chub



Razorback Sucker

Endangered fish research flows likely would be between 8,000 and 20,000 cfs with a steady pattern and monthly release volumes during the spring through fall months similar to the Seasonally Adjusted Steady Flow Alternative. The actual flows would be developed by the AMWG through a scientific process.

Research may require as many as 5 low-release years (annual release at or near 8.23 maf). Since low water release years are expected to occur only about half the time, it is uncertain how many total years it would take to complete the studies. However, it is likely that research flows could be completed within 10 years. Upon completion of the research flows and analysis of data, Reclamation would implement any necessary changes in operating criteria to comply with the Endangered Species Act.

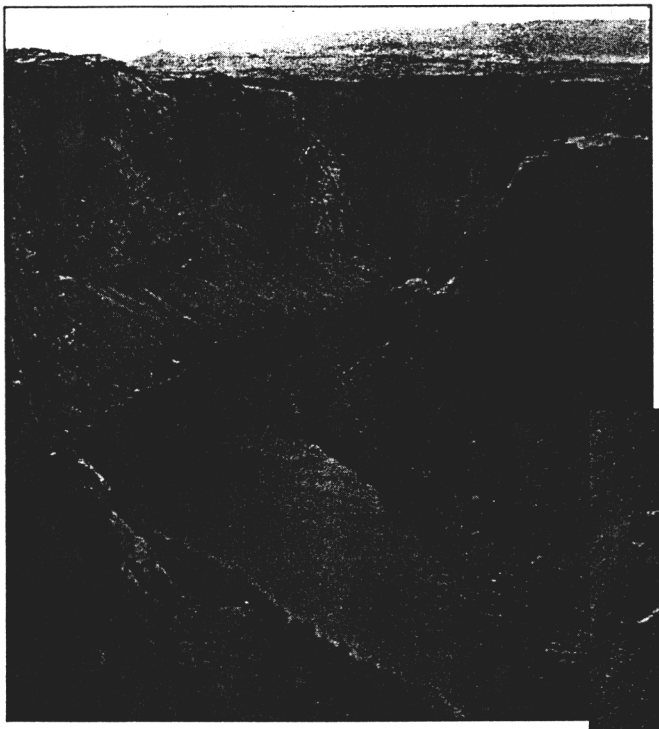
Monitoring and Protecting Cultural Resources

The existence and operation of Glen Canyon Dam has had an effect on the historic properties within the Colorado River corridor of Glen and Grand Canyons. These properties include prehistoric and historic archeological sites, along with Native American traditional cultural properties and resources. Impacts are likely to occur to some of these historic properties regardless of the EIS alternative chosen for implementation.

The National Historic Preservation Act, as amended in 1992, instructs Federal agencies to develop measures to avoid or minimize loss of historic properties resulting from their actions. Due to potential impacts of any dam operation, Federal agency compliance with sections 110 and 106 of the National Historic Preservation Act will be required.

Given the potential impacts of the existence and operation of Glen Canyon Dam, Reclamation and NPS have complied with documentation requirements in established regulations (36 CFR 800). A programmatic agreement that ensures that both Reclamation's and NPS's responsibilities are satisfied was completed in February 1994. Along with the Advisory Council on Historic Preservation and Arizona State Historic Preservation Officer, Reclamation, NPS, and the following tribes are signatories to this programmatic agreement:

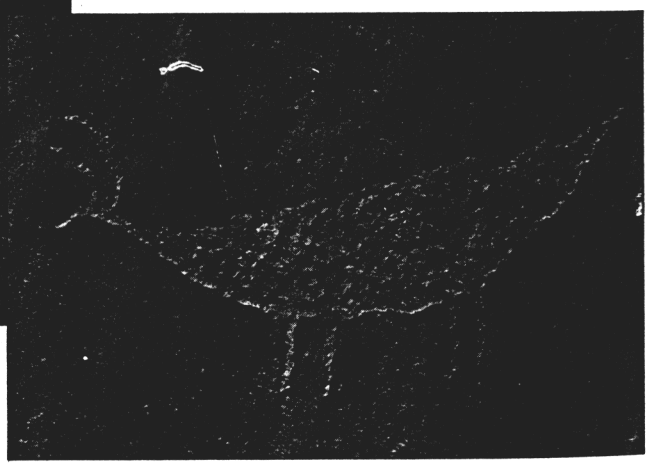
- Havasupai Tribe
- Hopi Tribe
- Hualapai Tribe
- Kaibab Paiute Tribe
- Navajo Nation
- San Juan Southern Paiute Tribe
- Shivwits Paiute Tribe
- Zuni Pueblo



The last remaining reach of the Colorado River in Glen Canyon.

Administration, implementation, and refinement of the program design are detailed in the programmatic agreement and accompanying monitoring and historic preservation plans.

The programmatic agreement and accompanying plans direct long-term monitoring that includes continuing consultation, identification, inspection,



Rock art found on canyon wall in the Glen Canyon reach.

analysis, evaluation, and remedial protection actions necessary to preserve the historic properties within Glen and Grand Canyons. Remedial actions would be performed on an as-needed basis as the result of knowledge gained through monitoring. NPS would be the lead agency in any required NEPA compliance. The ongoing consultation process should minimize the influence of Glen Canyon Dam operations on cultural resources.

Flood Frequency Reduction Measures

Although infrequent floodflows may be considered beneficial to downstream resources, frequent or unscheduled floods—particularly those of long duration—are damaging to downstream resources. Under this common element, the frequency of unscheduled floodflows greater than 45,000 cfs would be reduced to no more than 1 year in 100 years as a long-term average. This would allow management of the habitat maintenance flows and beach/habitat-building flows described later in this section. Floodflow frequency of once in 100 years is considered rare enough for resource needs, while not imposing unreasonable requirements on Lake Powell water storage.

Two separate methods of reducing flood frequency have been identified. These methods focus on reserving additional storage space for flood control.

1. Increase the capacity of Lake Powell 0.75 maf by raising the height of the four spillway gates 4.5 feet to elevation 3704.5 feet (currently, each gate is 40 feet wide and 52.2 feet high). This additional capacity would be nonviolable flood control space and would be used only in years when existing flood protection measures were insufficient. Construction of this project would cost about $3 million. No permits under the Clean Water Act or Rivers and Harbors Act would be required.

2. Change releases to target a maximum reservoir content of 23.3 maf (1 maf less than the current active capacity) in the spring until the runoff peak has clearly passed. This additional space would allow improved management of late-season forecast errors, the primary cause of flood releases that exceed 45,000 cfs. The amount of required vacant space in the spring months would eventually decrease as Upper Basin depletions increase.

By implementing either flood protection measure, additional reserved reservoir space would be available from January 1 through July 1 to store any additional unforecasted inflow.

Beach/Habitat-Building Flows

Sandbars above the normal peak river stage would continue to erode, and backwater habitat within normal stage would tend to fill with sediment under any EIS alternative. To alleviate this, beach/habitat-building flows have been incorporated in all restricted fluctuating and steady flow alternatives.

Beach/habitat-building flows would be scheduled high releases of short duration designed to rebuild high elevation sandbars, deposit nutrients, restore backwater channels, and provide some of the dynamics of a natural system. A frequency of 1 in 5 years (when the reservoir is low) was assumed for analyzing the environmental consequences. These flows would be avoided during high reservoir conditions because of the increased risk of unscheduled flows greater than powerplant capacity.

Magnitudes would be at least 10,000 cfs greater than the allowable peak discharge in a minimum release year for a given alternative. Releases would be increased at no more than 4,000 cfs/hour and decreased at a maximum of 1,500 cfs/hour. As part of adaptive management, a test of a beach/habitat-building flow would be conducted prior to long-term implementation of this element to test the predictions made about its impacts. Scheduled flows exceeding powerplant capacity (33,200 cfs) may require legislation to implement.

Beach/habitat-building flows could be scheduled in the spring (to coincide with the May/June peak in the natural hydrologic cycle) or in late summer when, due to local thunderstorms, tributaries are expected to supply large quantities of sediment and nutrients. Initially, these flows would be scheduled for a duration of 1 to 2 weeks. Additional water would be scheduled in the spring to support this flow.

Beach/habitat-building flows would be recommended under the Adaptive Management Program and scheduled as part of the Annual Operating Plan. Such flows would be recommended during years when sufficient quantities of sediment are available, but not following a year in which a large population of young humpback chub is produced.

New Population of Humpback Chub

The Grand Canyon population of humpback chub (an endangered species) uses habitats in both the Colorado River mainstem and the Little Colorado River (LCR). Conditions in the mainstem (principally water temperatures) are not conducive to humpback chub spawning or survival of eggs and young. The only confirmed successful spawning habitat for that population is in the LCR, with individuals moving between that tributary and the mainstem.

Since the only known humpback chub population in the Lower Colorado River Basin depends on the LCR for survival, a catastrophic event or a series of incidents that would reduce the viability of this spawning habitat could cause the loss of this population. This possibility will persist until or unless:

1. At least one more population is established in the mainstem or one or more of the tributaries below Glen Canyon Dam, and/or

2. Mainstem water temperatures are sufficiently warmed to support spawning and recruitment.

Therefore, in consultation with FWS, NPS, AGFD, and other land management entities such as the Havasupai Tribe, Reclamation would make every effort—through funding, facilitating, and technical support—to establish a new population of humpback chub within Grand Canyon.

Further Study of Selective Withdrawal

Increasing mainstem water temperatures by means of selective withdrawal structures installed at Glen Canyon Dam offers the greatest potential for creating new spawning populations of humpback chub and other native fish in Grand Canyon.

Water released from Glen Canyon Dam to produce hydroelectricity is withdrawn from the cold depths of Lake Powell at an elevation of 3470 feet—230 feet below the water surface when the reservoir is full (3700 feet). The river water temperature at Lees Ferry, 16 miles downstream, is nearly constant year round and averages about 46 degrees Fahrenheit (°F).

Only a few species of aquatic organisms thrive under these conditions, but those few species are abundant. However, many native species cannot reproduce in these constant, cold temperature conditions.

Except for draining the reservoir, no operational method could prevent the continued release of cold water. Multilevel intake structures (a means of selective withdrawal) could be built at Glen Canyon Dam to provide seasonal variation in water temperature. A structure would be attached to each of the eight existing 15-foot-diameter penstocks to withdraw warmer water from upper levels of the reservoir.

Preliminary studies indicated that multilevel intake structures on each of the eight existing penstocks could increase the downstream river temperature 5 to 18 °F above present conditions (river temperatures between 54 and 69 °F from May to October). This temperature increase is still 7 to 16 °F cooler than predam conditions during the summer months

and is the warmest possible temperature (not necessarily the optimum temperature) for native fish or other resources. Withdrawal levels could be seasonally adjusted to meet ecological objectives, although this would involve complex factors.

Releasing warmer water during the spring and summer months could possibly raise river temperatures in some downstream reaches to a level that would support spawning by humpback chub and other native fish. However, increasing the temperature of river water may also create problems for species currently inhabiting the Colorado River below Glen Canyon Dam. The cold river temperatures may act as a barrier to the establishment of non-native predatory fish from Lake Mead. Higher water temperatures may encourage the upstream migration and establishment of predatory fish, further endangering humpback chub and other native fish through increased predation or competition from non-native migrants and resident non-native fish.

The cost of installing multilevel intake structures at Glen Canyon Dam has been estimated at $60 million. This estimate is based on actual costs for similar structures at Flaming Gorge Dam.

Reclamation would implement a selective withdrawal program and determine feasibility by aggressively pursuing and supporting research on the effects of multilevel intake structures at Glen Canyon Dam and would use the research results to make a firm decision on construction. FWS, in consultation with AGFD, would be responsible for recommending to Reclamation whether or not selective withdrawal should be implemented at Glen Canyon Dam. Reclamation would be responsible for design, NEPA compliance, permits, construction, operation, and maintenance.

Emergency Exception Criteria

Normal operations described under any alternative would be altered temporarily to respond to emergencies. These changes in operations would be of short duration (usually less than 4 hours) and would be the result of emergencies at the dam, downstream, or within the interconnected electrical system. Examples of system emergencies include:

- Insufficient generating capacity
- Transmission system: overload, voltage control, and frequency
- System restoration
- Humanitarian situations (search and rescue)

UNRESTRICTED FLUCTUATING FLOWS

The two unrestricted fluctuating flow alternatives would allow flows to vary, as necessary, for power generation purposes.

No Action Alternative

Minimum releases (cfs)	Maximum releases (cfs)	Allowable daily fluctuations (cfs/24 hrs)	Ramp rate (cfs/hr)
1,000 Labor Day to Easter 3,000 Easter to Labor Day	31,500	30,500 Labor Day to Easter 28,500 Easter to Labor Day	Unrestricted

The No Action Alternative (historic operations) is presented first to provide an understanding of baseline conditions and operations at Glen Canyon Dam. Many resources in the river and adjacent riparian zone developed in response to dam operations under no action conditions. Thus, this alternative provides the basis for impact comparison.

Within the overall CRSP purpose, the objective of the No Action Alternative is to produce the greatest amount of firm capacity and energy practicable while adhering to the releases required under the "Law of the River." Under no action, Glen Canyon Dam operations would be the same as they were from 1963—when the dam was placed in operation—until the research flows began in June 1990. This alternative would continue operations established under the *Criteria for Coordinated Long-Range Operation of Colorado River Reservoirs* (Long-Range Operating Criteria) including daily fluctuating releases. The maximum allowable discharge during fluctuations is 31,500 cfs. Releases fluctuate when the dam is being operated to follow power system load changes, to produce peaking power, to regulate the power system, or to respond to power system emergencies.

Annual Release Volume

Annual release volume is based on inflow and remaining space in Lake Powell and Lake Mead. Annual release volumes vary greatly, but all adhere to the Long-Range Operating Criteria objectives of an 8.23-maf minimum annual release and equalized storage between the two reservoirs. Annual releases greater than the minimum are permitted to avoid anticipated spills and to equalize storage.

From 1966 to 1989, annual releases ranged from 8.23 maf to 20.4 maf (1984). The minimum release has occurred in about half the years since the dam was closed in 1963.

Monthly Release Volume

Under the No Action Alternative, the volume of water released from Lake Powell each month depends on forecasted inflow, existing storage levels, monthly storage targets, and annual release requirements. Demands for electrical energy, fish and wildlife needs, and recreation needs also are considered and accommodated as long as the risk of spilling and storage equalization between Lakes Powell and Mead are not affected. Power demand is highest during winter and summer months, and recreation needs are highest during the summer. Therefore, higher volume releases are scheduled during these months whenever possible to benefit these uses.

Spills are excess annual releases that cannot be used for project purposes; they usually are the result of inflow forecast changes. Floodflows—the spills of principal concern—are releases greater than the designed powerplant capacity that are discharged through the river outlet works and spillways.

Each month during the inflow forecast season (January to July), the volume of water to be released for the rest of the year is recomputed based on updated streamflow forecast information. Scheduled releases for the remaining months are adjusted to avoid anticipated spills and maintain conservation storage in accordance with the Long-Range Operating Criteria.

Under high storage conditions, fall and early winter releases are designed to meet the January 1 storage target (22.6 maf). Under lower storage conditions, releases are scheduled at a minimum of about 550,000 acre-feet per month. January through July releases are scheduled to create space in the reservoir so that forecasted runoff will not produce spills but will fill the reservoir in July. July through September releases are used to meet both the minimum annual release requirement and the January 1 target of 22.6 maf.

Floodflow Avoidance

Methods for providing protection against flood releases under the No Action Alternative are:

1. Storage in Lake Powell is not allowed to exceed 22.6 maf as of January 1 of each year (before the forecast season) in preparation for storing and regulating spring runoff.

2. On the first of each month from January to June, a protection factor is added to the forecasted inflow so that more water is assumed to be coming into the reservoir than indicated by the forecast.

3. Throughout the streamflow forecast season (January 1 to July 1), operations are planned as though Lake Powell has 500,000 acre-feet less capacity than it actually has. This provides a storage buffer to further protect against unforecasted inflow.

Hourly Operations

Hourly releases are set to reach monthly release volumes, to maintain established minimum flow rates, and to follow energy demand. Emergency conditions—such as search and rescue operations, generating equipment failures, or power system emergencies—may cause extreme departures from normal operations. Except for search and rescue operations, these departures are short lived (generally 1 hour or less) and their effects on water releases can be adjusted in a short time (less than 4 hours).

Hourly power operations are most flexible during months with moderate release volumes. The need to maintain minimum flows in months with low release volumes limits flexibility to accommodate changing hourly power demands. If the reservoir is nearly full and inflow is extremely high, monthly releases are scheduled at or near maximum capacity most of the time, leaving little flexibility for hourly releases to change in response to power demand.

Releases fluctuate when the generating units are being operated to follow changes in power system load, to produce peaking power, to regulate the power system, or to respond to power system emergencies. During a minimum release year, the greater the daily release volume the greater the daily fluctuation. To the extent possible within higher priority operating constraints, the following guidelines are used in producing hydroelectric power:

- Maximize water releases during the peak energy demand periods, generally Monday through Saturday between 7 a.m. and 11 p.m.
- Maximize water releases during peak energy demand months and minimize during low demand months
- Minimize and, to the extent possible, eliminate powerplant bypasses

Minimum Flow. Minimum flows are restricted to no less than 1,000 cfs from Labor Day until Easter and 3,000 cfs from Easter until Labor Day (the recreation season). Also during the recreation season, weekday releases must average no less than 8,000 cfs from 8 a.m. to midnight. The minimum flow for any given hour typically depends on the monthly release volume and the magnitude and predictability of electrical load

across and within the hour. In some cases, dispatcher experience may be a factor. For a number of reasons (typically for meeting monthly release volumes), minimum flows are frequently above the objective minimum. Occasionally, power system emergencies prevent meeting the minimum release objectives.

Maximum Flow. Maximum flows are determined by powerplant capacity, the power demand at the time of release, and the amount of water required and/or available for release in a given month. As much as 33,200 cfs can be discharged through the powerplant if the reservoir is at the appropriate elevation. Flows greater than 33,200 cfs are discharged through the outlet works first and then through the spillways. Peak discharges under normal no action operations do not exceed 31,500 cfs. Releases greater than 31,500 cfs are steady on a daily basis.

Range of Fluctuating Flows. The range of daily fluctuations under the No Action Alternative is only restricted to between the minimum and maximum flows. However, power considerations often considerably restrict the actual range of fluctuations.

Ramp Rate. The ramp rate is the rate of change in discharge to meet the electrical load by achieving either higher or lower releases. North American Electric Reliability Council operating criteria require Western to meet scheduled load changes by ramping up or down beginning at 10 minutes before the hour and ending at 10 minutes after the hour. Any ramping to meet scheduled load changes occurs during that same 20-minute period. The principal times of change are in the morning, when releases are increased to respond to the peak daytime demand, and at night, when releases are decreased as the electrical demand diminishes. A computerized automatic generation control (AGC) system controls the rate of release and generation on an instantaneous basis.

Under historical operations, scheduled ramping typically has resulted in large river stage changes. However, the continuous small changes in discharge caused by AGC rarely affect river stage by more than a foot.

Under the No Action Alternative, the only restriction on ramp rates is the physical capability of the generators. The 1-hour up ramp rates have been less than 4,000 cfs per hour about 32 percent of the time and greater than 8,000 cfs about 11 percent of the time. The down ramp rates have been less than 4,000 cfs about 29 percent of the time and greater than 8,000 cfs about 7 percent of the time.

Maximum Powerplant Capacity Alternative

Minimum releases (cfs)	Maximum releases (cfs)	Allowable daily fluctuations (cfs/24 hrs)	Ramp rate (cfs/hr)
1,000 Labor Day to Easter 3,000 Easter to Labor Day	33,200	32,200 Labor Day to Easter 30,200 Easter to Labor Day	Unrestricted

This alternative was developed to allow use of the maximum powerplant discharge capacity that resulted from the previously discussed 1987 uprate and rewind. Operations under the Maximum Powerplant Capacity Alternative would be the same as under the No Action Alternative except that use of the full powerplant capacity (estimated flows of 33,200 cfs) would be allowed. Monthly and annual operations, including flood control, would be identical to those described under no action. Releases in excess of 31,500 cfs would be possible only when Lake Powell's elevation is greater than 3641 feet. This additional capacity would be used when power demand is high—typically 4 hours or less.

Daily and Hourly Operations

Minimum releases would be at least 3,000 cfs from Easter to Labor Day and 1,000 cfs for the remainder of the year. The range in daily release fluctuations and ramp rates would be restricted only by the physical capability of the generators.

RESTRICTED FLUCTUATING FLOWS

The restricted fluctuating flow alternatives were designed to provide a range of downstream resource protection measures, while offering varying amounts of flexibility for power operations. All four alternatives—high, moderate, modified low, and interim low fluctuating flows—restrict daily fluctuations at Glen Canyon Dam as compared to the No Action and Maximum Powerplant Capacity Alternatives. Each alternative also specifies ramp rate restrictions and minimum release requirements.

Within the constraints of the alternatives, maximum water releases would be scheduled to coincide with times of peak electrical demand. Low releases are made at night to maximize the amount of water available for daytime generation and thus minimize expensive daytime power purchases.

Scheduled annual and monthly release volumes would be determined using essentially the same considerations described under the No Action Alternative. Beach/habitat-building flows would modify monthly release volumes when Lake Powell is drawn down.

Habitat maintenance flows—short-term high releases during the spring—are included in the Moderate and Modified Low Fluctuating Flow Alternatives to transport and deposit sand for maintaining camping beaches and fish habitat. These maintenance flows were not included in the other restricted fluctuating flow alternatives for the following reasons. With habitat maintenance flows, the High Fluctuating Flow Alternative would, over the long term, move more sand than supplied by tributaries and would result in net erosion. Maintenance flows were not included in the Interim Low Fluctuating Flow Alternative in order to preserve the current interim flow operations for which nearly 3 years of data have been collected.

High Fluctuating Flow Alternative

Minimum releases (cfs)	Maximum releases (cfs)	Allowable daily fluctuations (cfs/24 hrs)	Ramp rate (cfs/hr)
3,000 5,000 8,000 depending on monthly volume, firm load, and market conditions	31,500	15,000 to 22,000 depending on monthly release volume	Unrestricted up 5,000 or 4,000 down

The High Fluctuating Flow Alternative was developed to slightly reduce fluctuating flows, with the goal of protecting or enhancing downstream resources while allowing flexibility for power operations. Releases would be tied to hydrology and power system demand. This alternative would have the same annual and monthly operation plan as described under the No Action Alternative but would include additional restrictions on daily and hourly operations. Parameters such as minimum flows, down ramp rates, and allowable daily fluctuations were designed to provide some resource protection, but without substantial impacts to hydropower. Although daily fluctuation limits would be constant within a month, the minimum and maximum flows might be different each day.

Daily and Hourly Operations

Minimum flows would be 3,000, 5,000, or 8,000 cfs depending on monthly release volume, firm load, and power market conditions. The maximum flow during hourly fluctuating releases would be limited to 31,500 cfs. When high inflow volumes and storage conditions require releases greater than 31,500 cfs, such releases would be steady on a daily basis.

The limit on daily fluctuations often would be more restrictive than the minimum and maximum flow rates. Fluctuations would be limited to 15,000 to 22,000 cfs over any 24-hour period, depending on the monthly release volume. Maximum flows during a minimum release year normally would not exceed 25,000 cfs.

The ramp rate would follow the power load for increasing flows without restriction, but decreasing flows would be limited to 5,000 cfs per hour (winter and summer) or 4,000 cfs per hour (spring and fall).

Moderate Fluctuating Flow Alternative

Minimum releases (cfs)	Maximum releases (cfs)	Allowable daily fluctuations (cfs/24 hrs)	Ramp rate (cfs/hr)
5,000	31,500	±45% of mean flow for the month not to exceed ±6,000	4,000 up 2,500 down

The Moderate Fluctuating Flow Alternative was developed to reduce daily flow fluctuations below no action levels and to provide special high steady releases of short duration, with the goal of protecting or enhancing downstream resources while allowing intermediate flexibility for power operations. This alternative would have the same annual and essentially the same monthly operating plan as described under no action (except for the addition of habitat maintenance flows), but would restrict daily and hourly operations more than the No Action, Maximum Powerplant Capacity, or High Fluctuating Flow Alternatives. Parameters such as minimum flows, ramp rates, and allowable daily fluctuations were designed to provide resource protection through consistent release patterns throughout each month.

Daily and Hourly Operations

Minimum flows for a given month would vary depending on the monthly release volume but would be no less than 5,000 cfs. The maximum rate of release for a given month also would vary depending on the monthly release volume but would be no greater than 31,500 cfs under normal

operations. When high inflow volumes and storage conditions require releases greater than 31,500 cfs, such releases would be steady on a daily basis. Because of restrictions on daily fluctuations and ramp rates, maximum flows during a minimum release year normally would not exceed 22,300 cfs. The ramp rate would be limited to 4,000 cfs per hour for increasing flows and 2,500 cfs per hour for decreasing flows.

Allowable daily fluctuations as well as minimum and maximum flows would be determined based on the mean releases for the month. The allowable fluctuation would be plus or minus 45 percent of the mean daily flow, not to exceed plus or minus 6,000 cfs.

Habitat Maintenance Flows

Habitat maintenance flows are included in this alternative to re-form backwaters and maintain sandbars, which are important for camping beaches and fish habitat. Habitat maintenance flows are high, steady releases within powerplant capacity (33,200 cfs) for 1 to 2 weeks in spring. The exact month would be determined under the Adaptive Management Program and the Annual Operating Plan. A more complete description of habitat maintenance flows can be found under the Modified Low Fluctuating Flow Alternative that follows.

Modified Low Fluctuating Flow Alternative *(Preferred Alternative)*

Minimum releases (cfs)	Maximum releases (cfs)	Allowable daily fluctuations (cfs/24 hrs)	Ramp rate (cfs/hr)
8,000 between 7 a.m. and 7 p.m. 5,000 at night	25,000	5,000 6,000 or 8,000	4,000 up 1,500 down

The Modified Low Fluctuating Flow Alternative was developed to reduce daily flow fluctuations well below no action levels and to provide special high steady releases of short duration, with the goal of protecting or enhancing downstream resources while allowing limited flexibility for power operations. This alternative would have the same annual and essentially the same monthly operating plan as described under the No Action Alternative but would restrict daily and hourly operations more than any of the previously described fluctuating flow alternatives.

Additional information on the effects of dam operations has been gathered since the interim operating criteria were developed. Some of this preferred

alternative's parameters have changed slightly since the draft EIS was published based on new information and public comments.

To reduce long-term flood frequency, a single method is advanced under this alternative—raising the height of the four spillway gates by 4.5 feet (see "Common Elements"). However, since other methods are available to accomplish this same goal, a final decision about the method ultimately used would not be made until additional NEPA compliance has been completed to evaluate impacts related to Lake Powell shoreline resources. Lake Powell's current elevation is well below the level that would require reserving additional storage space, thus accomplishing the objective of reducing the frequency of flood releases. The lake level is not expected to reach full elevation for another 4 or 5 years. Until the spillway gates were installed, additional operational measures would be implemented through the Annual Operating Plan to provide the recommended flood protection.

Daily and Hourly Operations

Minimum flows would be no less than 8,000 cfs between 7 a.m. and 7 p.m. and 5,000 cfs at night. The maximum rate of release would be limited to 25,000 cfs during fluctuating hourly releases. Any releases greater than 25,000 cfs (other than for emergencies) would be steady on a daily basis and would be made in response to high inflow and storage conditions. Ramp rates would be limited to 4,000 cfs per hour for increasing flows and 1,500 cfs per hour for decreasing flows.

Fluctuations would be limited during any 24-hour period to either 5,000; 6,000; or 8,000 cfs, depending on monthly release volumes. The maximum allowable release under this alternative was increased from 20,000 to 25,000 cfs since the draft EIS was published. However, flows are expected to only rarely exceed 20,000 cfs during a minimum release year (less than 1 percent of the time). This is because the maximum allowable daily change constraint overrides the maximum allowable release and because monthly release volumes are lower during minimum release years.

The increased maximum allowable releases would not result in any measurable difference in impacts on downstream resources.

Habitat Maintenance Flows

Maximum releases under the Modified Low Fluctuating Flow Alternative normally would not exceed 25,000 cfs during a minimum release year. Without higher flows:

- Portions of sandbars above the normal peak stage could not be rebuilt.
- Sediment would accumulate at low elevations, including backwaters.
- Camping beaches and return-current channels would likely become filled with sediment and eventually overgrown with vegetation.

Although an occasional floodflow (greater than 33,200 cfs) may rebuild high elevation beaches and re-form backwaters, frequent floodflows would likely transport more sand than could be supplied by the tributaries—resulting in long-term sandbar erosion. Therefore, habitat maintenance flows are included in this alternative to re-form backwaters, which are important for fish habitat.

Habitat maintenance flows are high, steady releases within powerplant capacity for 1 to 2 weeks in the spring. The exact month would be determined under the Adaptive Management Program and the Annual Operating Plan. March was assumed for evaluating impacts for the following reasons:

- Backwater channels could be re-formed prior to the humpback chub spawning period.
- More sediment is likely to be supplied by tributary flow in March than later in the spring.
- March is prior to the peak recreation use season.

Habitat maintenance flows would not be scheduled when the projected storage in Lake Powell on January 1 is greater than 19 maf. Annual release volumes under such conditions are typically greater than the minimum annual release volume (8.23 maf), and such flows already may be near or exceed powerplant capacity.

Although habitat maintenance flows are defined as steady, minor fluctuations of up to plus or minus 1,000 cfs would be permitted to regulate voltage within the power grid. Maintenance flows would begin by increasing flows at a rate no greater than 4,000 cfs/hour and would conclude by decreasing flows back to the normal operating range at a rate no greater than 1,500 cfs/hour. The limit on daily change in flow would not apply during these transitions.

Habitat maintenance flows differ from beach/habitat-building flows because they would be within powerplant capacity and would occur nearly every year when the reservoir is low. Habitat maintenance flows would not occur in years when a beach/habitat-building flow is scheduled. Neither of these special releases would be scheduled in a year when there is concern for a sensitive resource—such as sediment or an endangered species.

Increasing the flow to 30,000 cfs for 10 days would result in the release of an additional 412,000 acre-feet of water in March, which would require adjusting the release volumes in the other months. This scheduling adjustment would be determined during the Annual Operating Plan preparation and may vary from year to year.

Endangered Fish Research

Further studies of the linkages between endangered fish, their habitat, and Colorado River flows which were a part of this alternative in the draft EIS have been moved to the scientifically based Adaptive Management Program (see "Common Elements").

Interim Low Fluctuating Flow Alternative

Minimum releases (cfs)	Maximum releases (cfs)	Allowable daily fluctuations (cfs/24 hrs)	Ramp rate (cfs/hr)
8,000 between 7 a.m. and 7 p.m. 5,000 at night	20,000	5,000 6,000 or 8,000	2,500 up 1,500 down

The Interim Low Fluctuating Flow Alternative was developed to reduce daily flow fluctuations to well below no action levels, with the goal of protecting or enhancing downstream resources while allowing limited flexibility for power operations. This alternative would have the same annual and monthly operating plan as the No Action Alternative but would restrict daily and hourly operations as much as or more than any alternative allowing fluctuating flows. This alternative is the same as the Interim Operating Criteria implemented on November 1, 1991 (except for the addition of the common elements). Parameters such as minimum flows, maximum flows, ramp rates, and allowable daily fluctuations were designed to protect downstream resources until completion of the final EIS and ROD.

Daily and Hourly Operations

Minimum flows would be no less than 8,000 cfs between 7 a.m. and 7 p.m. and 5,000 cfs at night. The maximum rate of release would be limited to 20,000 cfs during fluctuating hourly releases. Any releases greater than 20,000 cfs (other than for emergencies) would be steady on a daily basis and would be made in response to high inflow and storage conditions. Ramp rates would be limited to 2,500 cfs/hour for increasing flows and 1,500 cfs/hour for decreasing flows. The limit on daily fluctuations often would be more restrictive than the minimum and maximum flow rates. Fluctuations would be limited during any 24-hour period, depending on monthly release volumes.

STEADY FLOWS

The steady flow alternatives were designed to provide a range of downstream resource protection measures by minimizing daily release fluctuations. Flows would be steady on either a monthly, seasonal, or year-round basis. The monthly distribution of release volumes would differ, but daily and hourly operating criteria would be the same for all steady flow alternatives. Flows would be the same each day within the month or season (except during flood control operations). The scheduled annual release volume would be determined in accordance with the Long-Range Operating Criteria.

Monthly or seasonal release volumes would be based on the month-to-month pattern specified for the alternative. Although the goal would be to maintain steady (uniform) water releases for selected durations, the ability to maintain a steady flow from one period to the next would depend on the accuracy of streamflow forecasts and the space available in Lake Powell.

Minimum or maximum flow rates would be determined by the monthly water volume to be released. The goal would be to hold flows steady to within plus or minus 1,000 cfs per day and adjust them between months in response to forecast changes. Ramp rates within this flow range would not be restricted because river stage fluctuations would be within a few inches. The maximum change in releases between months would be 2,000 cfs per day.

Daily variations of plus or minus 1,000 cfs per day (approximately 42 megawatts) would allow some minor flexibility in dam operations, primarily for electrical system regulation. AGC would cause minor fluctuations as the powerplant's computerized regulation system made adjustments every 2 to 6 seconds. Resulting changes in river stage would not be noticeable downstream. Flow fluctuations of this magnitude were measured during steady research flows, and the corresponding river stage fluctuations were small. Glen Canyon Powerplant likely would not be relied on for extended periods of AGC if a steady flow alternative is implemented.

Water releases in excess of powerplant capacity would flow through the outlet works and/or spillways during high water years or, as necessary, during beach/habitat-building flows.

The habitat maintenance flows included in the Seasonally Adjusted Steady Flow Alternative were not included in the other steady flow alternatives. Such flows would be contrary to the concepts for which these steady flow alternatives were developed; i.e., to keep flows steady under

the Year-Round Steady Flow Alternative and to retain the pattern of historic monthly releases under the Existing Monthly Volume Steady Flow Alternative.

Existing Monthly Volume Steady Flow Alternative

Minimum releases (cfs)	Maximum releases (cfs)	Allowable daily fluctuations (cfs/24 hrs)	Ramp rate (cfs/day)
8,000	Monthly volumes prorated	±1,000	2,000 between months

The Existing Monthly Volume Steady Flow Alternative was developed to provide steady flow on a monthly basis while continuing to maintain flexible monthly release volumes to avoid spills and maintain conservation storage. Steady flows were included each month with the goal of protecting or enhancing downstream resources, especially the aquatic ecosystem that exists downstream from the dam.

This alternative would have the same annual and monthly operating plan as the No Action Alternative, but releases would be steady within months. Also, beach/habitat-building flows would modify monthly release volumes when Lake Powell is drawn down.

Minimum Flow

Both minimum and maximum flows would be within plus or minus 1,000 cfs of the mean monthly release. Based on analysis of historical releases, minimum flows rarely would be below 8,000 cfs (476,000-acre-foot monthly volume).

Monthly Release Volume

The scheduled monthly release volumes would be the same as the monthly volumes under the No Action Alternative. Based on the period 1963-89, February has the lowest monthly median release volume (556,000 acre-feet—equivalent to 10,000 cfs), and August has the highest monthly median release volume (903,000 acre-feet—equivalent to 14,700 cfs).

Seasonally Adjusted Steady Flow Alternative

Minimum releases (cfs)	Maximum releases (cfs)	Allowable daily fluctuations (cfs/24 hrs)	Ramp rate (cfs/day)
8,000 Oct-Nov 8,500 Dec 11,000 Jan-Mar 12,500 Apr 18,000 May-Jun 12,500 Jul 9,000 Aug-Sep	18,000	±1,000	2,000 between months

The Seasonally Adjusted Steady Flow Alternative was developed to enhance the aquatic ecosystem by releasing water at a constant rate within defined seasons and by using habitat maintenance flows. Seasonal variations in minimum flows and habitat maintenance flows were designed with the goal of protecting and enhancing native fish. Monthly release patterns would differ from the No Action Alternative as explained in more detail below.

This alternative would provide steady flows on a 1- to 3-month basis, providing seasonal variations throughout the year to meet downstream resource needs. The highest releases would occur in May and June, with relatively low releases from August through December.

Minimum Flow

The minimum monthly constant release for each season is shown above. These minimum release requirements would be relaxed to avoid spills during high storage or inaccurate forecast situations.

Monthly Release Volume

Releases within each month would be steady and would have to equal or exceed the monthly minimums. Any additional water in excess of the minimum annual release volume would be distributed equally among the 12 months, subject to an 18,000-cfs maximum. This 18,000-cfs maximum would be exceeded when the annual release is more than 13.14 maf. If forecasts changed, the volume of water to be released during the remainder of the year would be recomputed monthly based on updated forecasts, and the constant rate of release would be adjusted accordingly.

Habitat Maintenance Flows. Habitat maintenance flows are included in this alternative to re-form backwaters and maintain sandbars, which are important for camping beaches and fish habitat. Habitat maintenance

flows are high, steady releases within powerplant capacity (33,200 cfs) for 1 to 2 weeks in the spring. The exact month would be determined under the Adaptive Management Program and the Annual Operating Plan. Habitat maintenance flows are described in more detail under the Modified Low Fluctuating Flow Alternative.

Year-Round Steady Flow Alternative

Minimum releases (cfs)	Maximum releases (cfs)	Allowable daily fluctuations (cfs/24 hrs)	Ramp rate (cfs/day)
Yearly volume prorated	Yearly volume prorated	±1,000	2,500 up

The Year-Round Steady Flow Alternative was developed to eliminate fluctuating flows, both daily and seasonal. Year-round steady flows were designed with the goal of protecting or enhancing downstream resources by providing the greatest amounts of river-stored sediment and biomass possible in the postdam environment.

Minimum Flow

Minimum flows would be determined from the mean monthly release but would correspond generally to the minimum annual release volume of 8.23 maf, which is about 11,400 cfs. The minimum release requirement would be relaxed to avoid spills during high storage or inaccurate forecast situations.

Monthly Release Volume

The monthly volume would be approximately the annual volume divided by 12, except when response to forecast changes would be required. If forecasts changed, the volume of water to be released during the remainder of the year would be recomputed monthly based on updated forecasts, and the constant rate of release would be adjusted accordingly. The ability to maintain a constant rate of release for the entire year would depend on the accuracy of streamflow forecasts and the amount of space remaining in Lake Powell. Approximately half of the time, lake elevation would be high enough that forecast changes could cause some variations in monthly volumes.

MITIGATION

All environmental mitigation has been incorporated into the alternatives; no other mitigation elements are presently included. Future measures that could be considered as mitigation for the loss of power are described below.

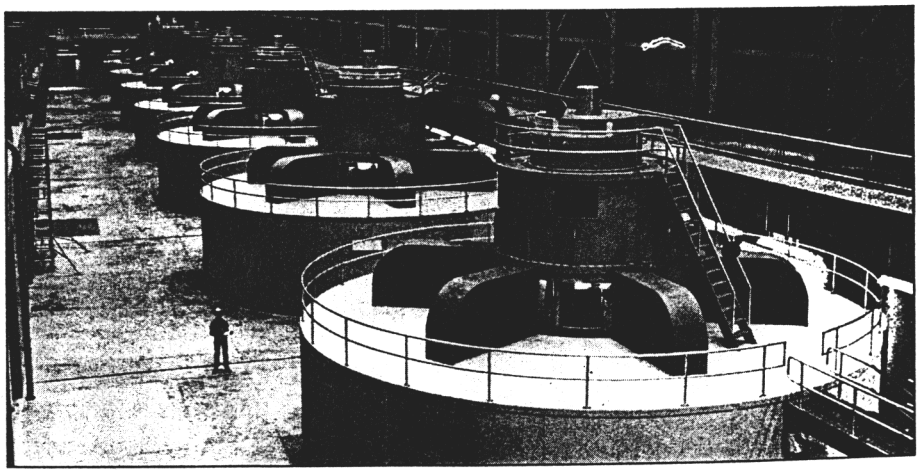
Power Adjustments

The Grand Canyon Protection Act directs the Secretary of Energy to consult with other agencies and the public to identify economically and technically feasible methods of replacing any power generation that is lost through changed operations at Glen Canyon Dam. The Secretary of Energy must present a report of the findings and draft implementing legislation, if necessary, not later than 2 years after adoption of new operating criteria (ROD). That process should result in acquisition of permanent replacement power.

How Western markets energy and capacity from Glen Canyon Dam would differ for each alternative. Some basic options to replace lost power are listed below.

- Purchase power from alternate sources
- Increase energy conservation
- Change transmission system capability
- Build new generating facilities

Some of these options may take 5 to 7 years to implement fully. Continuing use of the financial exception criteria allowed under interim operations is a potential short-term (5- to 7-year) mitigation measure. These



Generators at Glen Canyon Powerplant.

financial exception criteria relate to Western's ability to demonstrate that unused generation capacity is available to meet firm (guaranteed) contract commitments at times when nonfirm thermal energy is being used to meet those commitments. Under interim operations, operational limits can be exceeded for financial reasons up to 3 percent of the time (22 hours) in any consecutive 30-day period, with no carryover.

Actually exceeding operating criteria for financial reasons is unlikely. While Western's customers have benefited from having financial exception criteria available during interim operations, Western has not had to exceed operating criteria for financial reasons. If financial exception criteria are part of the selected alternative, the availability of capacity and energy would be maintained, and costs to customers would be expected to increase at a slower rate.

Western may have to change the way power is marketed in the region as a result of changed operations at Glen Canyon Dam. Western currently is preparing an EIS to evaluate systemwide power marketing and allocations.

PERMITS AND REGULATORY APPROVALS

No permits or regulatory approvals would be necessary immediately to implement any of the alternatives. Depending on the results of long-term monitoring and research under adaptive management, permits under sections 402 and 404 of the Clean Water Act may be needed in the future.

ALTERNATIVES ELIMINATED FROM DETAILED ANALYSIS

During the scoping process, including formulation of alternatives, various alternatives and concepts were considered. Some were determined not reasonable for detailed analysis, as explained below.

Run-of-the-River Alternative

Many comments received during the scoping process expressed a desire that the dam be operated to mimic predam conditions in Grand Canyon. The EIS team responded by formulating the Run-of-the-River Alternative, with the goal of achieving predam conditions through operational changes, sediment augmentation, and selective withdrawal.

Conclusion

A return to a seasonal streamflow pattern emulating the magnitude of historic spring flows would be very destructive to downstream resources unless a large-scale, long-term sediment augmentation program were added. However, sediment augmentation would cause an increase in

turbidity and disrupt the aquatic food chain below Lees Ferry. Other potentially adverse impacts are unknown. A sediment slurry pipeline would require 15 to 20 years to implement, and a plan to operate the dam in the interim still would be needed. If sediment augmentation is desired in the future, this action would be the subject of a separate EIS.

Without sediment augmentation, the flows under this alternative would cause more erosion to sediment deposits below Glen Canyon Dam than other alternatives, including no action.

Historic Pattern Alternative

This alternative was a modification of the Run-of-the-River Alternative. It attempted to more closely follow predam water flow patterns, while still managing flows within current powerplant capacity. The Historic Pattern Alternative also included a sediment slurry pipeline and selective withdrawal.

Conclusion

This alternative was eliminated from detailed study for most of the same reasons as the Run-of-the-River Alternative. A sediment slurry pipeline would require 15 to 20 years to implement, and a plan to operate the dam in the interim still would be needed.

Without sediment augmentation, the flows under this alternative would cause more erosion to sediment deposits below Glen Canyon Dam than other alternatives, including no action. Mitigating these impacts by reducing seasonally high flows creates a flow regime incorporated into the Seasonally Adjusted Steady Flow Alternative. For these reasons, the Historic Pattern Alternative was not further considered.

Reregulated Flow Alternative

The EIS team responded to scoping comments requesting full use of Glen Canyon Dam Powerplant's generating capacity by developing the Reregulated Flow Alternative. The objective of this alternative was to initiate operational changes to fully use the powerplant's generating capacity (flows of 33,200 cfs) while reducing, to the extent possible, existing adverse impacts on downstream resources by constructing a reregulation dam.

Conclusion

Constructing a reregulation dam in Glen Canyon National Recreation Area would require changes in existing laws that protect the values for which the recreation area was established and prohibit construction of a dam within a national park or monument. While most downstream resources would experience improved conditions over the No Action Alternative, resources in the Glen Canyon reach would experience negative impacts.

Resources in the Glen Canyon reach that would be adversely impacted include sandbars, riparian vegetation and associated terrestrial wildlife, *Cladophora* and associated algal and invertebrate communities, a regionally important trout fishery, recreation potential, Native American cultural and sacred sites, and archeological and historic areas/sites. Impacts to the *Cladophora*-based aquatic food chain could have effects throughout Grand Canyon.

Most of these impacts would result from the greater frequency and magnitude of fluctuations behind the reregulating dam constructed to protect downstream resources from those same fluctuations. A reregulating dam would require $60 to $110 million to construct and 5 to 15 years to implement without any opposition.

Impacts in the Glen Canyon reach could be mitigated by reducing the frequency and magnitude of daily river fluctuations. However, without maximum fluctuations, there would be no need for a reregulation dam. Reduced fluctuations and elimination of the reregulation dam create conditions identical to those evaluated under other fluctuating flow alternatives, including no action.

Eliminated Concepts

Some comments received during the scoping process suggested the following concepts that were eliminated from detailed study.

- Sand pumping
- Beach protection
- Remove Glen Canyon Dam
- Move hydropower peaking from Glen Canyon Dam to Hoover Dam

Although sand pumping and beach protection were eliminated from detailed study in this EIS, both could be considered during long-term monitoring under adaptive management.

Removing the dam represents an alternative to the dam itself and would not meet the CRSP project purpose.

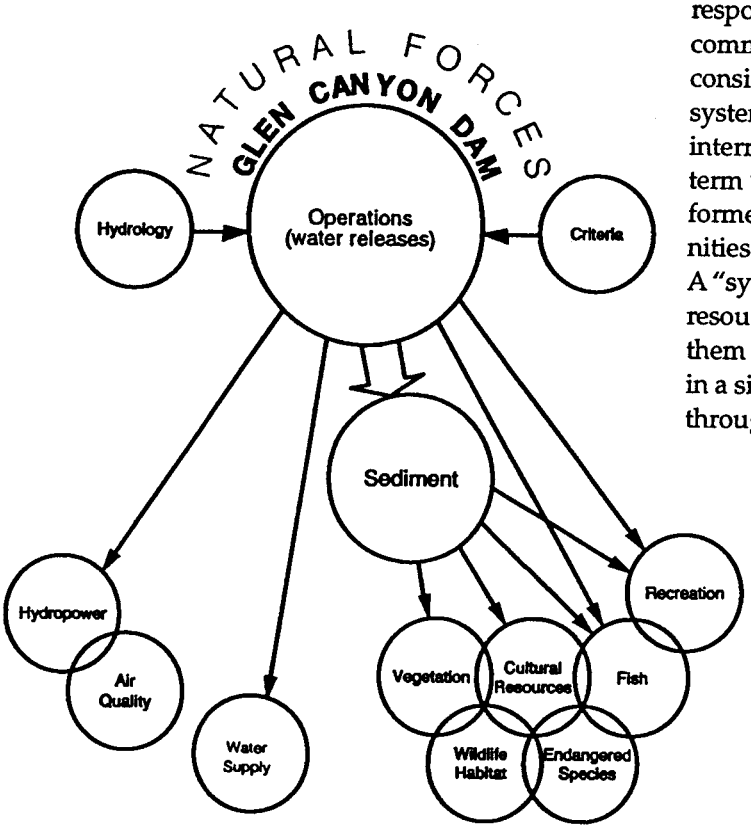
Hoover Powerplant already is operated as a hydroelectric power peaking plant. No excess capacity or energy is available at Hoover to substitute for reduced peaking at Glen Canyon, as all of the capacity and energy at Hoover is allocated by existing contracts.

Affected Environment and Environmental Consequences

This section describes how resources in the Colorado River system are linked, what resources are affected in the study area, and evaluates the effects of the alternatives on these resources. The baseline conditions described are those that existed in 1990, prior to the GCES research flows. The summary table at the end of this section compares the alternatives and their impacts.

COLORADO RIVER SYSTEM RESOURCE LINKAGES

Resources downstream from Glen Canyon Dam through Grand Canyon are interrelated, or linked, since virtually all of them are associated with or dependent on water and sediment. This section gives an overview of linkages to better illustrate the interdependence of processes and resources in the study area. A detailed description of resources follows this overview.



This resource linkage overview specifically responds to the EIS scoping process. Many comments from the public called for consideration of the "Grand Canyon ecosystem," showing public awareness of the interrelationships among resources. The term "ecosystem" refers to the system formed by interactions between communities of organisms and their environment. A "system" is based on the concept that resources and the processes that drive them are linked. In an ecosystem, changes in a single process can affect resources throughout the entire system.

This EIS emphasizes the holistic pattern of system behavior rather than impacts on separate elements. However, it cannot provide a complete, scientific study of the Grand Canyon ecosystem because such an approach is too technically detailed for the purpose and scope

of this document. Also, all the linkages among resources of the Grand Canyon ecosystem are not fully understood at this time. A program of monitoring and adaptive management is required to expand our understanding of how changes in processes affect this system.

The Glen Canyon Dam EIS focuses on the following processes, resources, and their linkages:

- Water release and sediment transport patterns
- Aquatic and terrestrial "indicator resources" within the system

The system of concern in this study is the Colorado River corridor—from Glen Canyon Dam through Grand Canyon to Lake Mead—and includes resources located in the river channel and in a narrow band of adjacent land (figure 4). Resources within this system depend on factors outside these operationally defined boundaries, including the physical and biological constraints of Lake Powell and, to a lesser extent, Lake Mead and tributaries such as the LCR.

The Grand Canyon ecosystem originally developed in a sediment-laden, seasonally fluctuating environment. The construction of Glen Canyon Dam altered the natural dynamics of the Colorado River. Today, the ecological resources of Grand Canyon depend on the water releases from the dam and variable sediment input from tributaries. The alternatives evaluated through this EIS must take into account not only the short-term needs of the environment but also the long-term requirements for maintaining and supporting the ecological elements of Grand Canyon.

Lake Powell traps water, sediment, and associated nutrients that previously traveled down the Colorado River. Interruption of riverflow and regulated release of lake water now support aquatic and terrestrial systems that did not exist before Glen Canyon Dam. Some changes are lamented while others are valued. The following discussion addresses the current systems, their resources, and how dam operations affect them either directly or through linkages among resources. The present interactions among water volume and release patterns, sediment transport, and downstream resources have created and support a complex system much different from predam conditions.

Water Volume and Pattern of Release

The major function of Glen Canyon Dam (and Lake Powell) is water storage. The dam is managed to release at least 8.23 million acre-feet (maf) of water annually to the Lower Basin. In this EIS, riverflows below the dam are referred to as releases or discharge. The measure of riverflow is in cubic feet per second (cfs). Annual and monthly volumes are measured in acre-feet. To put these relationships in perspective, Glen Canyon Dam

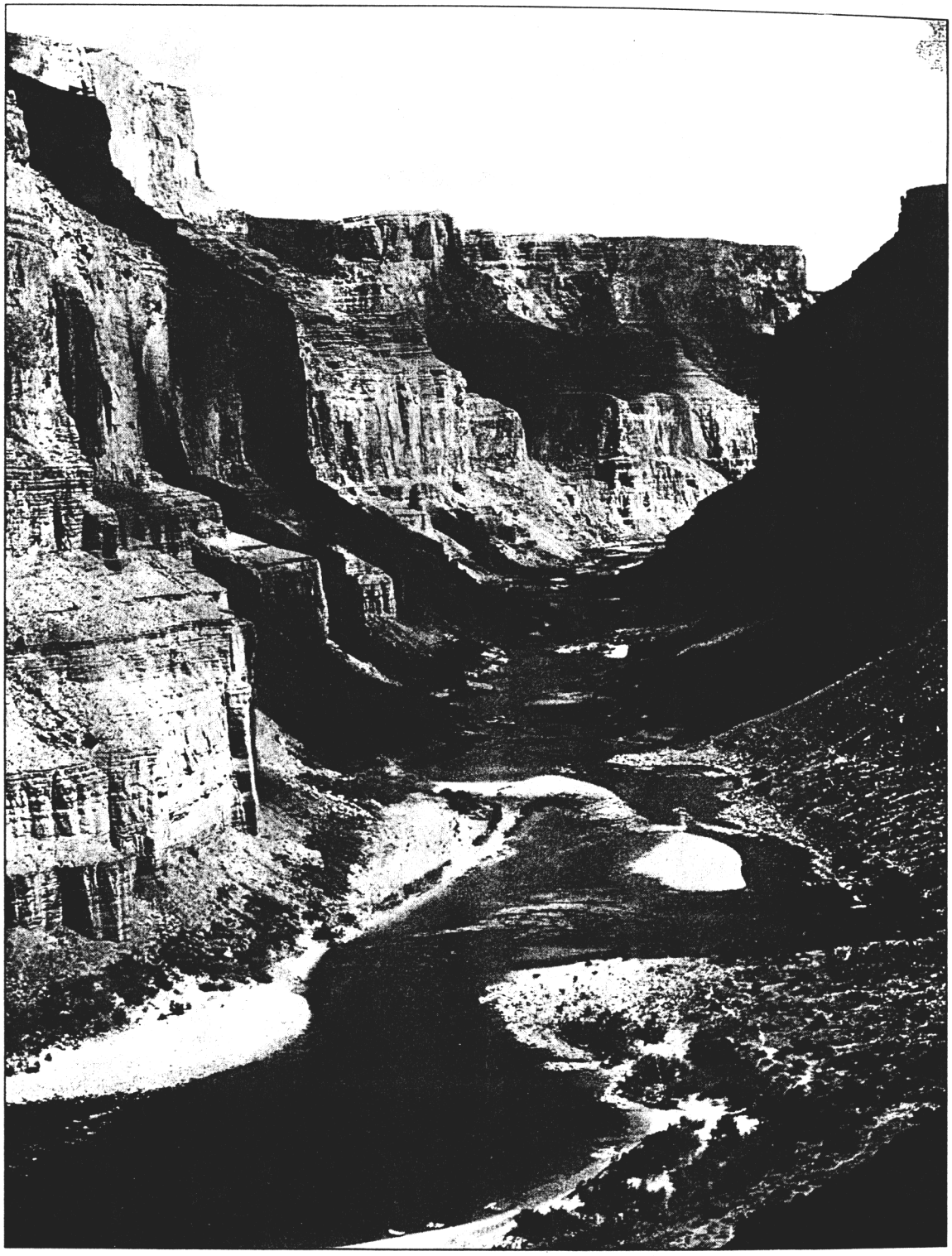


Photo by Gary Ladd

Figure 4.—Photograph of Colorado River corridor looking downstream from Nankoweap Creek.

would have to release approximately 11,400 cfs, 24 hours per day, every day of the year to release 8.23 maf. The amount of water and its pattern of release directly or indirectly affect physical, biological, cultural, and recreational resources within the river corridor.

Predam flows ranged seasonally from spring peaks sometimes greater than 100,000 cfs to winter lows of 1,000 to 3,000 cfs. During spring snowmelt periods and flash floods, significant daily and hourly flow fluctuations often occurred. While annual variability in water volume was high, a generally consistent pattern of high spring flows followed by lower summer flows provided an important environmental cue to plants and animals in the river and along its shoreline.

The frequency of daily and hourly fluctuations has increased since the dam was completed. Water is released to maximize the value of generated power by providing peaking power during high-demand periods. More power is produced by releasing more water through the dam's generators. Daily releases can range from 1,000 to 31,500 cfs, but actual daily fluctuations have been less than this maximum range. These fluctuations result in a downstream "fluctuating zone" between low and high river stages (water level associated with a given discharge) that is inundated and exposed on a daily basis. For purposes of this analysis, flows are defined as fluctuating if they both increase and decrease more than 2,000 cfs in a 24-hour period.

Hydropower conserves nonrenewable fuel resources and is cleaner, more flexible, and more responsive than other forms of electrical generation. Glen Canyon Powerplant is an important component of the electrical power system of the Western United States. The powerplant has eight generating units with a maximum combined capacity of 1,356 megawatts. When possible, higher releases are scheduled in high-demand winter and summer months to generate more electricity. Glen Canyon Powerplant historically has produced about $55 million in revenue in a minimum water release (8.23-maf) year.

Glen Canyon Dam also affects downstream water temperature and clarity. Historically, the Colorado River and its larger tributaries were characterized by heavy sediment loads, variable water temperatures, large seasonal flow fluctuations, extreme turbulence, and a wide range of dissolved solids concentrations. The dam has altered these characteristics. Before the dam, water temperature varied on a seasonal basis from highs around 80 °F to lows near freezing. Now, water released from Glen Canyon Dam averages 46 °F year round. Very little warming occurs downstream. Lake Powell traps sediment that historically was transported downstream. The dam releases clear water, and the river becomes muddy only when downstream tributaries contribute sediment.

Sediment Transport and Its Effect on Other Resources

Sediment can be considered a basic resource, linked in some way to most of the resources within Glen and Grand Canyons. The discussions in the EIS deal mainly with sand-size particles, although all sizes of sediment—from the smallest clays and silts to the largest boulders—are important system components. Sediment occurs both above and below the river's surface, and its transport and deposition are important considerations in many resource analyses.

Exposed and submerged sediment deposits throughout Glen and Grand Canyons are very important for cultural, recreational, and biological resources. Sediment is critical for stabilizing archeological sites and camping beaches, for developing and maintaining backwater fish habitats, for transporting nutrients, and for supporting vegetation that provides wildlife habitat.

Large annual floodflows—sometimes greater than 100,000 cfs—historically transported tremendous quantities of sediment that accumulated in high deposits and sometimes formed terraces. Wind and water eroded these deposits after the return to lower flows. Natural cycles of deposition and erosion generally prevented establishment of vegetation near the river.

Sediment supply and the river's capacity to transport sediment (especially sand and larger particles) both have been reduced. Maximum water releases (31,500 cfs) are much lower than the peak flows that occurred before Glen Canyon Dam. During normal operations, the riverbed and low elevation sandbars tend to build up (aggrade), and high elevation sandbars tend to erode. The only sources for resupplying sediment to the river below the dam are tributaries—primarily the Paria River, LCR, and Kanab Creek.

The 1983-86 floodflows (similar to predam spring peaks) transported sand stored within the river channel, eroded low elevation sandbars, and aggraded high elevation sandbars in wide reaches. In many places, vegetation that had developed since dam construction was scoured, drowned, or buried. Some archeological sites also were damaged. The high elevation sandbars eroded following the return to lower flows (as they did predam). Because floods of predam magnitude and sediment concentration can no longer occur, erosion of high terraces will continue.

The future existence of Grand Canyon sandbars depends on sand supplied from tributaries, daily water release patterns, and the long-term frequency and magnitude of flood releases from the dam. Cycles of sediment deposition and erosion are a natural process for rivers in the Southwestern United States. High flows—whether daily or annual—are necessary to replenish sand deposits, but high flows occurring too frequently in the dam-altered river will lead to long-term net erosion.

Flows, Sediment, and Downstream Resources

The Colorado River is the main influence in this dynamic ecosystem—changes in its flow ripple outward to affect both aquatic (water) and terrestrial (land) resources downstream. The system now contains a mixture of native and non-native plant and animal communities that began developing prior to the dam, with the introduction of non-native fish and vegetation. Dam construction and operation further modified this mixture and created the current system that is supported by postdam conditions. The river is forever changed. That change—brought about by Glen Canyon Dam—permitted this ecosystem to develop and establish itself.

Aquatic Resources

The predam aquatic system supported an array of native and non-native fish. Non-native carp and channel catfish have probably been present since the late 1800's. Channel catfish comprised 90 percent of fish captures in Glen Canyon in the late 1950's. At the time of the dam closure in 1963, at least eight species of non-native fish also were present in the system. During the 4 years following dam closure, when water temperature still varied seasonally from 45 to 70 °F, relative abundance of native fish increased over non-natives in the Glen Canyon area. By 1968, non-native fish once again became more abundant than natives, with trout dominating the now cold water system immediately below the dam.

The biological foundation of the aquatic system in the postdam Colorado River below Glen Canyon Dam is *Cladophora glomerata*, a filamentous green alga. River conditions created by the dam—low temperatures, nutrients from Lake Powell, and clear water—make possible the abundant growth of *Cladophora*. *Cladophora* filaments provide attachment sites for diatoms and hiding places for insect larvae. The non-native small crustacean, *Gammarus lacustris*, feeds on diatoms and uses *Cladophora* as a refuge. Together, *Cladophora*, diatoms, and associated invertebrates (*Gammarus* and insects) provide an important food source for other organisms in the aquatic food chain.

Several species of fish, including trout, were stocked in the Colorado River and some of its tributaries before construction of Glen Canyon Dam. Trout could not survive in the seasonally warm, muddy river. The postdam conditions described above, including the *Cladophora*-diatom-*Gammarus* food chain, now support a blue ribbon rainbow trout fishery in the Glen Canyon reach below the dam. However, water quality changes with distance from the dam, and aquatic communities change in response. While water temperature increases only slightly downstream, sediment from tributaries accumulates, turbidity increases, and the abundance of food-chain organisms decreases. The sediment particles' abrasive action also decreases the abundance of food organisms. As their food supply decreases downstream, trout decrease in abundance and condition.

Before the dam, eight native and several non-native fish species inhabited the river. Today, three native species have been extirpated, two are listed as endangered, and one is a candidate for listing under the Endangered Species Act. Two natives remain relatively common in tributaries and certain sections of the river. Non-native carp and channel catfish also have declined, while trout have increased. The reasons for extirpations or declines are undoubtedly complex, but principal known factors are competition and predation by non-native fish and habitat changes brought about by construction and operation of Glen Canyon Dam.

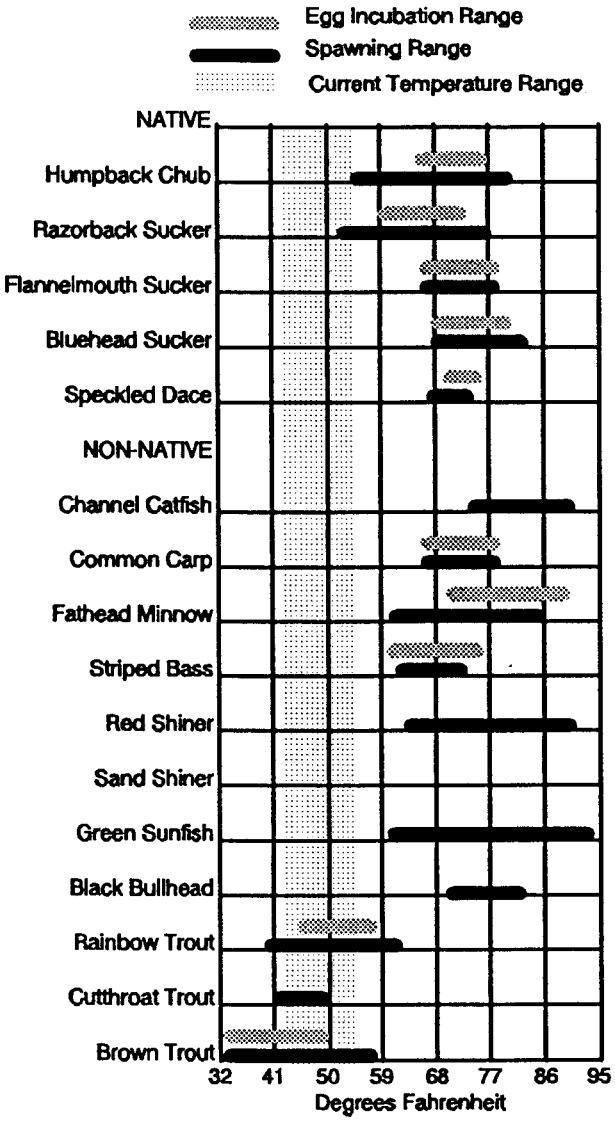


Figure 5.—Spawning and egg incubation temperatures for native and non-native fish. Shaded area denotes current temperature range.

Because of cold water temperatures, suitable habitats for young native and non-native fish in Grand Canyon are confined to tributaries, tributary mouths, and backwaters. Reproduction of warm-water fish species is restricted to within the tributaries, which are mostly outside the dam's influence. Figure 5 shows spawning and egg incubation temperatures for native and non-native fish.

The slow-moving water in backwaters and nearshore areas protects young fish from the stress and dangers of the main channel. Under the proper conditions, backwaters have higher water temperatures than the main channel and better food conditions for young fish.

Those native fish populations that remain in Grand Canyon may derive some indirect protection from cold releases. Year-round releases of uniformly cold water may discourage further invasion and reproduction of warmwater non-native fish that prey on native fish or compete with them for food or other resources.

Not only do the physical characteristics of water affect aquatic resources, but how water is released from the dam also affects them. For example, periods of exposure (6 to 8 hours) can adversely affect *Cladophora* and its associated invertebrates through drying, freezing, or ultraviolet light. Fluctuating discharges may dislodge segments of *Cladophora* and

temporarily increase drifting clumps of this important food-bearing resource downstream for trout and other organisms. The fluctuating zone supports fewer aquatic invertebrates than do sites that are continuously inundated. Insect larvae are uncommon in the fluctuating zone.

Flow fluctuations affect the spawning attempts of all fish. Although the trout fishery is maintained by stocking, mature trout attempt to spawn at suitable river sites and in certain tributaries. Rapid decreases in discharge can strand spawning trout, and low river stages can expose their nests and limit their access to tributaries. Fluctuating releases also may affect fish access to tributaries and backwater habitat. Flow fluctuations destabilize backwaters and nearshore areas and may force fish out of these more favorable habitats into the harsher conditions of the mainstem.

Bald eagles—which only passed through Grand Canyon before the dam—now stop during winter at sites along the river to feed on spawning trout and fish stranded by fluctuating flows.

Water release patterns also affect recreation. Three groups account for almost all recreational use of the Colorado River corridor: anglers, day rafters, and white-water boaters. Most trout fishing occurs in the 15-mile Glen Canyon reach below the dam. While some bank fishing occurs, most anglers are also boaters who motor upstream from Lees Ferry. Low flows can expose submerged cobble bars and make navigation difficult.

Terrestrial Resources

Riparian (near water) vegetation is a major terrestrial "indicator resource" below the dam. Before Glen Canyon Dam, seasonally high riverflows reworked sediment deposits and scoured most vegetation from the river corridor below the 100,000- to 125,000-cfs river stage elevation. The only riparian vegetation present along the river developed above this scour zone in what is known as the old high water zone (OHWZ). Dominant plants in the OHWZ include acacia, mesquite, and hackberry.

Following dam construction, protection from annual high flows permitted riparian vegetation to develop below the OHWZ in what has become known as the new high water zone (NHWZ). Today, this new zone of vegetation provides over 1,000 acres of additional habitat for native wildlife. A mixture of native and non-native plant species provides habitat for numerous species of mammals, birds, amphibians and reptiles, and terrestrial invertebrates. Many of these plants and animals have cultural significance to Native Americans.

Riparian vegetation reflects water flow patterns and sediment dynamics and is an excellent example of how system processes affect linked resources. High flows transport available sediments. Some sediments are deposited and become sandbars after flows recede, while other sediments are carried out of the system to become part of Lake Mead's delta. Before the dam, annual high flows carried large sediment loads through Glen and

Grand Canyons, scouring or burying any vegetation below the OHWZ. With the dam, flows are regulated, sediment supplies are limited, and riparian vegetation has become established in the NHWZ.

Riparian vegetation in the NHWZ grows on sediment deposits. While high flows can rapidly and dramatically restructure sandbars and associated riparian vegetation, daily dam release patterns influence the distribution of plants on sediment deposits. Below the level of maximum flow, sediment deposits are unstable and generally unsuitable for the establishment of woody vegetation. NHWZ plants grow in the area between maximum river stage and the level where limited ground water no longer supports growth.

Emergent marsh vegetation, such as cattails, often develops in areas with low water velocity, high concentrations of silt and clay, and a reliable water supply—typically backwaters. Under fluctuating releases, these important sites are periodically flooded and dewatered, allowing patches of emergent marsh plants to become established. Marshes probably did not occur in Glen and Grand Canyons before dam construction. Even though emergent marsh vegetation now makes up less than 2 percent of the total riparian vegetation, it greatly enhances plant diversity in the river corridor.

While riparian vegetation supports its own insect populations, it also provides habitat for insects emerging from the river (figure 6). Structural

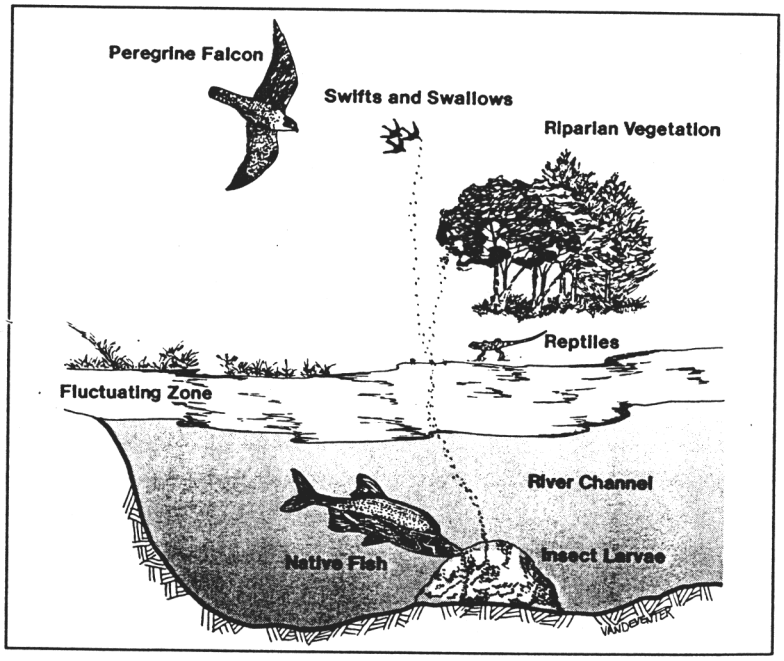


Figure 6.—Insects are an important linkage between aquatic and terrestrial systems in Grand Canyon. Swallows, swifts, and bats feed on insects; peregrine falcons—an endangered species—feed on these foraging species.

diversity of the riparian plant communities and abundant invertebrates make the riparian zone—especially the NHWZ vegetation resulting from dam-regulated flows—valuable wildlife habitat. The riparian zone is attractive to mammals because it provides them with cover and food, and some mammals—like bats—eat the abundant insects in the river corridor.

Birds are more dependent than mammals on riparian vegetation for cover, specifically nesting cover. Over half of the bird species nesting along the river corridor nest in riparian vegetation. Many birds eat insects or feed insects to their young, relying on the river and riparian vegetation for this important food. Some breeding bird densities in the riparian zone are among the highest recorded for their species. One of the highest known densities of peregrine falcons in North America resides in Grand Canyon, feeding on swallows, swifts, and bats.

The importance of riparian zone resources as wildlife habitat is easily demonstrated by the distribution of four common lizards. These species are most abundant near the shoreline where invertebrates, including insects, are common. Densities of lizards in some Colorado River corridor locations are higher than anywhere else in the Southwest.

WATER

Issue

How do dam operations affect the amount and quality of WATER available from Lake Powell at specific times?

Indicators

Acre-feet of **streamflows**
Frequency and volume of **floodflows and other spills**
Reservoir storage in Lakes Powell and Mead
Acre-feet of annual **water allocation deliveries**
Acre-feet of **Upper Basin yield determination**
Chemical, physical, and biological characteristics of **water quality**

Affected Resources

Existing statutes and rules guide the determination of annual streamflows—volumes of water released from Glen Canyon Dam—to spread the benefits of the Colorado River among the seven Basin States. The target minimum annual release from Lake Powell is 8.23 maf.

Floodflows are defined as releases in excess of the 33,200-cfs powerplant capacity. **Other spills** are excess annual releases from Lake Powell—greater than legally required—caused by scheduling difficulties (usually a substantial decrease in actual inflow from the initial forecasts). Any flows in excess of 33,200 cfs bypass the powerplant, with a corresponding loss in generated power.

Reservoir storage in Lakes Powell and Mead depends on annual and monthly reservoir inflow and release volumes. Storage levels affect shoreline resources and lake recreation. Further, the Upper Basin States use storage in Lake Powell to meet their water delivery requirements to the Lower Basin. The water storage necessary to carry the Upper Basin through a long drought would be reduced if alternative dam operations resulted in increased water releases.

Water allocation deliveries are the allowances of water diverted by each of the Basin States and those delivered to Mexico under the "Law of the River." **Upper Basin yield** is the legally determined maximum volume of water available for annual depletion by the Upper Basin States. Water depletions that New Mexico plans to use on an interim basis—in excess of its entitlement—are based on this determination.

Glen Canyon Dam altered downstream **water quality** by changing water temperature and clarity. Before the dam, water temperatures varied seasonally from about 80 °F to near freezing. Now water releases average 46 °F year-round, and very little warming occurs downstream. Lake Powell traps sediment, so the dam releases clear water, and the river becomes muddy only when downstream tributaries contribute sediment.

Effects of the Alternatives

Annual **streamflows** (release volumes) would differ only negligibly from no action under all alternatives and, therefore, are not expected to affect the distribution of benefits among the Basin States. The slight differences would result from modified monthly release patterns or from floodflow reduction measures.

The flood frequency reduction measures included in the restricted fluctuating and steady flow alternatives would reduce the frequency of unscheduled **floodflows** (greater than 45,000 cfs) from an average of once in 40 years to once in 100 years. **Other spills** would differ only negligibly from no action under all alternatives. Any differences would be due to more difficult water scheduling as a result of floodflow reduction measures or from revised monthly release patterns.

Reservoir storage under all fluctuating flow alternatives would be essentially the same as under the No Action Alternative. The steady flow alternatives could cause storage differences of a few feet within the year (due to revised monthly release patterns), but year-end storage would be essentially unchanged.

Water allocation deliveries would be affected negligibly under all alternatives. However, if reserving more space in the reservoir is used to reduce flood frequency, the **Upper Basin yield determination** would be reduced

from 6 maf to 5.96 maf. If the height of the spillway gates is raised to reduce flood frequency, the Upper Basin yield determination would be unchanged.

None of the alternatives affect **water quality** under normal reservoir levels, which occur 95 percent of the time.

SEDIMENT

Issue *How do dam operations affect SEDIMENT throughout Glen and Grand Canyons?*

Indicators
Probability of net gain in **riverbed sand**
Active width and height of **sandbars**
Erosion of **high terraces**
Constriction of **debris fans and rapids**
Elevation of **lake deltas**

Affected Resources

Sediment particles of all sizes—from clay to boulders—are derived from the weathering of rock and are transported and deposited by water and wind. Most of the sediment that enters the river is silt and clay. Only a small percentage of this fine sediment is deposited in low velocity areas. The rest is transported directly through to Lake Mead. Sand is the most abundant sediment temporarily stored in Grand Canyon. Most sand moves through the canyon in long sequences of deposition and scour.

Riverbed sand and **sandbars** are the sediment resources of primary interest affected by riverflows below Glen Canyon Dam. For sandbars to exist, sufficient amounts of sand must be stored on the riverbed, and flows must be large enough to move the sand and redeposit it on sandbars. The dam traps sediment, so sand supply is now limited to whatever is contributed by downstream tributaries—mainly the Paria River, LCR, and Kanab Creek—and hundreds of side canyons.

The dam not only cut off the upstream sediment supply, it also greatly reduced the river's capacity to transport sediment. Even so, frequent high flows—either from floods or large daily fluctuations—can transport greater amounts of sand than are contributed by the tributaries, causing a net decrease in both the amount of stored riverbed sand and the size of sandbars. Water release patterns also modify the natural process of sandbar deposition and erosion. Rapid drops in river stage drain the ground water stored during rising river stages from the sandbars, thus accelerating sandbar erosion.

High terraces, debris fans and rapids, and lake deltas are other sediment features of concern. **High terraces**—some containing archeological

remains—were deposited by infrequent, very high floodflows before the dam and cannot be replenished by postdam releases. A few of these terraces are directly exposed to erosion during floodflows. At the mouths of side canyons, **debris fans** are created and enlarged by occasional large debris flows of sediment and rock mixed with water. The largest particles—boulders—can be moved off the debris fans only by very large riverflows. These debris fans can constrict the river channel, creating **rapids** that may become narrower and steeper over time. Debris fans also create downstream eddies where most of the camping beaches used by river runners are deposited. The return-current channels associated with the eddies become backwaters used by fish during lower flows.

The rates of growth of Lake Powell **deltas** are independent of dam operations, but delta crest elevation may vary in response to water release patterns. In contrast, the growth of the Colorado River delta in Lake Mead depends on the delivery of sediment from Grand Canyon, which depends on tributary supply and the river's transport capacity. The Lake Mead delta crest elevation may vary with the water release pattern at Glen Canyon Dam, in combination with the release pattern at Hoover Dam.

Effects of the Alternatives

Potential changes in **riverbed sand** storage and in **sandbar** size and stability vary across the alternatives.

- Alternatives with high daily or annual maximum flows have greater potential to transport sand and deposit it at higher elevations, but over the long term would have relatively little sand to deposit.

- Alternatives with low daily or annual maximum flows have more sand to deposit but relatively little capacity to transport and deposit it at high elevations.

Under any circumstances, the long-term (50 years) sand load transported by the river will equal the long-term supply from the tributaries, although gains and losses may not balance out in the short term (20 years). How that sand is distributed determines sandbar size and stability. Under any alternative, the river reach between the Paria River (river mile (RM) 0) and the LCR (RM 61) is the most susceptible to long-term net loss of sand. In the clear water reach upstream from the Paria River, sand loss would continue but at a very slow rate. Long-term net changes downstream from Phantom Ranch (RM 88) are expected to be negligible.

The Modified Low Fluctuating Flow Alternative has a higher probability of net gain in riverbed sand than the No Action, Maximum Powerplant Capacity, and High Fluctuating Flow Alternatives; about the same as the Moderate and Interim Low Fluctuating Flow Alternatives; and somewhat less than the steady flow alternatives. With habitat maintenance flows,

however, the Moderate and Modified Low Fluctuating and Seasonally Adjusted Steady Flow Alternatives have potential to build sandbars about as high as under alternatives with greater daily fluctuations.

Eddy backwaters (return-current channels) would tend to fill with clay, silt, and sand under all alternatives. The filling rate would be smallest under alternatives with high maximum flows and highest under steady flow alternatives without habitat maintenance flows (Existing Monthly Volume and Year-Round Steady Flow Alternatives). Periodic flood releases and beach/habitat-building flows may restructure many backwaters.

The range in effects of the alternatives on other sediment resources is not as great. **High terraces**, not replenished under any alternative, would continue to erode. The river's capacity to move large boulders on **debris fans** would be about the same under all alternatives, including no action. Some **rapids** would gradually become narrower and steeper under any alternative.

Lake delta crest elevations would be the same under all alternatives except the Seasonally Adjusted and Year-Round Steady Flow Alternatives. Lake Powell delta crest elevations under these two alternatives could range from 0 to 2 feet lower than under the other alternatives; similarly, the Lake Mead delta crest elevation could range from 0 to 1 foot higher. Over the long term, the growth rate of the Lake Mead delta would be approximately 12 million tons per year—the amount of sediment delivered by tributaries—under any alternative.

FISH

Issue

How do dam operations affect FISH—their food base, life cycles, habitat, and ability to spawn?

Indicators

Abundance of *Cladophora* and associated diatoms for **aquatic food base**
Reproduction, recruitment, and growth of **native fish**
Reproduction, recruitment, and growth of **non-native warmwater and coolwater fish**
Level of **interactions between native and non-native fish**
Reproduction, recruitment, and growth of **trout**

Affected Resources

The present aquatic ecosystem below Glen Canyon Dam is the result of complex interactions between habitat, released water, and the organisms that inhabit it. Minimum flows establish limits on productivity; and clear, cold water further defines the system. The *Cladophora*-diatom-*Gammarus*-dominated food base that supports the aquatic system is constrained by

riverflow. The number of native and non-native warmwater fish has declined and some species have disappeared from the river, while introduced trout have flourished and been developed into a blue ribbon sport fishery. Changes in water temperature and turbidity resulting from dam construction play a large part in these responses.

Because of the dynamic interaction between resources and riverflow, changes in water release patterns would be expected to affect aquatic resources. However, because of the large variety of aquatic resources and their differing water requirements, a comprehensive evaluation of the effects of all alternatives on all aquatic resources is beyond the scope of the report. Therefore, the five indicators listed previously were selected for detailed evaluation of impacts on fish.

Effects of the Alternatives

None of the alternatives under consideration would affect the temperature of dam releases, which is generally too cool for reproduction by **native and non-native warmwater fish**. Thus, reproduction would continue to be restricted to tributaries. Alternatives that provide a minimum reliable flow of 5,000 cfs—all alternatives except the No Action, Maximum Powerplant Capacity, and High Fluctuating Flow Alternatives—would permit unlimited access to tributaries. It is unknown if the low flows of those three alternatives would actually restrict access to tributaries for more than short periods of time.

Increased minimum flows would benefit the **aquatic food base** and the fish and wildlife that depend on it. Increased minimum flows also would benefit **trout** spawning in the main channel. However, even at 8,000-cfs flows, up to an estimated 59 percent of known trout nests would be exposed by daily or seasonally changing flows. Increased minimum flows under the Modified Low and Interim Low Fluctuating Flow Alternatives and the three steady flow alternatives may permit a self-sustaining trout fishery to develop.

Interactions between native and non-native fish are expected to increase as habitat conditions improve. Such interactions would reach a level of concern under steady flow alternatives.

Maintenance of backwaters, important as rearing habitat for young native fish, is a concern. Backwaters would experience greater warming under steady flow alternatives. However, the exact effects of this warming on native and non-native warmwater fish are unknown. Backwaters are expected to be maintained by habitat maintenance and beach/habitat-building flows designed to restructure return-current channels. There is concern by some resource specialists that warm refuge areas might intensify competition and predation by non-natives on native fish.

Endangered fish research flows (likely a seasonally steady release pattern) would be implemented and evaluated through adaptive management. The extent to which such flows would be permanently incorporated into the selected alternative would depend on evaluation of the research results and a determination by the U.S. Fish and Wildlife Service. In years when they occur, endangered fish research flows are expected to have impacts on fish similar to those under the Seasonally Adjusted Steady Flow Alternative (see Summary Comparison of Alternatives and Impacts table at the end of this section).

VEGETATION

Issue *How do dam operations affect VEGETATION throughout Glen and Grand Canyons?*

Indicators Area of **woody plants** and species composition
Area of **emergent marsh plants**

Affected Resources

Plant communities affected by Glen Canyon Dam releases exist in a restricted zone at the juncture between the river's edge and upland desert—the riparian zone. Water, sediment, and plants interact in this riparian zone. Water transports and deposits sediment, and the availability of water at sediment deposits supports plants that otherwise could not survive in a desert climate. The type of vegetation present in the riparian zone reflects the water release pattern that supports it.

Because of the dynamic interaction between riparian vegetation and water availability, changes in water release patterns would affect plant abundance and distribution. Since many different plants grow in the riparian zone and have differing water requirements, a comprehensive evaluation of the effects of all alternatives on all plants in the riparian zone is beyond the scope of this report. Therefore, two plant groups were selected for detailed evaluation to serve as indicators of impacts on riparian vegetation: **woody plants** (trees and shrubs) and **emergent marsh plants** (cattails and others).

Effects of the Alternatives

The Maximum Powerplant Capacity Alternative would result in reduced area of riparian vegetation because its maximum flows would be higher than the No Action Alternative and would increase erosion. Under no action, **woody plants** would be maintained within a zone equivalent to flows between about 22,000 and 40,500 cfs. Periodic inundation would maintain **emergent marsh plants** where they now exist.

All the restricted fluctuating and steady flow alternatives would permit riparian vegetation to expand (in differing amounts) into suitable sites made available by reduced maximum flows; acreage of **woody plants** would increase. The potential area available for plant expansion would increase from 15 to 35 percent (High Fluctuating Flow Alternative) to 94 percent (Year-Round Steady Flow Alternative) over no action. Under alternatives with beach/habitat-building flows, some woody vegetation would be lost as sand is deposited on high elevation sandbars. Woody plants would again develop on suitable sites in the years following such flows.

Some new establishment of **emergent marsh plants** would occur at the mouths of return-current channels and at other suitable sites. Some patches of emergent marsh plants would disappear and be replaced by woody plants as they lose their water supply under restricted fluctuating flow alternatives. Alternatives that include periodic habitat maintenance and beach/habitat-building flows would maintain newly established woody plants as well as restructure return-current channels that support emergent marsh plants. Patches of emergent marsh plants would be lost through scouring or burial as return-current channels are restructured, and new patches would develop at suitable new sites in the years following such flows. The total area of marsh plants would be the same as or less than under no action, depending on the alternative.

WILDLIFE AND HABITAT

Issue *How do dam operations affect area WILDLIFE AND their HABITAT?*

Indicators Area of **woody and emergent marsh plants** for riparian habitat
Abundance of **aquatic food base** for wintering waterfowl

Affected Resources

Wildlife is both diverse and abundant within the river corridor through Glen and Grand Canyons. Riparian vegetation plays an important role as habitat to support wildlife by providing food and cover for numerous mammals, birds, reptiles and amphibians, and invertebrates. Wintering waterfowl are attracted to and use the Colorado River below Glen Canyon Dam. Waterfowl depend on the aquatic food chain associated with the abundant green alga, *Cladophora glomerata*, that has developed in the clear, cold water below the dam.

The variety of animals present in the river corridor, their habitats, and how they use these habitats create a complex system that would be difficult to evaluate in detail. However, like other resources in the study area, this

system is linked to the river and, ultimately, to dam operations. The indicators listed above provide a way to analyze effects of the alternatives on wildlife and their habitat.

Effects of the Alternatives

As a result of the linkages among water, sediment, and riparian vegetation, alternative dam operations would affect wildlife by changing their habitat. Because of higher maximum flows, the Maximum Powerplant Capacity Alternative would reduce riparian vegetation and thus reduce wildlife habitat, while the area of **woody and emergent marsh plants** would not change under the No Action Alternative.

Riparian vegetation and wildlife habitat would expand into suitable sites made available by reduced maximum flows under the High, Moderate, Modified Low, and Interim Low Fluctuating Flow Alternatives and all the steady flow alternatives. The increased area available for plant expansion would range from 15 to 35 percent (High Fluctuating Flow Alternative) to 94 percent (Year-Round Steady Flow Alternative) over no action conditions.

Some patches of emergent marsh plants would disappear and be replaced by woody plants as they lose their water supply under restricted fluctuating flow alternatives, and some additional patches would be established at suitable sites. Habitat maintenance and beach/habitat-building flows would maintain these habitats. Some woody vegetation and patches of emergent marsh plants would be lost through scouring or burial as sand is deposited on high elevation sandbars and return-current channels are restructured during beach/habitat-building flows. Woody vegetation and emergent marsh plants would again develop at suitable new sites in the years following such flows.

Changes in minimum releases would affect wintering waterfowl by changing the **aquatic food base**. It is assumed that increased minimum flows would benefit the aquatic food base and wintering waterfowl. Because minimum flows would remain at 1,000 cfs under the No Action and Maximum Powerplant Capacity Alternatives, no changes are anticipated in the aquatic food base or the waterfowl using it. The remaining alternatives would increase minimum flows in amounts ranging from 3,000 cfs under the High Fluctuating Flow Alternative to 11,400 cfs under the Year-Round Steady Flow Alternative.

ENDANGERED AND OTHER SPECIAL STATUS SPECIES

Issue *How do dam operations affect the populations of ENDANGERED AND OTHER SPECIAL STATUS SPECIES throughout Glen and Grand Canyons?*

Indicators
Reproduction, recruitment, and growth of **humpback chub, razorback sucker,** and **flannelmouth sucker**
Trout and aquatic food base for **bald eagle**
Aquatic food base for **belted kingfisher**
Area of woody plants for **southwestern willow flycatcher**
Maximum flow for **Kanab ambersnail**

Affected Resources

The 10 special status species that occupy or use the river corridor through Glen and Grand Canyons are a diverse group. One species, the southwestern river otter, is believed extinct. Two others—the peregrine falcon and osprey—would not be adversely affected by dam operations. The remaining seven species (see indicators above) are evaluated in detail.

Clear, cold releases from Glen Canyon Dam; the introduction of non-native fish; and other factors have contributed to a decline in native fish populations. The humpback chub, razorback sucker, and flannelmouth sucker are native to the Colorado River Basin. The **humpback chub**, an endangered species, is found at specific sites in the main channel and reproduces in the LCR. The endangered **razorback sucker** is rare in the study area, and no reproduction is known to occur. The **flannelmouth sucker** is a candidate for listing under the Endangered Species Act, but this fish is relatively abundant and reproduces in several tributaries.

Effects of the Alternatives

Since all alternatives would continue to release clear, cold water from the dam, native fish reproduction would be limited to suitable tributaries. Backwater habitat, important to early life stages of humpback chub and flannelmouth sucker, would be warmer in the summer under steady flow alternatives. Nearshore and backwater habitats would also be more stable under steady flows.

The endangered **bald eagle** is linked to dam operations because it eats trout during the winter spawning period. All alternatives except the No Action and Maximum Powerplant Capacity Alternatives would provide minimum reliable flows greater than 1,000 cfs, which would improve trout spawning conditions.

The **southwestern willow flycatcher** has been proposed for listing as endangered under the Endangered Species Act. This bird winters in the tropics and nests in riparian vegetation in the Southwest; numbers are

limited in the Grand Canyon. All alternatives except the Maximum Powerplant Capacity Alternative would result in at least some increase in riparian vegetation. These increases would add potential nesting habitat for southwestern willow flycatchers but would not necessarily result in more birds using the Grand Canyon.

Because the **Kanab ambersnail** habitat has grown toward the river during interim operations, flows above 20,000 cfs would cause some incidental take of individuals of the population.

The **belted kingfisher** is an Arizona species of concern. All alternatives except the No Action and Maximum Powerplant Capacity Alternatives would increase minimum flows and thus benefit the aquatic food base. Improvements in the food base should benefit this bird species.

The FWS biological opinion on the preferred alternative contained a finding of no jeopardy for the bald eagle, peregrine falcon, and Kanab ambersnail and a jeopardy opinion for the humpback chub and razorback sucker. As required by the Endangered Species Act, the opinion contained a "reasonable and prudent alternative" that could remove the likelihood of jeopardizing the continued existence of the humpack chub and razorback in Grand Canyon. In accordance with this reasonable and prudent alternative, endangered fish research flows would be implemented through adaptive management to study the effects of low, steady flows in summer and fall combined with higher, steady flows in spring.

CULTURAL RESOURCES

Issue *How do dam operations affect the continued existence of CULTURAL RESOURCES in Glen and Grand Canyons?*

Indicators Number of **archeological sites** directly, indirectly, or potentially affected
Number of **Native American traditional cultural properties and resources** directly, indirectly, or potentially affected

Affected Resources

Cultural resources include **archeological sites** (both prehistoric and historic) and **Native American traditional cultural properties and resources.** The affected area containing these sites and properties includes a 255-mile section of the Colorado River corridor within Glen and Grand Canyons and lands adjacent to the Navajo Nation, the Havasupai and Hualapai Reservations, and Lake Mead National Recreation Area. These resources relate to cultural traditions dating from approximately 2500 B.C. to the present. Indian Tribes that have ancestral claims to the Grand Canyon and that continue to use the area today include the Havasupai, Hopi, Hualapai, Navajo, Southern Paiute, and Zuni.

A total of 475 prehistoric and historic sites have been located within the affected environment. Of these, 323 sites have been determined eligible for inclusion on the *National Register of Historic Places* (National Register). Anglo-American historic use of the area is represented by 71 sites dated between 1869 and 1940. One such resource, the Charles H. Spencer Steamboat, was listed on the National Register in 1974.

While archeological data provides some information about traditional uses of the area, each of the six tribes mentioned above has its own account of its history and relationships with other tribes and Grand Canyon. The Colorado River, the larger landscape in which it occurs, and the resources it supports are all considered sacred by Native Americans. Within this landscape, specific places—including shrines, burial locations, archeological sites, and mineral collection areas—are considered important by each tribe. The locations of these traditional cultural properties are sometimes closely held secrets, and it is often with reluctance that tribes reveal specific sites. Although some resources may be linked to specific locations, some are place independent or encompass numerous locations. All natural resources are considered sacred by Native Americans. Values placed by Native Americans on the land in general—as well as on specific sites, locations, and natural resources—represent traditions that are centuries old.

Effects of the Alternatives

Glen Canyon Dam changed the pattern of sediment deposition, erosion, and flooding through Glen and Grand Canyons. As a result, general loss of river-deposited high terraces has occurred. **Archeological sites** once protected by sandbars and terraces have become increasingly exposed to erosion by wind, rainfall, and the river. None of the alternatives considered in this EIS would alter postdam sediment input. Therefore, it is expected that impacts on archeological sites related to the existence—rather than operation—of the dam would continue regardless of alternative flow patterns. However, the rate at which impacts would occur could be affected by alternative operations. Similarly, many of the **Native American traditional cultural properties and resources** (especially plant and animal species) also depend on sandbars and high terraces along the river.

Generally, alternatives that would maintain the sand balance and allow for its distribution along the river corridor would enhance long-term preservation of cultural resources. The most favorable alternatives would produce a positive net sand balance in the system, while maintaining higher elevation sand deposits. Alternatives that fulfill these requirements are the Moderate and Modified Low Fluctuating Flow Alternatives and the Seasonally Adjusted Steady Flow Alternative.

Given the potential impacts of Glen Canyon Dam operations, Reclamation and NPS complied with National Historic Preservation Act documentation requirements. The Advisory Council on Historic Preservation,

Arizona State Historic Preservation Officer, Reclamation, NPS, and Indian Tribes completed a programmatic agreement that will ensure that Reclamation's and NPS's responsibilities under the act are satisfied. The programmatic agreement and accompanying plans dictate long-term monitoring that includes continuing consultation, identification, inspection, analysis, evaluation, and remedial protection actions to preserve historic properties within Glen and Grand Canyons.

AIR QUALITY

Issue *How do dam operations affect other electrical power production in the area, including those methods that have impacts on AIR QUALITY?*

Indicators Sulfates in **Grand Canyon air**
Tons of sulfur dioxide and nitrogen oxides (NO_x) in **regional air**

Affected Resources

The Grand Canyon enjoys some of the cleanest air in the lower 48 States, resulting in a visual range that sometimes exceeds 240 miles. However, haze—consisting of air pollution brought into the Grand Canyon area from urban and industrial areas—results in a summertime average visibility of only 100 miles. Sulfates, which are produced from sulfur dioxide (SO_2), are the major contributors to haze at Grand Canyon.

Navajo Generating Station near Page, Arizona, has been identified as a major source of SO_2 and, therefore, sulfates in Grand Canyon air. In response to these findings, the Environmental Protection Agency mandated that modifications to reduce emissions begin in 1995 with completion by 1999. Navajo Generating Station is independent of Glen Canyon Dam operations. The modifications will be made, and improvements in **Grand Canyon air quality** will be the same, regardless of which alternative is implemented.

Regional air quality is affected by the operation of interconnected powerplants. The operation of these powerplants would be affected by changes in Glen Canyon Dam operations.

Effects of the Alternatives

The restricted fluctuating and steady flow alternatives would reduce the amount of electrical energy produced during the day and correspondingly increase the amount of energy produced at night. This would mean that as demand for electrical energy increases, additional powerplants would be needed sooner than under no action. New powerplants would produce

less emissions than existing plants because of today's more restrictive emissions standards and because some of these new powerplants would burn natural gas.

Although total emissions from all new and existing powerplants may increase during the day, there would be an even greater reduction of emissions at night because Glen Canyon Dam Powerplant and additional new cleaner and more efficient powerplants would be producing more power at night. Therefore, the net effect on **regional air quality** under all restricted fluctuating and steady flow alternatives would be a slight reduction in emissions.

Additional power modeling studies completed since the draft EIS for the preferred alternative support this conclusion. The analysis predicted that total emissions of SO_2 would be reduced by 100,000 tons, and emissions of NO_x would be reduced by nearly 80,000 tons over a 20-year period relative to the No Action Alternative.

RECREATION

Issue *How do dam operations affect RECREATION in the study area?*

Indicators
Fishing trip attributes, safety, and access
Day rafting trip attributes and access
White-water boating trip attributes, camping beaches, safety, and wilderness values
Lake activities and facilities
Net **economic value** of recreation

Affected Resources

Fishing in Glen Canyon occurs mostly from boats, but some anglers wade in the area around Lees Ferry. The magnitude and rate of change in river stage increases the danger for anglers wading in the Glen Canyon reach.

Anglers fishing upstream from Lees Ferry must reach their desired fishing sites by boat. Access over 3-Mile Bar can be particularly hazardous during flows less than 3,000 cfs. Damage to boats and motors is more likely during the low flow periods that typically occur in the morning before peak-power generation periods—the time when many anglers are traveling upstream to reach fishing sites.

Only flows above 33,200 cfs affect the quality of **day rafting**. During these rare floodflows, use of dam outlet works and/or spillways prevents launching from the site below the dam. Day rafters must motor upstream from Lees Ferry and then float back down to the starting point, which reduces the trip quality for many users.

The wilderness characteristics of **white-water boating** trips are influenced by fluctuating river stages and by the conditions of beaches, vegetation, and other features of the riparian zone. Many river users believe that fluctuations detract from a trip's wilderness character.

White-water trip safety depends both on flow levels and on the timing and variation in river stage. Very low flows may make some rapids impassable, and very high flows create additional risks of capsizing. The safety and ease of access for handicapped individuals largely mirrors these safety concerns.

Usable beach area, the area above the high water line, is quite limited in some narrow reaches of the canyon. In the short term, high flows and large fluctuations in river stage limit usable beaches by completely inundating some and reducing the usable area of others. Low flows result in more available and usable beaches.

Net **economic value,** a measure of the value over and above the costs of participating in a recreation activity, is related to the number of recreators who participate in each activity, the time of year they participate, and the value of each trip taken.

Effects of the Alternatives

Since fluctuations are reduced and the rate at which river stage rises is constrained, **fishing** safety would improve under the Moderate, Modified Low, and Interim Low Fluctuating Flow Alternatives. All of the steady flow alternatives essentially eliminate river stage changes, producing a major improvement in angler safety.

Upstream fishing access under the Maximum Powerplant Capacity Alternative is the same as under no action. Increased minimum flows under the High Fluctuating Flow Alternative would result in a negligible increase in the ease of upstream access by anglers. Increased minimums and changes in the magnitude of up and down ramp rates would greatly improve upstream access under all other alternatives.

The flood control measures included in the restricted fluctuating and steady flow alternatives would reduce the probability of flood events and the corresponding need to launch from Lees Ferry, thus improving the quality of the **day rafting** experience in Glen Canyon.

The risk of **white-water boating** accidents would be highest under the No Action and Maximum Powerplant Capacity Alternatives, slightly lower under the High Fluctuating Flow Alternative, and decreased under the remaining restricted fluctuating flow alternatives. All steady flow alternatives would decrease the risk of white-water boating accidents 50 percent from no action.

Wilderness characteristics would improve as variations in riverflow are reduced. To the extent that habitat maintenance and beach/habitat-building flows maintain beaches and reduce the rate of vegetative encroachment, the alternatives with these flows would further enhance wilderness values.

In the short term, the greatest increase in available beach area would occur under the steady flow alternatives. In the long term, low steady flows would remove all the system's natural variation. The absence of natural system cycles is likely to encourage vegetation growth and result in net loss of campable beach area. Available beach area would be slightly increased under the Moderate, Modified Low, and Interim Low Fluctuating Flow Alternatives in the short term. In the long term, habitat maintenance flows (included in the Moderate and Modified Low Fluctuating and Seasonally Adjusted Steady Flow Alternatives) would help maintain the number of beaches and their campable area.

Since riverflows and the magnitude and frequency of fluctuations differ under each alternative, the net **economic value** of recreation also would differ. These economic values do not take into account long-term changes in the number and size of camping beaches.

The Maximum Powerplant Capacity and High Fluctuating Flow Alternatives have no effect on the net economic value of recreation relative to no action. The Moderate Fluctuating Flow Alternative increases the net economic value of recreation approximately $0.40 million in equivalent annual terms, followed by the Year-Round Steady Flow Alternative, which would increase the net economic value by $2.93 million annually. The Modified Low Fluctuating Flow Alternative would increase benefits by $3.74 million; and the Interim Low Fluctuating Flow and Existing Monthly Volume Steady Flow Alternatives would increase the net economic value by $3.94 million annually.

The Seasonally Adjusted Steady Flow Alternative would provide the most economic benefits, increasing the annual net economic value of recreation by $4.76 million.

HYDROPOWER

Issue *How do dam operations affect the ability of Glen Canyon Powerplant to supply HYDROPOWER at the lowest possible cost?*

Indicators **Power operations** flexibility
Power marketing resources, costs, and rates

Affected Resources

Glen Canyon Dam and Powerplant are part of the Colorado River Storage Project, one of the Federal projects from which Western Area Power Administration markets power. Glen Canyon Dam generates approximately 75 percent of the total CRSP power.

Western sells the power generated at Glen Canyon Dam to approximately 180 preference customers, including municipal and county utilities, rural electric cooperatives, water districts, irrigation districts, U.S. Government installations, and other nonprofit organizations. In total, nearly 4 million people throughout a six-State area in the Western United States purchase electricity from one of these preference wholesale customers. Federal hydropower consistently is one of the lowest-cost power sources available. Glen Canyon Dam has the ability to generate electricity without causing air pollution or using nonrenewable fuel resources.

The amount of power produced depends on the amount of water released through the powerplant. Western's Salt Lake City Area markets more than 4 billion kilowatthours (kWh) from Glen Canyon Dam each year.

The law requires Western to keep prices as low as possible, but high enough to pay for all construction, operation, maintenance, and transmission costs. If dam operating restrictions reduce the amount of power generated during periods of high demand and higher value, then electricity rates must increase.

As part of its **power marketing** program, Western sells power primarily on a firm (guaranteed), long-term basis. However, Western does not try to sell all available power from Glen Canyon Dam in this manner, since the amount of water and resulting electricity vary from year to year. The total annual amount of power marketed from the dam is based on actual water conditions. When flows allow, short-term sales are made to sell the power generated in excess of firm commitments or to take advantage of market conditions.

The flexibility of **power operations** at Glen Canyon Dam allows the powerplant to quickly and effectively respond to demand for electricity by instantaneously increasing or decreasing water releases. Coal-fired or

nuclear powerplants cannot respond as quickly. Western uses the flexibility of Glen Canyon Dam to generate more power when needed, provide electrical service assistance to other utilities, and take advantage of changing market conditions to sell short-term power.

Power is most valuable when it's most in demand—during the day when most industry and businesses are operating, and even more so during the hottest summer days and the coldest winter days when more power is needed to control building temperatures. Consequently, releasing more water during these times generates more power when it is most valuable. Western thus has historically asked Reclamation to release more water during the day and less at night.

Effects of the Alternatives

The restrictions that would be imposed on operations at Glen Canyon Dam under all alternatives except No Action and Maximum Powerplant Capacity Alternatives would reduce the flexibility of **power operations** and increase **power marketing** costs and rates. Specifically, restrictions would:

- Decrease the amount of firm capacity and value of energy that could be marketed
- Decrease the amount and value of power and electrical service assistance that could be offered to utilities
- Increase the cost of electricity to utilities and their customers
- Create a regional need to build additional powerplants and associated powerlines 5 to 10 years sooner than would otherwise have been necessary

Replacement capacity would be primarily from gas-fired powerplants, energy conservation, wind turbines, and pumped storage.

There are approximately 5.6 million end-use customers (residential, commercial, and industrial) in the six-State impact area. Approximately 3.9 million (70 percent of total) would either experience no increase in power rates or their rates would decline slightly if their utility is able to make additional sales as a result of changes in dam operations. The remaining 1.7 million end users are composed of 1.3 million (23 percent of total) large system customers and 0.4 million (7 percent of total) small system customers. The retail rates of these end users would be affected to varying degrees. Estimated retail rate impacts for small system customers are shown in the Summary Comparison of Alternatives and Impacts table at the end of this section. The retail rate impacts on large system customers are not known at this time. Because the large systems are less reliant on Federal hydropower and have greater access to alternative sources of supply, rate impacts would likely be less than those for the small systems.

Under the restricted fluctuating flow alternatives, average household electric bills for small system customers that rely on generation from Glen Canyon Dam (7 percent of total) would increase by $5 to $58 per year (0.8- to 10.0-percent increase), based on a household consumption of 9,000 kWh per year. Under the steady flow alternatives, a small system customer's average household electric bill would increase by $80 to $106 per year (13.8- to 18.4-percent increase).

Impacts on the national economy range from a gain of $1.5 million annually under the Maximum Powerplant Capacity Alternative to a cost of $123.5 million annually under the Seasonally Adjusted Steady Flow Alternative.

Endangered fish research flows (likely a seasonally steady pattern) would be implemented and evaluated through adaptive management during minimum release years. These research flows would have the potential to increase impacts of the selected alternative on power economics up to the level of impacts described for the Seasonally Adjusted Steady Flow Alternative. If endangered fish research flows occur only during the initial years of implementation, additional impacts would be minor. However, if steady flows were permanently incorporated in the operating criteria, impacts would be closer to those under the Seasonally Adjusted Steady Flow Alternative.

NON-USE VALUE

Issue *What effects do changes in Glen Canyon Dam operations have on NON-USE VALUE?*

Indicators Non-use economic value in **dollars**

Affected Resources

Studies have shown that individuals are affected by changes in the status of the natural environment, even though they may never visit or otherwise use a specific site. The value expressed by these non-users about changes in the environment or its features is termed non-use value. Non-use value is relevant if people care about the resources, can differentiate the effects of the alternatives on them, and can place value on these effects.

Effects of the Alternatives

The pilot phase of the non-use value study was completed in June 1994. Results indicate that members of the general public care about the affected resources, can place a value on them, and that this value is positive and

significant. A full-scale investigation of non-use value is now underway. Results of this investigation will be reported in a separate document when they become available in early 1995.

While it is impossible to estimate the magnitude of non-use value under each of the alternatives at this time, it is possible to characterize—in a relative fashion—the likely results of the study. Since non-users have indicated that they are most concerned about impacts on vegetation and its associated wildlife, native fish, Native Americans currently living near Grand Canyon, and archeological sites, the alternatives that most benefit these affected resources are also likely to have the highest non-use value.

CUMULATIVE IMPACTS

Cumulative impacts on the environment result from incremental impacts of the action when added to other past, present, and reasonably foreseeable future actions regardless of what agency (Federal or non-Federal) or person undertakes such actions. Since there are no anticipated construction projects on the Colorado River between Lakes Powell and Mead, there are no cumulative impacts in the immediate area.

Endangered fish research flows (likely a seasonally steady release pattern) would be implemented and evaluated through the Adaptive Management Program. The extent to which these steady flows would be permanently incorporated would depend on evaluation of the research results. Because the research flows might not occur every year and because results will need to be evaluated, effects of these flows could not be integrated into the summary of impacts on each resource. However, a general range of impacts can be predicted for affected resources.

During years when they occur, endangered fish research flows would have impacts on water and fish similar to those described for the Seasonally Adjusted Steady Flow Alternative. These research flows would not be expected to result in any additional impacts on cultural resources, air quality, or endangered and other special status species (other than native fish). Impacts on sediment, vegetation, wildlife and habitat, recreation, and hydropower potentially would increase up to the level of impacts described under the Seasonally Adjusted Steady Flow Alternative.

Power

Some economic sectors would experience greater than average impacts. Irrigation districts in the region typically receive a substantial portion of the power they use for pumping ground and surface water from the CRSP. Independent studies suggest that net farm income in the CRSP market area

would be reduced by, at most, 0.41 percent under the preferred alternative. Small subregions may experience greater or lesser impacts. Nonetheless, expected impacts on farm income would be rather limited.

Air Quality

Although total emissions from all new and existing powerplants may increase during the day, there would be an even greater reduction of emissions at night because Glen Canyon Dam Powerplant and additional new, cleaner, and more efficient powerplants would be producing more power at night. Therefore, the net effect on regional air quality under all restricted fluctuating and steady flow alternatives would be a slight reduction in emissions.

UNAVOIDABLE ADVERSE IMPACTS

None of the alternatives are expected to result in unavoidable adverse impacts to downstream resources relative to no action. However, unavoidable loss of peaking power would result from implementation of any of the restricted fluctuating or steady flow alternatives.

INDIAN TRUST ASSETS

Bureau of Reclamation policy is to protect American Indian Trust Assets from adverse impacts resulting from its programs and activities when possible. Indian Trust Assets are property interests held in trust by the United States for the benefit of Indian Tribes or individuals. Lands, minerals, and water rights are common examples of trust assets. No adverse impacts to Indian Trust Assets are anticipated under the preferred alternative.

SUMMARY COMPARISON OF ALTERNATIVES AND IMPACTS

The following table summarizes the environmental impacts of the alternatives on each of the affected resources described in detail in the EIS.

Summary Comparison of Alternatives and Impacts

	No Action	Maximum Powerplant Capacity	High Fluctuating Flow	Moderate Fluctuating Flow
WATER				
Streamflows (1,000 acre-feet)				
Annual streamflows				
Median annual release	8,573	8,573	8,559	8,559
Monthly streamflows (median)				
Fall (October)	568	568	568	568
Winter (January)	899	899	899	899
Spring (May)	587	587	592	592
Summer (July)	1,045	1,045	1,045	1,045
SEDIMENT				
Riverbed sand (percent probability of net gain)				
After 20 years	50	49	53	61
After 50 years	41	36	45	70
Sandbars (feet)				
Active width	44 to 74	47 to 77	33 to 53	28 to 47
With habitat maintenance flows				41 to 66
Potential height	10 to 15	10 to 16	7 to 11	6 to 10
With habitat maintenance flows				9 to 14
FISH				
Aquatic food base	Limited by reliable wetted perimeter	Same as no action	Minor increase	Moderate increase
Native fish	Stable to declining	Same as no action	Same as no action	Same as no action
Non-native warmwater and coolwater fish	Stable to declining	Same as no action	Same as no action	Same as no action
Interactions between native and non-native fish	Some predation and competition by non-natives	Same as no action	Same as no action	Same as no action
Trout	Stocking-dependent	Same as no action	Same as no action	Increased growth potential, stocking-dependent

Preferred alternative

Modified Low Fluctuating Flow	Interim Low Fluctuating Flow	Existing Monthly Volume Steady Flow	Seasonally Adjusted Steady Flow	Year-Round Steady Flow
8,559	8,559	8,559	8,554	8,578
568 899 592 1,045	568 899 592 1,045	568 899 592 1,045	492 688 1,106 768	699 703 699 699
64 73	69 76	71 82	71 82	74 100
24 to 41 41 to 66 6 to 9 9 to 14	24 to 41 6 to 9	10 to 19 3 to 5	16 to 29 37 to 60 4 to 7 8 to 13	0 0 to 1
Potential major increase	Potential major increase	Major increase	Major increase	Major increase
Potential minor increase	Potential minor increase	Uncertain potential minor increase	Uncertain potential major increase	Uncertain potential minor increase
Potential minor increase	Potential minor increase	Potential minor increase	Potential minor increase	Potential minor increase
Potential minor increase in warm, stable microhabitats	Potential minor increase in warm, stable microhabitats	Potential minor increase in warm, stable microhabitats	Potential minor increase in warm, stable microhabitats	Potential minor increase in warm, stable microhabitats
Increased growth potential, stocking-dependent	Increased growth potential, stocking-dependent	Increased growth potential, possibly self-sustaining	Increased growth potential, possibly self-sustaining	Increased growth potential, possibly self-sustaining

Summary Comparison of Alternatives and Impacts–Continued

	No Action	Maximum Powerplant Capacity	High Fluctuating Flow	Moderate Fluctuating Flow
VEGETATION				
Woody plants (area)				
New high water zone	No net change	0 to 9% reduction	15 to 35% increase	23 to 40% increase
With habitat maintenance flows				0 to 12% increase
Species composition	Tamarisk and others dominate	Tamarisk and others dominate	Tamarisk, coyote willow, arrowweed, and camelthorn dominate	Tamarisk, coyote willow, arrowweed, and camelthorn dominate
Emergent marsh plants				
New high water zone				
Aggregate area of wet marsh plants	No net change	Same as no action	Same as or less than no action	Same as or less than no action
WILDLIFE AND HABITAT				
Riparian habitat	*See vegetation.*			
Wintering waterfowl (aquatic food base)	Stable	Same as no action	Same as no action	Potential increase
ENDANGERED AND OTHER SPECIAL STATUS SPECIES				
Humpback chub	Stable to declining	Same as no action	Same as no action	Same as no action
Razorback sucker	Stable to declining	Same as no action	Same as no action	Same as no action
Flannelmouth sucker	Stable to declining	Same as no action	Same as no action	Same as no action
Bald eagle	Stable	Same as no action	Same as no action	Potential increase
Peregrine falcon	No effect	No effect	No effect	No effect
Kanab ambersnail	No effect	Some incidental take	Some incidental take	Some incidental take
Southwestern willow flycatcher	Undetermined increase	Same as no action	Same as no action	Same as no action

Modified Low Fluctuating Flow	Interim Low Fluctuating Flow	Existing Monthly Volume Steady Flow	Seasonally Adjusted Steady Flow	Year-Round Steady Flow
30 to 47% increase 0 to 12% increase	30 to 47% increase	45 to 65% increase	38 to 58% increase 0 to 12% increase	63 to 94% increase
Tamarisk, coyote willow, arrowweed, and camelthorn dominate	Tamarisk, coyote willow, arrowweed, and camelthorn dominate	Tamarisk, coyote willow, arrowweed, and camelthorn dominate	Tamarisk, coyote willow, arrowweed, and camelthorn dominate	Tamarisk, coyote willow, arrowweed, and camelthorn dominate
Same as or less than no action	Same as or less than no action	Less than no action	Less than no action	Less than no action
Potential increase	Potential increase	Potential increase	Potential increase	Potential increase
Potential minor increase	Potential minor increase	Uncertain potential minor increase	Uncertain potential major increase	Uncertain potential minor increase
Potential minor increase	Potential minor increase	Uncertain potential minor increase	Uncertain potential minor increase	Uncertain potential minor increase
Potential minor increase	Potential minor increase	Uncertain potential minor increase	Uncertain potential major increase	Uncertain potential minor increase
Potential increase	Potential increase	Potential increase	Potential increase	Potential increase
No effect	No effect	No effect	No effect	No effect
Some incidental take	Some incidental take	Some incidental take	Some incidental take	Some incidental take
Same as no action	Same as no action	Same as no action	Same as no action	Same as no action

Summary Comparison of Alternatives and Impacts-Continued

	No Action	Maximum Powerplant Capacity	High Fluctuating Flow	Moderate Fluctuating Flow
CULTURAL RESOURCES				
Archeological sites (number affected)	Major (336)	Major (336)	Potential to become major (263)	Moderate (Less than 157)
Traditional cultural properties	Major	Same as no action	Potential to become major	Moderate
Traditional cultural resources	Major	Same as no action	Same as no action	Increased protection
AIR QUALITY				
Regional air quality				
Total emissions (thousand tons)				
Sulfur dioxide	1,960	Same as no action	Slight reduction	Slight reduction
Nitrogen oxides	1,954			
RECREATION				
Fishing				
Angler safety	Potential danger	Same as no action	Same as no action	Moderate improvement
Day rafting				
Navigation past 3-Mile Bar	Difficult at low flows	Same as no action	Negligible improvement	Major improvement
White-water boating				
Safety	High risk at very high and very low flows	Same as no action	Negligible improvement	Minor improvement
Camping beaches (average area at normal peak stage)	Less than 7,720 square feet	Same as no action	Same as no action	Minor increase
Wilderness values	Influenced by range of daily fluctuations	Same as no action	Minor increase	Moderate increase
Economic benefits				
Change in equivalent annual net benefits (1991 nominal $ million)	0	0	0	+0.4
Present value (1991 $ million)	0	0	0	+4.6

Modified Low Fluctuating Flow	Interim Low Fluctuating Flow	Existing Monthly Volume Steady Flow	Seasonally Adjusted Steady Flow	Year-Round Steady Flow
Moderate (Less than 157)	Moderate (Less than 157)	Moderate (Less than 157)	Moderate (Less than 157)	Moderate (Less than 157)
Moderate	Moderate	Moderate	Moderate	Moderate
Increased protection	Increased protection	Increased protection	Increased protection	Increased protection
Slight reduction	Slight reduction	Slight reduction	Slight reduction	Slight reduction
Moderate improvement	Moderate improvement	Major improvement	Major improvement	Major improvement
Major improvement	Major improvement	Major improvement	Major improvement	Major improvement
Minor improvement	Minor improvement	Moderate improvement	Potential to become major improvement	Major improvement
Minor increase	Minor increase	Major increase	Potential to become major increase	Major increase
Moderate to potential to become major increase	Moderate to potential to become major increase	Major increase	Major increase	Major increase
+3.7	+3.9	+3.9	+4.8	+2.9
+43.3	+45.6	+45.6	+55.0	+23.5

Summary Comparison of Alternatives and Impacts–Continued

	No Action	Maximum Powerplant Capacity	High Fluctuating Flow	Moderate Fluctuating Flow
POWER				
Annual economic cost				
1991 nominal $ million				
Hydrology	0	-1.5	2.1	54.0
Contract rate of delivery	0	0	2.5	36.7
Present value (1991 $ million)				
Hydrology	0	-17.3	24.3	624.5
Contract rate of delivery	0	0	28.9	424.5
Wholesale rate (1991 mills/kWh)	18.78	18.78	19.38 (+3.2%)	22.82 (+21.5%)
Retail rate (1991 mills/kWh)				
70% of end users	No change	No change	No change to slight decrease	No change to slight decrease
23% of end users	No change	No change	Slight decrease to moderate increase	Slight decrease to moderate increase
7% of end users (weighted mean)	64.1	64.1	64.6 (+0.8%)	69.7 (+8.8%)
NON-USE VALUE	*No data.*			

Modified Low Fluctuating Flow	Interim Low Fluctuating Flow	Existing Monthly Volume Steady Flow	Seasonally Adjusted Steady Flow	Year-Round Steady Flow
15.1 44.2	36.3 35.6	65.9 68.7	88.3 123.5	69.7 85.7
174.6 511.2	418.7 411.7	761.4 794.6	1,021.2 1,428.4	805.0 991.2
23.16 (+23.3%)	23.18 (+23.4%)	25.22 (+34.3%)	28.20 (+50.2%)	26.78 (+42.6%)
No change to slight decrease	No change to slight decrease	No change to slight decrease	No change to slight decrease	No change to slight decrease
Slight decrease to moderage increase	Slight decrease to moderage increase	Slight decrease to moderate increase	Slight decrease to moderate increase	Slight decrease to moderate increase
70.5 (+10.0%)	70.2 (+9.6%)	72.9 (+13.8%)	75.8 (+18.4%)	74.5 (+16.3%)

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