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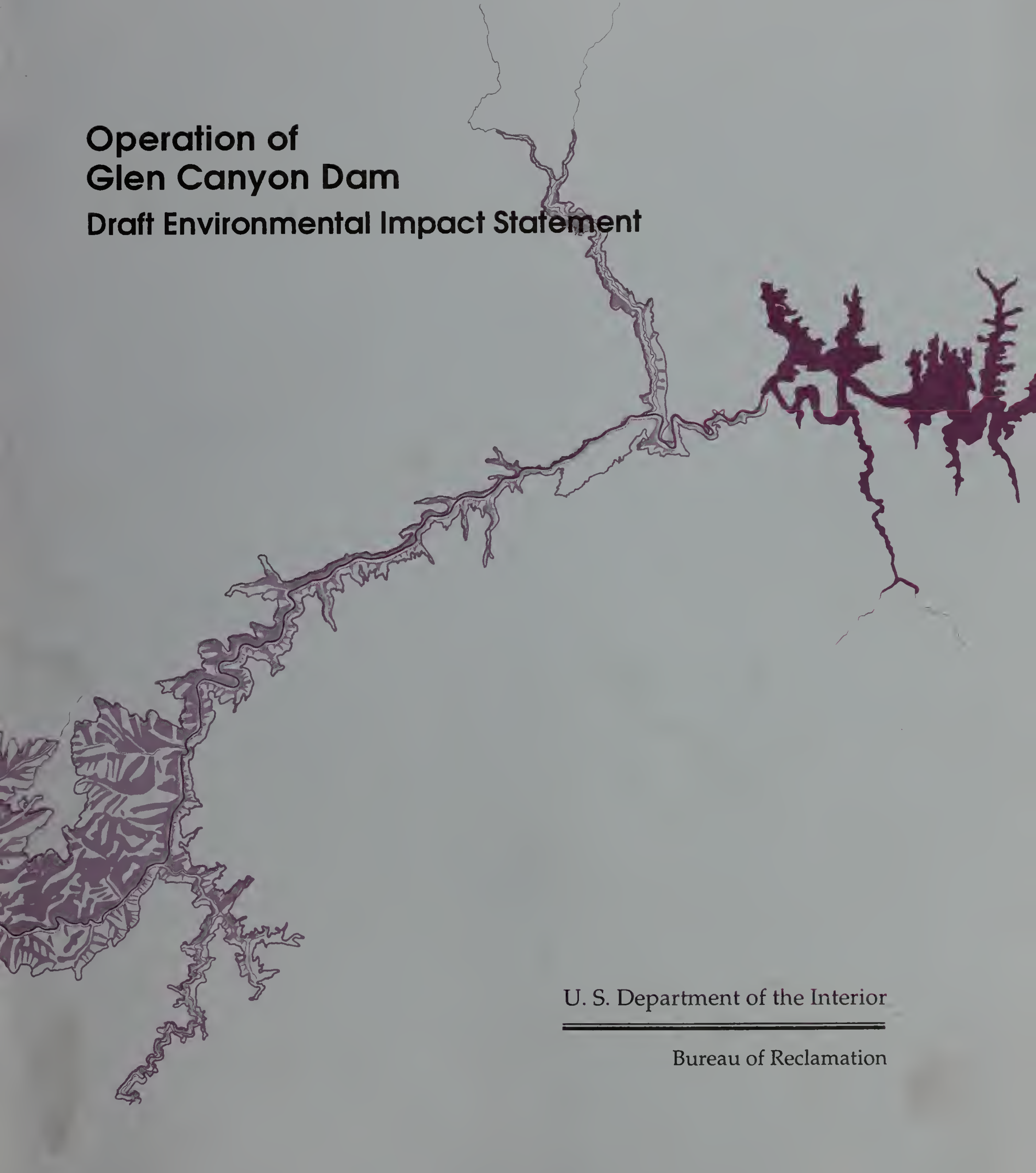
Operation of Glen Canyon Dam

Draft Environmental Impact Statement



U. S. Department of the Interior

Bureau of Reclamation

Acronyms and Abbreviations

AGC	Automated generation control
AGFD	Arizona Game and Fish Department
AMWG	Adaptive Management Work Group
AOP	Annual operating plan
BIA	Bureau of Indian Affairs
CFR	Code of Federal Regulations
cfs	Cubic feet per second
Corps	U.S. Army Corps of Engineers
CROD	Contract Rate of Delivery
CRSM	Colorado River Simulation Model
CRSP	Colorado River Storage Project
CRSS	Colorado River Simulation System
DO	Dissolved oxygen
DOE	Department of Energy
EIS	Environmental impact statement
°F	Degree Fahrenheit
FERC	Federal Energy Regulatory Commission
FONSI	Finding of no significant impact
FWCA	Fish and Wildlife Coordination Act
FWS	U.S. Fish and Wildlife Service
GCES	Glen Canyon Environmental Studies
GLCA	Glen Canyon National Recreation Area
GRCA	Grand Canyon National Park
GWh	Gigawatthour
IMPLAN	U.S. Forest Service input-output economic model
hr	Hour
IPP	Inland Power Pool
kV	Kilovolt
kW	Kilowatt
kWh	Kilowatthour
LCR	Little Colorado River
maf	Million acre-feet
mg/L	Milligrams per liter
MW	Megawatt
MWh	Megawatthour
NEPA	National Environmental Policy Act
NERC	North American Electrical Reliability Council
NHWZ	New high water zone
NO_x	Nitrogen oxide
NPS	National Park Service
OHWZ	Old high water zone
P.L.	Public Law
Reclamation	Bureau of Reclamation
RM	River mile
ROD	Record of decision
SLCA	Salt Lake City Area
SLCA/IP	Salt Lake City Area Integrated Projects
SO_2	Sulfur dioxide
SRP	Salt River Project
USC	United States Code
USGS	U.S. Geological Survey
WAUC	Western Area Upper Colorado
Western	Western Area Power Administration
WSCC	Western Systems Coordinating Council
>	Greater than
<	Less than

Draft Environmental Impact Statement
Operation of Glen Canyon Dam
Colorado River Storage Project
Coconino County, Arizona

Cooperating Agencies:

U.S. Department of the Interior
  Bureau of Reclamation (lead agency)
  Bureau of Indian Affairs
  Fish and Wildlife Service
  National Park Service
U.S. Department of Energy
  Western Area Power Administration
Arizona Game and Fish Department
Hopi Tribe
Hualapai Tribe
Navajo Nation
Pueblo of Zuni
San Juan Southern Paiute Tribe
Southern Utah Paiute Consortium

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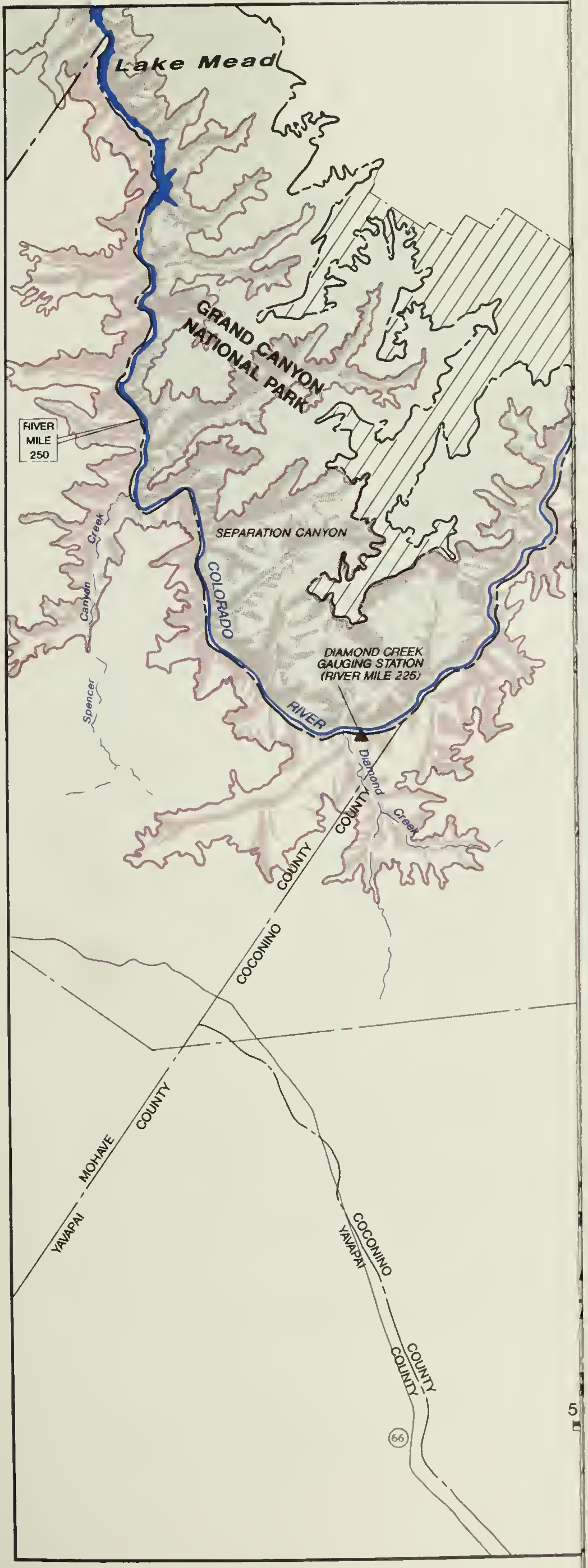
This draft environmental impact statement (EIS) analyzes the impacts of operations from 1963 to 1990 (baseline conditions) and alternative operations of Glen Canyon Dam on downstream environmental and cultural resources of Glen and Grand Canyons. Alternative operations evaluated include three that would provide steady flows; three that would provide various levels of fluctuating flows; and two, including no action, that would provide unrestricted fluctuating flows. Additional measures have been combined with the alternative operations, where appropriate, to provide additional resource protection or enhancement. The preferred alternative is the Modified Low Fluctuating Flow Alternative.

This draft EIS was prepared in compliance with the National Environmental Policy Act and Bureau of Reclamation procedures and is intended to serve environmental review and consultation requirements pursuant to Executive Order 11988 (Floodplain Management), Executive Order 11990 (Wetlands Protection), National Historical Preservation Act (Section 106), Fish and Wildlife Coordination Act, and Endangered Species Act (Section 7c). It is essential that those interested in this proposed action participate during the 90-day comment period. To be most helpful, comments on the draft should be as specific as possible and address the adequacy of the statement or the merits of the alternatives. Further, the Department of the Interior is not required to seek comments on the final EIS. It is, however, providing twice the amount of time for comment on the draft EIS than is required by the regulations. Therefore, you are encouraged to raise all comments, recommendations, or objections on the draft EIS so that substantive comments are made available to the lead agency in time for it to meaningfully consider and respond to them in the final EIS.

Comments must be received by April 11, 1994.


Lake Mead
GRAND CANYON NATIONAL PARK
RIVER MILE 250
SEPARATION CANYON
COLORADO
RIVER
Spencer
Canyon
Creek
DIAMOND CREEK GAUGING STATION (RIVER MILE 225)
Diamond
Creek
MOHAVE COUNTY
COCONINO COUNTY
COCONINO COUNTY
YAVAPAI COUNTY
COCONINO COUNTY
YAVAPAI COUNTY
66

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

GLEN CANYON DAM
ENVIRONMENTAL IMPACT STATEMENT

GENERAL MAP

DENVER, COLORADO
MAY 1993

U.S. GOVERNMENT PRINTING OFFICE 1993—839 094

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CHAPTER I

Purpose of and Need for Action

CHAPTER I

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, Arizona. The Secretary of the Interior (Secretary) called for a reevaluation of dam operations. The purpose of this reevaluation is to determine specific options that could be implemented to minimize—consistent with law—adverse impacts on the downstream environmental and cultural resources and Native American interests in Glen and Grand Canyons.

The need for this reevaluation stems from impacts to downstream resources caused by the operation of Glen Canyon Dam. Such impacts have been identified from scientific studies and have resulted 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 for future generations and producing hydropower, and to protect affected Native American interests.

The underlying project purpose(s) is defined by section 1 of the Colorado River Storage Project Act of 1956 (43 United States Code (U.S.C.) 620), which authorized the Secretary to "construct, operate, and maintain" Glen Canyon Dam:

> *. . . for the purposes, among others, of regulating the flow of the Colorado River, storing water for beneficial consumptive use, making it possible for the States of the Upper Basin to utilize, consistently with the provisions of the Colorado River Compact, the apportionments made to and among them in the Colorado River Compact and the Upper Colorado River Basin Compact, respectively, providing for the reclamation of arid and semiarid land, for the control of floods, and for the generation of hydroelectric power, as an incident of the foregoing purposes. . .*

In 1968, Congress enacted the Colorado River Basin Project Act (43 U.S.C. 1501 et seq.). This act provided for a program for further comprehensive development of Colorado River Basin water resources. Section 1501(a) states:

> *This program is declared to be for the purposes, among others, of regulating the flow of the Colorado River; controlling flood; improving navigation; providing for the storage and delivery of waters of the Colorado River for reclamation of lands, including supplemental water supplies, and for municipal, industrial, and other beneficial purposes; improving water quality; providing for basic public outdoor recreation facilities; improving conditions for fish and wildlife, and the generation and sale of electrical power as an incident of the foregoing purposes.*

In addition, the Criteria for Coordinated Long-Range Operation of Colorado River Reservoirs (including Glen Canyon Dam) were mandated by section 1552 of the Colorado River Basin Project Act. Article 1.(2) of these criteria requires that the annual operating plan for Colorado River reservoirs:

> *. . . shall reflect appropriate consideration of the uses of the reservoirs for all purposes, including flood control, river regulation, beneficial consumptive uses, power production, water quality control, recreation, enhancement of fish and wildlife, and other environmental factors.*

The Colorado River Compact (1922) and the Upper Colorado River Basin Compact (1948) do not affect obligations to Native American interests. Article VII and Article XIX, part a, respectively, of the 1922 and 1948 compacts provide that:

> *Nothing in this compact shall be construed as affecting the obligations of the United States of America to Indian Tribes.*

The Colorado River Storage Project Act of 1956, the Colorado River Basin Project Act of 1968, and the associated Criteria for Coordinated Long-Range Operation of Colorado River Reservoirs (Long-Range Operating Criteria) did not alter these compact provisions.

In addition to the Secretary's decision calling for a reevaluation, Congress subsequently enacted the Grand Canyon Protection Act of 1992. Section 1802 (a) of the act requires the Secretary to operate Glen Canyon Dam:

> *. . . in accordance with the additional criteria and operating plans specified in section 1804 and exercise other authorities under existing law in such a manner as to protect, mitigate adverse impacts to, and improve the values for which Grand Canyon National Park and Glen Canyon National Recreational Area were established, including, but not limited to natural and cultural resources and visitor use.*

Section 1802(b) of the act further requires that the above mandate be implemented in a manner fully consistent with existing law. Section 1802(c) states that the purposes for which Grand Canyon National Park and Glen Canyon National Recreation Area were established are unchanged by the act. Section 1804 (a) of the act requires the Secretary to complete an EIS no later than October 30, 1994, following which, under section 1804 (c), the Secretary is to "exercise other authorities under existing law, so as to ensure that Glen Canyon Dam is operated in a manner consistent with section 1802." Section 1804 (c) also requires that the criteria and operating plans are to be "separate from and in addition to those specified in section 602 (b) of the Colorado River Basin Project Act of 1968."

Glen Canyon Dam was completed by the Bureau of Reclamation (Reclamation) in 1963, prior to enactment of the National Environmental Policy Act (NEPA). Consequently, no EIS was filed regarding the construction or operation of Glen Canyon Dam. Since the dam has long been completed, alternatives to the dam itself have been excluded from the scope of the analysis.

This EIS is intended to meet the disclosure requirements of the National Environmental Policy Act of 1969.

Environmental impacts of the alternatives will be considered, along with other factors, in a separate record of decision (ROD) that will be prepared after filing the final EIS. The ROD will include the type or nature of the decision to be made, the forcing event, background information significant to an understanding of the situation, issues and decision factors, unresolved issues, and a clear description of options. It also will address comments received by Reclamation after filing the final EIS. The Secretary of the Interior is the responsible decisionmaker.

BACKGROUND

Since the dam was completed, increasing concern has been expressed by the public and Federal and State agencies about how Glen Canyon Dam operations may be adversely affecting downstream resources. In response to these concerns, the Secretary directed Reclamation to prepare an EIS on Glen Canyon Dam operations. In his July 1989 news release announcing the EIS, the Secretary stated: "It is time to gather the facts about this issue, to give all interested parties a chance to explain their positions, and to do so in full view of the American people." The Secretary noted that this issue is "an opportunity to balance energy and environment needs."

Glen Canyon Dam—the key feature of the Colorado River Storage Project—is a multipurpose facility. The Colorado River Storage Project Act directs the Secretary to operate project powerplants ". . . so as to produce the greatest practicable amount of power and energy that can be sold at firm power and energy rates . . .." To this end, the powerplant at Glen Canyon Dam historically has been used primarily for peaking power generation. Fluctuating releases associated with peaking power operations have caused concern among State, Federal, and Tribal resource management agencies; river users who fish in Glen Canyon and who take white-water raft trips in Grand Canyon; and Native American and environmental groups concerned about detrimental effects on downstream plants, animals, and their habitats.

These concerns were expressed most forcefully by the public during two Reclamation studies on possible increases in peaking power generation at Glen Canyon Dam. The studies were made to determine benefits and costs of:

1. Adding one or more generators at the dam (Peaking Power Study)

2. Increasing the capacity of the existing generators (Uprate and Rewind Program)

Adverse public reaction to the Peaking Power Study led to its termination in 1980. Reclamation published an environmental assessment (EA) and a finding of no significant impact (FONSI) on the Uprate and Rewind Program in December 1982. Subsequently, the uprate and rewind of the generators was completed, but Reclamation agreed not to use the increased powerplant capacity (as part of the EA and FONSI) until completion of a more comprehensive study on the impacts of historic and current dam operations on environmental resources throughout Glen and Grand Canyons. Therefore, 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.

In December 1982, Reclamation initiated Phase I of the multiagency Glen Canyon Environmental Studies (GCES) to respond to the concerns of the public and other Federal and State agencies. GCES Phase I was completed in 1988. Phase II is further defining impacts to the natural environment, associated public uses, cultural resources, non-use value, and power economics. Additional information on the GCES is found later in this chapter.

The environmental studies included special "research flows" that were conducted from June 1990 to July 1991 to evaluate resource responses to a variety of discharge parameters and to provide data for this EIS.

To protect downstream resources until completion of this EIS and the ROD, Reclamation began testing proposed interim flows on August 1, 1991. An EA and a FONSI (Bureau of Reclamation, 1991d) were completed, and the interim operating criteria 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 detailed under the Interim Low Fluctuating Flow Alternative in chapter II.

Cooperating Agencies

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

Representatives from Reclamation, NPS, FWS, Western, AGFD, U.S. Geological Survey (USGS), Hopi and Hualapai Tribes, the Navajo Nation, and a private consulting firm served on the interagency EIS team. The preparation of this EIS required close cooperation among the cooperating agencies, the interagency EIS team, and GCES (see figure I-1).

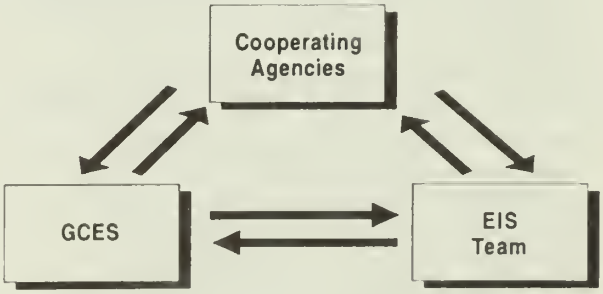

Figure I-1.—Ongoing interactive communication was essential to the Glen Canyon Dam EIS process.

Management Responsibilities

Federal agencies, the AGFD, the Hualapai Tribe, and the Navajo Nation have management responsibilities associated with Glen and Grand Canyons. These agencies have developed resource management objectives that describe the desired condition of specific resources and outline goals for future management.

Federal agencies with management objectives include Reclamation, NPS, FWS, Western, and BIA.

- Reclamation is responsible for operating the Colorado River Storage Project. Water management objectives are based on statutes specific to water storage and delivery (see "Law of the River"). Annual and long-term operating plans are prepared in consultation with the Basin States and the public, as well as agencies with jurisdiction by law.
- NPS manages Grand Canyon National Park and Glen Canyon and Lake Mead National Recreation Areas. NPS management objectives, which are based on the National Park Service Organic Act and the various statutes reserving these lands for park purposes, are described in the Colorado River Management Plan and other general management plans. These plans are prepared with public involvement and in consultation with Indian Tribes and other agencies with jurisdiction by law.
- FWS provides Federal leadership to conserve, protect and enhance fish and wildlife and their habitats for the continuing benefit of the public. In Glen and Grand Canyons, the fish and wildlife resource concerns of the FWS include threatened and endangered species, migratory birds, and native and sport fish. Objectives for fish and wildlife resources in the Grand Canyon ecosystem are addressed in the Fish and Wildlife Coordination Act Report (see FWS recommendations in attachment 4). Objectives for threatened and endangered species are specified in recovery plans, which are required by the Endangered Species Act.
- Western's management objectives are based on statutory responsibilities pursuant to the Department of Energy Organization Act; section 5 of the Flood Control Act; section 9 of the Reclamation Project Act; and, in the case of Glen Canyon Dam, the Colorado River Storage Project Act, as well as business, environmental, and other public concerns.
- Although BIA has no management role in the proposed action, it has management goals that include fostering the self-determination of Indian Tribes. Its role is to assure that Indian Tribe interests are coordinated with other Federal agencies and to provide advice and assistance to Tribes when requested to do so.

AGFD management objectives for the Colorado River fishery are specified in its Arizona Cold Water Sportfishes Strategic Plan, 1991-1995, and Non-Game and Endangered Wildlife Program Strategic Plan, 1991-1995. These management objectives are in concert with NPS objectives for the river corridor.

The Hualapai Tribe and Navajo Nation manage all natural and cultural resources within their reservation boundaries, which includes some lands along the river corridor downstream of Glen Canyon Dam. In addition, many sites located on Federal lands have cultural, ancestral, and spiritual significance to Native Americans—including Havasupai, Hopi, Hualapai, Navajo, Paiute, and Zuni—and these ties must be considered in Federal decisionmaking.

- The Hualapai Tribe cooperates with Federal, State, and local agencies in managing its resources. Management goals of the Tribe are long-term sustainable and balanced multiple use of its resources. The Hualapai Tribe's responsibility in relation to the Colorado River and Grand Canyon is one of stewardship of a sacred trust. The basis for its objectives come from its Conservation Ordinance 24-70, 1990 Revision.
- The Navajo Nation cooperates with Federal, State, and local agencies in managing its resources. The management objectives of the Navajo Nation are expressed in the Tribal regulations and internal policy statements and position papers.

Resource management objectives and an assessment of how well the various alternatives would achieve these objectives are presented in chapter II under "Summary Comparison of Alternatives."

DOCUMENT ORGANIZATION

This EIS consists of five chapters:

Chapter I: describes the purpose of and need for the proposed Federal action; location and setting; authorities and institutional constraints; Glen Canyon Environmental Studies; the relationship between this EIS and Western's Electric Power Marketing EIS; and a scoping summary.

Chapter II: describes the process used to formulate alternatives, the alternatives considered in detail, the alternatives considered but eliminated from detailed study, and a summary comparison of alternatives and impacts.

Chapter III: describes the environmental and other resources of the area that would be affected by the alternatives if they were implemented.

Chapter IV: describes and analyzes the environmental impacts of each alternative considered in detail.

Chapter V: describes the scoping process and coordination with the public, Federal agencies, Tribal Governments, and private organizations that occurred during preparation of this EIS; and the distribution list.

A list of preparers, glossary, conversion tables, and bibliography also are included as part of the document. A bookmark that briefly describes the alternatives is enclosed for easy reference.

The attachments include the environmental commitments; Grand Canyon Protection Act; Long-Range Operating Criteria; fish and wildlife consultation; programmatic agreement on cultural resources, and supporting data on the alternatives.

A separate appendix volume contains sections on long-term monitoring and research, hydrology, water quality, sediment, and hydropower.

LOCATION AND SETTING

The EIS focuses on the Colorado River corridor from Lake Powell, formed by Glen Canyon Dam in northwestern Arizona, southward through Glen and Marble Canyons and westward through Grand Canyon to Lake Mead (see frontispiece map). However, this document will disclose all significant impacts of the alternatives wherever they may occur.

The uppermost 15 miles of the river are in Glen Canyon, which is part of the Glen Canyon National Recreation Area; the remaining 278 miles of the river flow through Grand Canyon National Park. The Navajo Indian Reservation is immediately east of both park units and comprises the eastern part of Glen and Marble Canyons. The Hopi Indian Reservation is on the plateau farther east of Marble Canyon. The Havasupai Indian Reservation surrounds upper Havasu Creek, immediately south of Grand Canyon National Park. The Hualapai Indian Reservation comprises the southern portion of western Grand Canyon, adjacent to Grand Canyon National Park.

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

Grand Canyon National Park

Grand Canyon National Park, located downstream from Glen Canyon Dam, was first set aside for park purposes as a national monument on January 11, 1908, and was expanded and made a national park on February 16, 1919. Additions and boundary changes were made in 1927 and at various other times. The purposes for which these lands were reserved are stated in the various proclamations and acts creating the park. They identify these lands as "an object of unusual scientific interest, being the greatest eroded canyon within the United States" and warned unauthorized persons "not to appropriate, injure or destroy any feature" of the monument. In 1919, Congress dedicated these lands as "a public park for the benefit and enjoyment of the people" (Act of February 16, 1919, 40 Stat. 1175). In 1975, Congress declared that the entire Grand Canyon "is a natural feature of national and international significance" (16 U.S.C. 228a).

Grand Canyon National Park was dedicated as a World Heritage Site on October 26, 1979, joining "a select list of protected areas around the world whose outstanding natural and cultural resources form the common inheritance of all mankind."

Historical Perspective

Predam Flows

The predam period was characterized by dramatic, frequent, seasonal fluctuations in flow, sediment, and temperature. In spring and early summer, mean (average) daily flows in excess of 80,000 cfs were not uncommon; occasionally they were in excess of 100,000 cfs. In contrast, flows less than 3,000 cfs were frequent in the late summer, fall, and winter. Sediment load increased during the spring runoff and again in late summer from tributary floods. Water temperatures ranged from near freezing in winter to more than 80 degrees Fahrenheit (°F) in late summer.

Postdam Flows (Historic Operations)

Glen Canyon Dam replaced seasonal flow fluctuations with daily fluctuations, greatly reduced sediment load (supplied only by downstream tributaries), and resulted in nearly constant water release temperatures year-round—averaging a cool 46 °F.

The variability in average daily flows also has been reduced during the postdam period. Mean daily flows have exceeded 30,000 cfs (approximate powerplant capacity) only about 3 percent of the time and have been less than 5,000 cfs only about 10 percent of the time. Fluctuations within the day, however, have increased for power generation purposes. Median (equalled or exceeded 50 percent of the time) daily fluctuations (difference between minimum and maximum daily release) have ranged from about 12,000 cfs in October to about 16,000 cfs in January and August.

Glen Canyon Dam Operations

Glen Canyon Dam operations are affected by physical factors—including reservoir capacity, annual runoff, and discharge capacity—as well as by legal and institutional factors specified in various Federal laws, interstate compacts, international treaties, and Supreme Court decisions.

The Criteria for Coordinated Long-Range Operation of Colorado River Reservoirs contains the principal guidelines for annual and monthly operations resulting from the physical, legal, and institutional factors. These criteria are determined by the Secretary with participation by the States and are subject to a formal review at least every 5 years. (See attachment 3.)

A detailed description of Glen Canyon Dam operations can be found in chapter II under the No Action Alternative.

Physical Constraints. Glen Canyon Dam stores and releases water from Lake Powell, which has an active capacity of almost 25 million acre-feet (maf). Water can be released from Glen Canyon Dam in the following three ways.

1. *Powerplant releases.* Glen Canyon Powerplant has eight generators with a maximum combined capacity of 1,356,000 kilowatts (kW). The maximum combined discharge capacity of the eight turbines is approximately 33,200 cfs when Lake Powell is full; however, releases during fluctuations are limited to 31,500 cfs. When the reservoir is less than full, maximum possible discharge is reduced. Discharge through the turbines is the preferred method of release because electricity and its associated revenue are produced.

2. *River outlet works releases.* The capacity of the river outlet works is 15,000 cfs. The river outlet works are used when there is a need to release more water than can be passed through the powerplant. The outlet works are almost always used in conjunction with powerplant releases, producing combined releases up to 48,200 cfs.

3. *Spillway releases.* Releases through the spillways bypass both the powerplant and the river outlet works. The combined capacity of the right and left spillways is approximately 208,000 cfs. Spillway releases are made only when necessary to avoid overtopping the dam or to lower the level of Lake Powell. Spillway releases are avoided whenever possible, not only to prevent powerplant bypasses but also because the service life of the spillways is shorter than that of the other release structures.

Although the combined release capacity of these facilities is 256,000 cfs, the maximum combined release from Glen Canyon Dam is expected never to exceed 180,000 cfs.

AUTHORITIES AND INSTITUTIONAL CONSTRAINTS

Federal statutes establish a number of responsibilities for the Secretary. These legislated authorities relate to management of numerous agencies, projects, and lands–many of which have

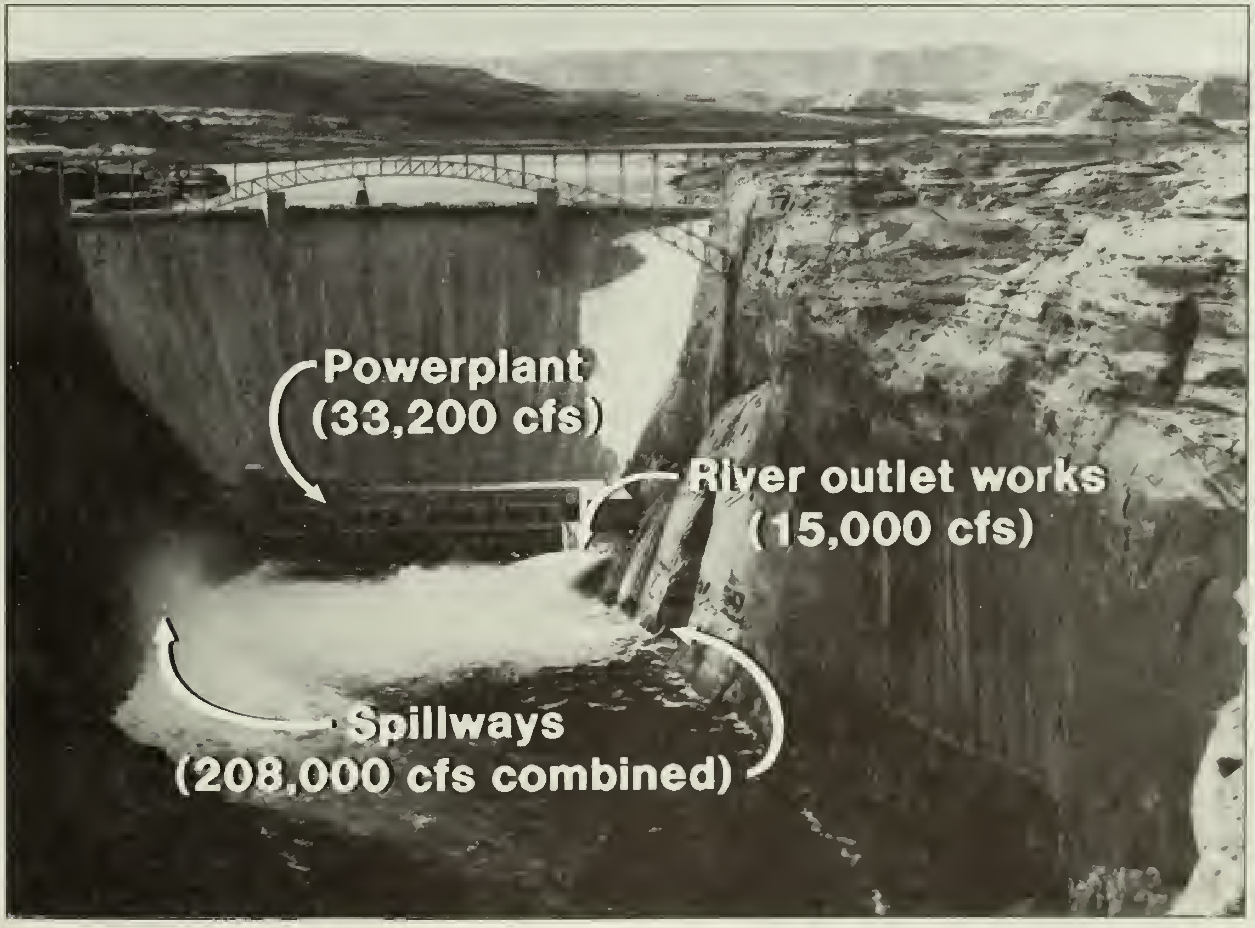

Figure I-2.—Photograph of Glen Canyon Dam and Powerplant showing water release capacities of the powerplant, outlet works, and spillways.

bearing on how Glen Canyon Dam is operated. Many responsibilities are specifically mandated, while discretionary authority is given for dealing with others.

Grand Canyon Protection Act of 1992 (Public Law 102-575)

This act addresses protection of Grand Canyon National Park, Glen Canyon National Recreation Area, interim operating criteria, long-term monitoring and research, and replacement power, as well as other administrative provisions related to preserving Grand Canyon. The act also requires that the Glen Canyon Dam final EIS be completed by October 30, 1994 (see attachment 2).

Law of the River

The "Law of the River," as applied to the Colorado River, is a collection of Federal and State statutes, interstate compacts, court decisions and decrees, an international treaty with Mexico, and criteria and regulations determined by the Secretary. Included are (in chronological order):

Colorado River Compact of 1922 (Wilbur and Ely, 1948)

Boulder Canyon Project Act of 1928 (43 U.S.C. 617-617t)

California Limitation Act of 1929 (Chapter 16, 48th Session (Sess.); Statutes and Amendments to the Codes, 1929, pp. 38-39)

California Seven-Party Agreement of 1931 (Nathanson, 1978)

Boulder Canyon Project Adjustment Act of 1940 (43 U.S.C. 618-618o)

Mexican Water Treaty of 1944, Treaty Series 994 (59 Statute (Stat.) 1219)

Upper Colorado River Basin Compact of 1948 (Nathanson, 1978)

Colorado River Storage Project Act of 1956 (43 U.S.C. 617)

General Principles to Govern, and Operating Criteria for, Glen Canyon Reservoir (Lake Powell) and Lake Mead during the Lake Powell Filling Period (*Federal Register*, 27 F.R. 6851, July 12, 1962)

Addition Regulation No. 1 (*Federal Register*, 27 F.R. 6850, July 12, 1962)

Arizona v. California et al., 373 U.S. 546 (1963)

Arizona v. California et al., (decree) 376 U.S. 340 (1964)

Arizona v. California et al., (supplemental decree) 439 U.S. 419 (1979)

Arizona v. California et al., (second supplemental decree) 466 U.S. 144 (1984)

Colorado River Basin Project Act of 1968 (43 U.S.C. 1501 et seq.)

Criteria for Coordinated Long-Range Operation of Colorado River Reservoirs (*Federal Register*, 35 F.R. 8951-52, June 10, 1970)

Colorado River Basin Salinity Control Act of 1974 (43 U.S.C. 620d, 1571-1578, 1591-1599)

Hoover Dam Flood Control Regulations of 1981 (33 Code of Federal Regulations (CFR) 208.11)

National Parks

Several laws established or added lands to national parks along the river corridor. These park units were established to provide for public outdoor recreation use and enjoyment and to preserve the scenic, scientific, and historic features of the area.

Antiquities Act of 1906 (16 U.S.C. 431 et seq.)

National Park Service Organic Act (16 U.S.C. 1-4, 22, 43)

National Park Service General Authorities Act of 1970 (16 U.S.C. 1a-1)

Grand Canyon National Park Establishment Act (16 U.S.C. 221, 221a, 221b)

Grand Canyon National Park Enlargement Act (16 U.S.C. 227, 228a-228j)

Lake Mead National Recreation Area Establishment Act (16 U.S.C. 460n, 460n-1-9)

Glen Canyon National Recreation Area Establishment Act (16 U.S.C. 460dd-1-9)

Environmental

Several laws and executive orders were designed to restore and protect the natural environment of the United States—air, water, land, and fish and wildlife.

Rivers and Harbors Act of 1899 (33 U.S.C. 401 et seq.)

Fish and Wildlife Coordination Act of 1958 (16 U.S.C. 661 et seq.)

Wilderness Act of 1964 (16 U.S.C. 1131 et seq.)

Wild and Scenic Rivers Act of 1968 (16 U.S.C. 1271 et seq.)

National Environmental Policy Act of 1969 (42 U.S.C. 4321 et seq.)

Clean Air Act (42 U.S.C. 7401 et seq.)

Clean Water Act of 1972 (33 U.S.C. 1251 et seq.)

Endangered Species Act of 1973 (16 U.S.C. 1532 et seq.)

Executive Order 11991, Protection and Enhancement of Environmental Quality, 1977

Executive Order 11988, Floodplain Management, 1977

Executive Order 11990, Protection of Wetlands, 1977

Cultural Preservation

Several laws and executive orders were designed to protect and preserve historic and cultural resources under Federal control in consultation with Indian Tribes.

Historic Sites, Buildings, and Antiquities Act (16 U.S.C. 461 et seq.)

Archaeological and Historic Preservation Act (16 U.S.C. 469 et seq.)

National Historic Preservation Act (16 U.S.C. 470 et seq.)

Executive Order 11593, Protection and Enhancement of the Cultural Environment, 1971

Archaeological Resources Protection Act of 1979 (16 U.S.C. 470 et seq.)

Native American

Several laws and treaties established reservations and protect the rights of Native Americans to express, believe, and exercise traditional religious practices. Federal agencies are responsible for consulting with Indian Tribal Governments and traditional religious leaders to determine appropriate actions necessary for protecting and preserving Native American religious cultural rights and practices.

American Indian Religious Freedom Act of 1978 (42 U.S.C. 1996)

Native American Graves Protection and Repatriation Act of 1990 (25 U.S.C. 3001 et seq.)

Laws or treaties establishing Indian Reservations within or adjacent to the study area:

Hualapai Indian Reservation: established by Executive Orders of January 4, 1883; June 2, 1911; and May 29, 1912.

Navajo Indian Reservation: established by Executive Order of January 8, 1900; an act to eliminate certain lands from the Tusayan National Forest, Arizona, as an addition to the Western Navajo Indian Reservation (May 23, 1930, chapter 317, 46 Stat. 378, 379, amended February 21, 1931, chapter 269, 46 Stat. 1204); an act to define the exterior boundaries of the Navajo Indian Reservation in Arizona (June 14, 1934, chapter 521, 48 Stat. 960-962).

GLEN CANYON ENVIRONMENTAL STUDIES

The Glen Canyon Environmental Studies are an interagency effort to examine short- and long-term effects of historic, current, and alternative dam operations on sediment, vegetation, wildlife, fisheries, recreation, cultural resources, power economics, and non-use values. Agencies cooperating in the studies are Reclamation, NPS, Western, USGS, FWS, and the Hopi Tribe, Hualapai Tribe, and Navajo Nation, with contributions from the AGFD, private consultants, universities, and river guides. Funding for these studies was provided mainly from the sale of hydropower.

GCES technical studies are reviewed by the responsible agency, the GCES senior scientist, and the National Research Council. These studies form the basis of the effects analysis presented in "Chapter IV, Environmental Consequences."

Review of the GCES by a National Research Council committee began in 1986. This Committee to Review Glen Canyon Environmental Studies has provided review and comment on the scientific and technical research studies associated with the GCES program and advice on alternative operation schemes for Glen Canyon Dam. In 1987, the committee completed its first report, *River and Dam Management: A Review of the Bureau of Reclamation's Glen Canyon Environmental Studies* (National Research Council, 1987). When preparation of this EIS was announced, the committee was requested to review the EIS as it developed. In May 1990, the committee conducted a symposium on the application of GCES results to the management of Glen Canyon Dam. A proceedings of the symposium was published entitled *Colorado River Ecology and Dam Management* (National Research Council, 1991).

Phase I (1982-88)

The GCES began as an interagency effort to study conditions downstream from the dam related to two major questions:

1. Are current operations of the dam, through control of the flows in the Colorado River, adversely affecting the existing river-related environmental and recreational resources of Glen and Grand Canyons?

2. Are there ways to operate the dam, consistent with Colorado River Storage Project water delivery requirements, that would protect or enhance the environmental and recreational resources?

To accomplish the study goals, more than 30 technical studies in the fields of biology, recreation, sedimentation, and hydrology were conducted. A final report integrating the results of all studies (U.S. Department of the Interior, 1988) as well as executive summaries of these reports (U.S. Department of the Interior et al., 1988) were published. These studies were conducted during the wettest 3 years on record (1983-85). While the studies provided considerable information on the effects of floods, they provided only limited information on the effects of powerplant operations.

Results of Phase I studies indicated the following relationships:

- Glen Canyon Dam and its operation have had an impact on the downstream environment. Changes have occurred and continue to occur to many ecosystem resources. Some changes are considered positive and some negative.

- Operations and management can be modified to minimize losses of some resources and to protect and enhance others.

- The ecosystem of Glen and Grand Canyons is dynamic and, with careful management, gradually may be able to reestablish more harmonious environmental relationships.

At the conclusion of these studies (now referred to as GCES Phase I), Reclamation determined that additional research was needed to more fully respond to the initial questions and to provide needed information; therefore, a second group of studies was initiated.

Phase II (1988-present)

In June 1988, the Department of the Interior determined that the GCES should be continued to gather additional data on specific operational elements. This phase of studies initially was to take place over 4 to 5 years; however, the timetable and research approach were adjusted after the Secretary announced on July 27, 1989, that an EIS would be prepared.

The research schedule was accelerated by using special "research flows" to provide more timely data for the EIS. These research flows were a series of carefully designed discharges and data collection programs conducted from June 1990 through July 1991. Each research flow lasted 14 days and included 3 days of steady 5,000-cfs flow and 11 days of either steady or fluctuating flow. The research flows provided a means to evaluate short-term responses of certain resources to a variety of discharge parameters, including minimum and maximum flows, rate of change in flow, and range of daily fluctuations.

Phase II research is based on an ecological system approach structured around specific hypotheses and research flows (Bureau of Reclamation, 1990c). Included are 10 primary study components and 2 monitoring components. Certain GCES studies will extend beyond the EIS schedule; however, sufficient information was available to prepare this EIS.

RELATIONSHIP BETWEEN GLEN CANYON DAM EIS AND ELECTRIC POWER MARKETING EIS

Western Area Power Administration is preparing an EIS on its Salt Lake City Area (SLCA) Integrated Projects Electric Power Marketing and Allocation Criteria. The criteria establish the terms used to allocate capacity and energy generated by the dams of the Colorado River Storage, Collbran, and Rio Grande Projects (collectively called the SLCA Integrated Projects). Powerplants in the SLCA Integrated Projects operated by Reclamation are Glen Canyon, Flaming Gorge, Blue Mesa, Morrow Point, Crystal, Upper Molina, Lower Molina, Fontenelle, and Elephant Butte. Glen Canyon Dam is the largest power producer within this group.

Although all of these hydroelectric powerplants are interconnected, Glen Canyon operations by Reclamation and power marketing by Western are appropriately addressed as two separate (but related) matters. The primary focus of the Glen Canyon Dam EIS is the physical environment of the Colorado River downstream from the dam. The primary focus of the Western EIS is systemwide power marketing and allocation. The power marketing EIS will look at possible environmental or operational effects caused by changes in power marketing programs, while the Glen Canyon Dam EIS evaluates the effects of differing modes of dam operations on the human environment. Ultimately, the Glen Canyon Dam EIS will identify a level of power resource that will be available for Western to market. Western can evaluate different ways of marketing power before knowing the specific operational changes that may be adopted for Glen Canyon Dam. Similarly, a Department of the Interior decision to change how water is released from the dam can be made before the Department of Energy decides how to market power.

SCOPING SUMMARY

The Glen Canyon Dam EIS scoping process was initiated in early 1990 to receive public input on the appropriate scope of the EIS, consistent with NEPA requirements and implementing regulations. Thorough effort was made to notify all potentially interested parties about the Glen Canyon Dam EIS scoping process and opportunities to provide comment. Reclamation increased opportunities for public participation through public meetings, news releases, mailings, legal notices, and 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, Denver, Phoenix, Flagstaff, Los Angeles, San Francisco, and Washington, DC. More than 17,000 comments were received during the scoping period, reflecting national attention and the intense interest of people in the Western States.

Public Issues and Concerns

Reclamation contracted with Bear West Consulting Team, a private business, to prepare a detailed content analysis of the oral and written scoping comments. Their methods and analysis were approved by the cooperating agencies.

As a result of the analysis, 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 (Bureau of Reclamation, 1990b).

Following the formal public scoping period and review of the comments, representatives from the cooperating agencies and public interest groups met in July 1990 to determine criteria for developing reasonable alternatives for the EIS. These criteria directed that the alternatives:

- Be consistent with the scope of the EIS
- Be economically and technically feasible
- Reflect legal considerations
- Have general institutional acceptability
- Be timely to implement
- Be able to be monitored and adjusted
- Meet various agency mandates
- Be supported by data
- Be multipurpose (integrated) and include all major resources
- Include mitigation

A more detailed discussion of scoping can be found in "Chapter V, Consultation and Coordination."

Significant Issues Identified for Detailed Analysis

The EIS team consolidated and refined the issues of concern to the public and Federal, State, and Tribal Governments, identifying the resources and their significant issues to be analyzed in detail. The following presentation summarizes the issues and the resource indicators that will be used to measure impacts of the alternatives.

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** Acre-feet **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**
Issue:	*How do flows affect **SEDIMENT** resources throughout the study area?*
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 **deltas**
Issue:	*How do flows affect **FISH**—their 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** Reproduction, recruitment, and growth of **trout**

Issue: *How do flows affect* ***VEGETATION*** *in the river corridor?*

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

Issue: *How do flows affect area* ***WILDLIFE AND*** *their* ***HABITAT****?*

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

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

Indicators: Tributary access, backwaters, and nearshore habitat for **humpback chub and razorback and flannelmouth suckers**
Trout and aquatic food base for **bald eagle**
Aquatic food base for **belted kingfisher**
Area of woody plants for **southwestern willow flycatcher**

Issue: *How do flows affect the continued existence of* ***CULTURAL RESOURCES*** *in the study area?*

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

Issue: *How do dam operations affect other 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 in **regional air**

Issue: *How do flows affect* ***RECREATION*** *in the study area?*

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

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

Issue: *How do changes in Glen Canyon Dam operations affect* ***NON-USE VALUE****?*

CHAPTER II

Description of Alternatives

CHAPTER II

Description of Alternatives

This chapter presents the process used to formulate alternatives, the alternatives considered in detail, the alternatives eliminated from detailed study, and a summary comparison of the alternatives and their impacts.

PROCESS USED TO FORMULATE ALTERNATIVES

Alternatives for the draft Glen Canyon Dam Environmental Impact Statement (EIS) were formulated through a systematic process using public input, technical information, interdisciplinary discussions, and professional judgment. The process began with consideration of Glen Canyon Environmental Studies (GCES) Phase I recommendations and comments from the 1990 public scoping activities.

In July 1990, representatives from cooperating agencies and various interest groups participated in a "brainstorming" workshop to fully consider all concepts and suggestions in formulating alternatives (Bureau of Reclamation, 1990a).

The interdisciplinary, interagency EIS team then formulated ten preliminary alternatives divided into three descriptive categories: fluctuating flows, steady flows, and flows mimicking predam conditions. Some of these preliminary alternatives included various structural elements that would provide warmer release temperatures in the summer, bypass sediment around the dam, or reregulate releases to provide steady flows downstream.

The team presented these alternatives to the cooperating agencies and, following their approval, presented them to the public in a newsletter (Bureau of Reclamation, 1991a) and three public meetings held in Salt Lake City, Flagstaff, and Phoenix during April 1991. These original alternatives ranged from providing high, warm, and sediment-laden flows each spring (with relatively low flows the remainder of the year) to providing steady, cool, and clear flows throughout the year. They ranged from steady flows throughout the day to high daily fluctuations.

The public was asked to comment on the range of preliminary alternatives as part of the EIS scoping process (Bureau of Reclamation, 1991b). The predominant public comment was the need for "operation only" alternatives and/or separate analysis of operational and nonoperational (structural) measures. Other comments most frequently voiced were:

- An alternative should be developed that maximizes benefits to endangered species and recreation.
- Alternative dam operations should be considered to reduce the frequency of floods and daily fluctuations.
- The reregulation dam is not a reasonable alternative and should not be considered.
- Not only is a reregulation dam a viable alternative, but a powerplant should be added to help pay the cost.
- The historic or natural flow patterns should serve as the baseline (No Action Alternative) for comparison of alternatives.
- None of the alternatives should include structural elements.
- The environmental, social, and economic effects of reduced electrical generation should be evaluated in steady flow alternatives.
- A lower fluctuating flow alternative should be formulated with a maximum of 20,000 cubic feet per second (cfs) and a minimum of 8,000 cfs. Ramp rates should be 1,000 cfs per hour up and 500 cfs per hour down, with no more than 3,000 cfs change from day to day. (Many comments on flow regime variations were received.)

Using this additional input, professional judgment, and analysis of interim flows, the EIS team reviewed and revised the preliminary alternatives. Seven alternatives were then identified for detailed analysis, and others were considered and eliminated from detailed study. Later, to present a full range of reasonable operations, two more alternatives were formulated. Figure II-1 summarizes these alternatives and their descriptions.

ALTERNATIVES CONSIDERED IN DETAIL

The nine alternatives considered in detail are described below, beginning with the No Action Alternative (historic operations) to provide a baseline for comparison. Table II-1 presents a summary of operating limits under the nine alternatives identified for detailed analysis.

The eight action alternatives were designed to provide a broad spectrum of options. One alternative would allow unlimited fluctuations in flow to maximize the value of power, 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.

Table II-2 shows the frequency of minimum and maximum releases and daily fluctuations under all Glen Canyon Dam EIS alternatives.

All of the restricted fluctuating flow and steady flow alternatives include the following elements designed to provide additional resource protection or enhancement. These common elements are discussed in detail later in this chapter.

- Adaptive management (including ongoing monitoring and research)
- Monitoring and protecting cultural resources
- Flood frequency reduction measures
- Beach/habitat-building flows
- New population of humpback chub
- Further study of selective withdrawal
- Emergency exception criteria

Table II-2.–Percent of days that minimum and maximum releases and daily fluctuations occur under the alternatives

Alternative	Minimum releases <8,000 cfs	Maximum releases >20,000 cfs	Daily fluctuations >6,000 cfs
	(percent of days)		
No action	90	72	97
Maximum powerplant capacity	90	73	97
High fluctuating flow	79	65	96
Moderate fluctuating flow	41	23	89
Modified low fluctuating flow	29	19	54
Interim low fluctuating flow	29	19	54
Existing monthly volume steady flow	<1	[1]7 to 18	0
Seasonally adjusted steady flow	<1	[1]5 to 27	0
Year-round steady flow	<1	[1]8 to 12	0

[1] Depending on season.

Unrestricted Fluctuating Flows

No Action Alternative

Minimum releases (cfs)	Maximum releases (cfs)	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. This alternative provides the basis for impact comparison.

Alternative	Description
STUDIED IN DETAIL:	
Unrestricted Fluctuating Flows	
No Action	**Maintain fluctuating releases and provide a baseline for impact comparison.**
Maximum Powerplant 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 and endangered fish research.**
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.**
CONSIDERED BUT ELIMINATED:	
Mimic Predam Flows	
Run-of-the-River **Historic Pattern**	**Provide flow conditions similar to predam conditions: high, warm spring floods and sediment augmentation.**
Reregulated Flow	**Maximize fluctuations from the dam to Lees Ferry, with a reregulation dam providing near-steady flows downstream.**

Figure II-1.—Glen Canyon Dam EIS alternatives.

Table II-1.–Operating limits of alternatives identified for detailed analysis

	Unrestricted Fluctuating Flows		Restricted Fluctuating Flows				Steady Flows		
	No Action	Maximum Powerplant Capacity	High	Moderate	Modified Low	Interim Low	Existing Monthly Volume	Seasonally Adjusted	Year-Round
Minimum releases (cfs)[1]	1,000 Labor Day–Easter [2]3,000 Easter–Labor Day	1,000 Labor Day–Easter [2]3,000 Easter–Labor Day	3,000 5,000 8,000 depending on monthly volume, firm load, and market conditions	5,000	8,000 between 7 a.m. and 7 p.m. 5,000 at night	8,000 between 7 a.m. and 7 p.m. 5,000 at night	8,000	[3]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	Yearly volume prorated[4]
Maximum releases (cfs)[5]	31,500	33,200	31,500	31,500 (may be exceeded during habitat maintenance flows)	20,000 (exceeded during habitat maintenance flows)	20,000	Monthly volumes prorated	18,000 (exceeded during habitat maintenance flows)	Yearly volume prorated[4]
Allowable daily flow fluctuations (cfs/24 hours)	30,500 Labor Day–Easter 28,500 Easter–Labor Day	32,200 Labor Day–Easter 30,200 Easter–Labor Day	15,000 to 22,000	±45% of mean flow for the month not to exceed ±6,000	[6]5,000 6,000 or 8,000	[6]5,000 6,000 or 8,000	[7]±1,000	[7]±1,000	[7]±1,000
Ramp rates (cfs/hour)	Unrestricted	Unrestricted	Unrestricted up 5,000 or 4,000 down	4,000 up 2,500 down	2,500 up 1,500 down	2,500 up 1,500 down	2,000 cfs/day between months	2,000 cfs/day between months	2,000 cfs/ day between months
Common elements	None	None	Adaptive management including long-term monitoring and research Monitoring and protecting cultural resources Flood frequency reduction measures Beach/habitat-building flows New population of humpback chub Further study of selective withdrawal Emergency exception criteria						

[1] In high volume release months, the allowable daily change would require higher minimum flows (cfs).

[2] Releases each weekday during recreation season (Easter to Labor Day) would average not less than 8,000 cfs for the period from 8 a.m. to midnight.

[3] Based on an 8.23-million-acre-foot (maf) year; in higher release years, additional water would be added equally to each month, subject to an 18,000-cfs maximum.

[4] For an 8.23-maf year, steady flow would be about 11,400 cfs.

[5] Maximums represent normal or routine limits and may necessarily be exceeded during high water years.

[6] Daily fluctuation limit of 5,000 cfs for monthly release volumes less than 600,000 acre-feet; 6,000 cfs for monthly release volumes of 600,000 to 800,000 acre-feet; and 8,000 cfs for monthly volumes over 800,000 acre-feet.

[7] Adjustments would allow for small power system load changes.

Within the overall Colorado River Storage Project 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) (see attachment 3) as well as daily fluctuating releases. The maximum allowable discharge during fluctuations is 31,500 cfs. Fluctuating releases occur 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. The principal factors considered in determining annual release volumes are:

- Releasing a minimum of 8.23 maf (specified in the Long-Range Operating Criteria)
- Maintaining conservation storage
- Avoiding anticipated spills
- Balancing storage between Lakes Powell and Mead

Annual release volume is based on inflow and remaining space in the two reservoirs. 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 Lake Powell and Lake Mead. 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. Historic predam and postdam annual flows at Lees Ferry are shown in figure II-2(a). This figure shows the reduced variation in annual flows after closure of the dam.

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 are the spills of principal concern. Floodflows 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.

Figure II-2(b) shows historic monthly release volumes for a low (minimum) release year, which occurs the most frequently. Figure II-3 presents a comparison of historic monthly releases among example low, moderate, and high release years.

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 the forecasted runoff will not produce spills but will fill the reservoir in July. July through September releases are used to meet the minimum annual release requirement and reach the January 1 target of 22.6 maf.

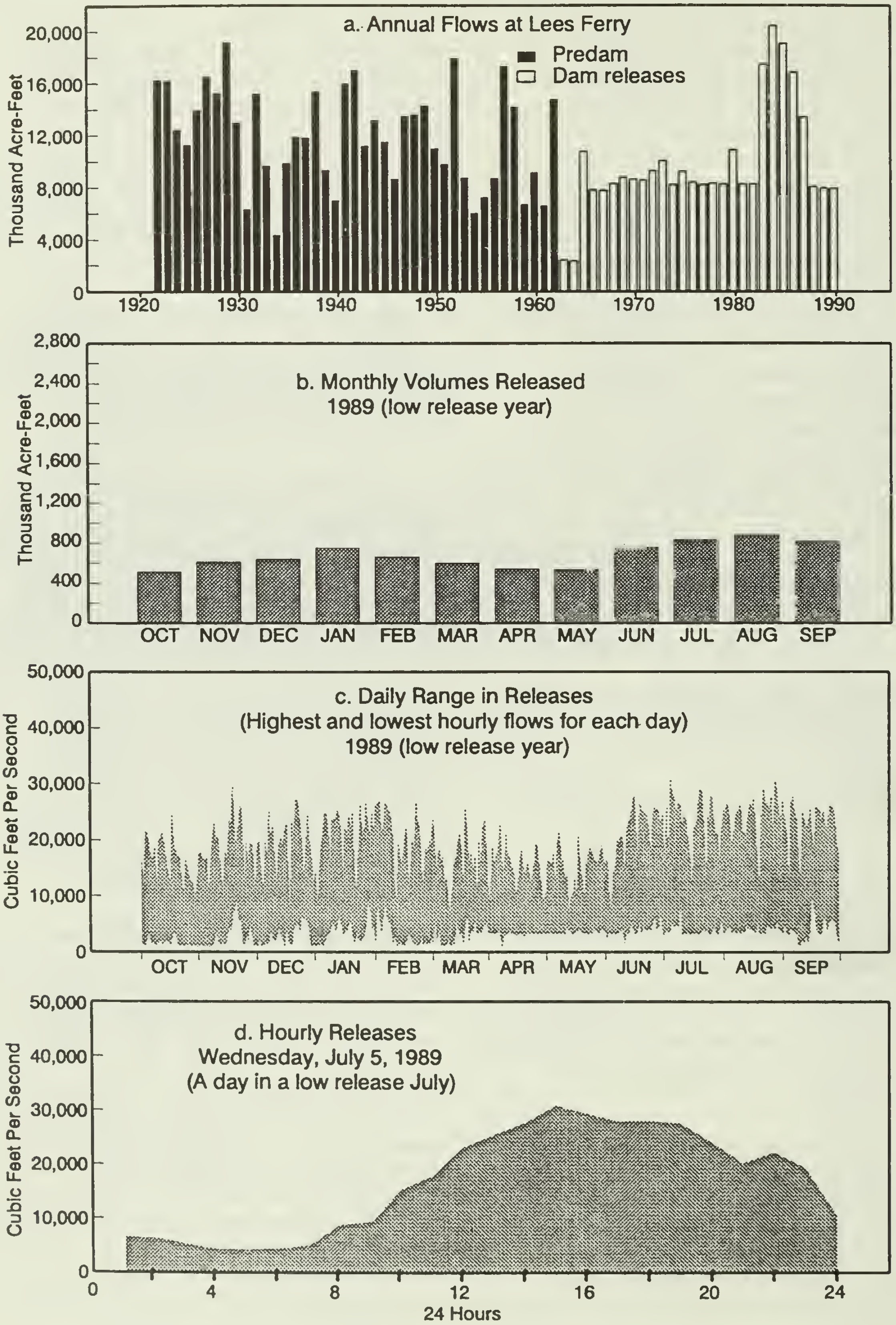

Figure II-2.—Historic water releases from Glen Canyon Dam.

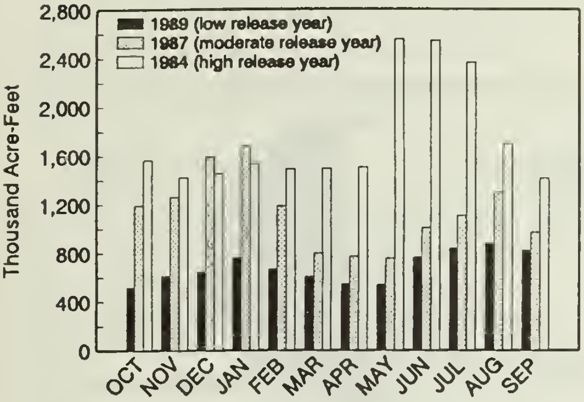

Figure II-3.—Comparison of monthly volumes released during low, moderate, and high release years.

Floodflow Avoidance Measures. 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 (error term) is added to the forecasted inflow so that more water is assumed to be coming into the reservoir than indicated by the forecast. The error terms are listed below.

Date	Additional inflow (maf)
January 1	4.98
February 1	4.26
March 1	3.60
April 1	2.97
May 1	2.53
June 1	2.13

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 the monthly release volumes, to maintain established minimum flow rates, and to follow the pattern of 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 (less than 4 hours), 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.

Typical hourly releases for a sample 24-hour period are shown in figure II-2(d). Also, figure II-4 compares 24-hour releases for typical low, moderate, and high release volume days. Fluctuating releases are made when the generating units are being operated to follow changes in power system load, produce peaking power, regulate the power system, or respond to power system emergencies. 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

Historic daily ranges of hourly releases are shown for an entire minimum release year in figure II-2(c). During a minimum release year, the greater the daily release volume, the greater the daily fluctuation.

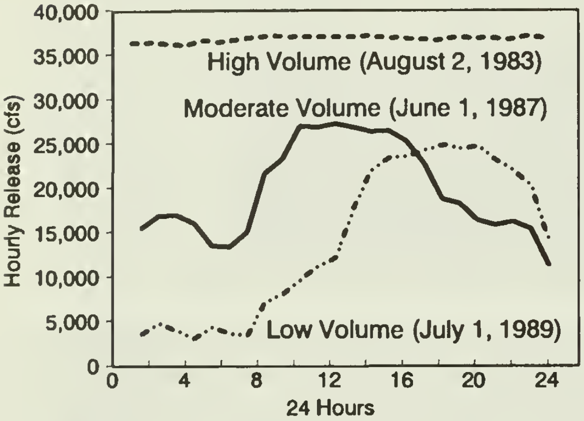

Figure II-4.—Hourly releases for typical summer days with low, moderate, and high release volumes.

Minimum Flow.–Figure II-5(a) shows the historic distribution of minimum flows. 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). An additional requirement during the recreation season is that weekday releases average not less than 8,000 cfs for the period 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. Occasionally, power system emergencies occur that prevent meeting the minimum release objectives.

Maximum Flow.–The maximum flow is 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, as required. Peak discharges under normal no action operations do not exceed 31,500 cfs. Any releases greater than 31,500 cfs are steady on a daily basis. Figure II-5(b) shows the historic distributions of maximum flows.

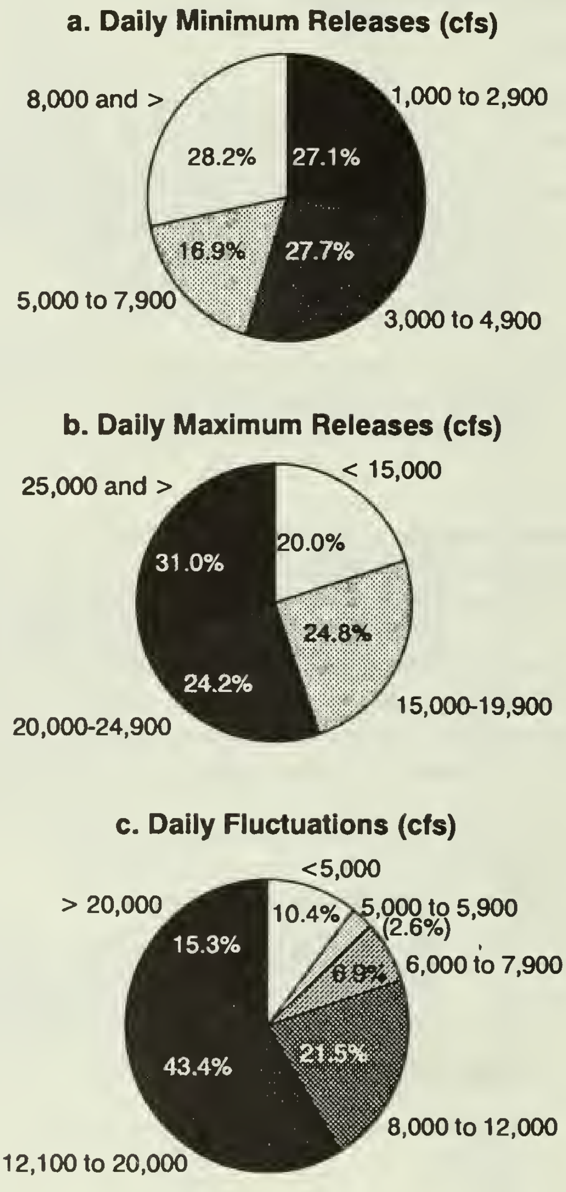

Figure II-5.—Historic distributions of daily minimums, maximums, and fluctuations in cfs (1965-89).

Range of Fluctuating Flows.–The range of daily fluctuations under the No Action Alternative is restricted only to between the minimum and maximum flows. Figure II-5(c) shows the historic distribution of daily fluctuations.

Ramp Rate.–The ramp rate is the rate of change in discharge, integrated across the hour, to meet the electrical load by achieving either higher or lower releases. North American Electric Reliability Council (NERC) operating criteria require Western Area Power Administration (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 ramped upward to respond to the peak daytime demand, and at night, when releases are ramped downward as the electrical demand diminishes. A computerized automatic generation control (AGC) system controls the rate of release and generation on an instantaneous basis. It also measures the power flow at all electrical interconnections with other control areas.

Under historical operations, scheduled ramping has typically resulted in large changes in river stage. 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. Figure II-6 shows the historic up and down ramp rates. 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.

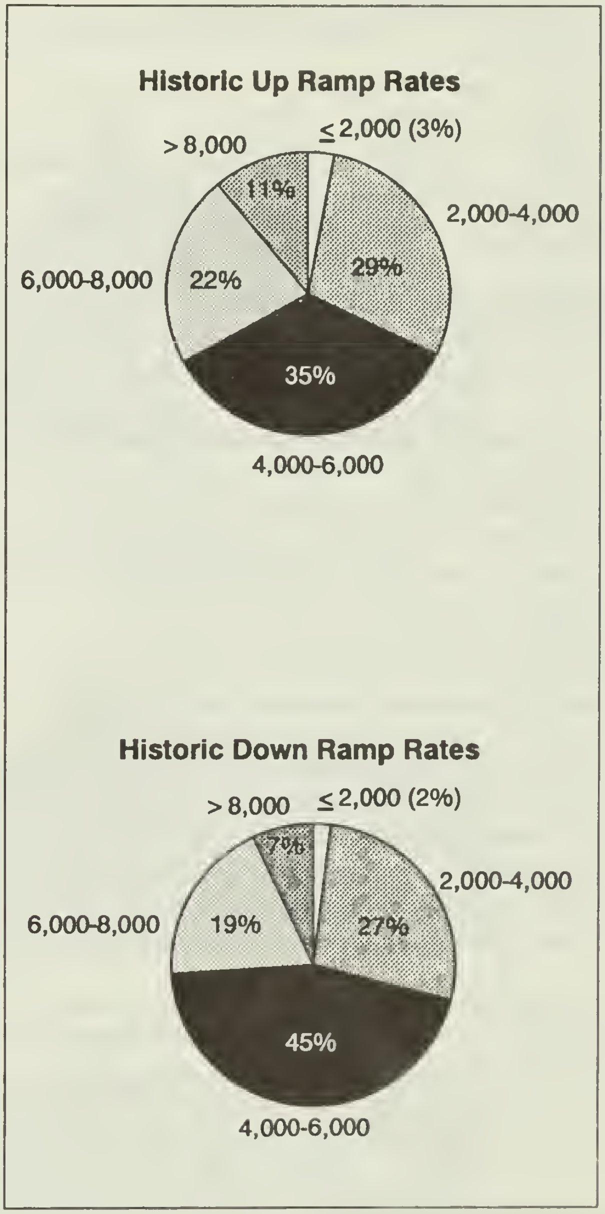

Figure II-6.—Historic (1966-89) distribution of 1-hour ramp rates in cfs per hour. (Maximum daily values for moderate monthly releases of 800,000 acre-feet.)

Maximum Powerplant Capacity Alternative

Minimum releases (cfs)	Maximum releases (cfs)	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 1987 uprate and rewind (see "Background" in chapter I). Operations under the Maximum Powerplant Capacity Alternative would be the same as under the No Action Alternative except that 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 the No Action Alternative. 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 and typically would last 4 hours or less (based on historical operations).

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 unrestricted.

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. Figure II-7 compares operations under these alternatives with historic operations for three different daily water release situations in the peak power month of July.

Within the constraints of the alternatives, maximum water releases would be scheduled to coincide with times of peak electrical demand. If additional energy must be purchased to meet daily demand, attempts would be made to schedule low hourly releases at night to allow those purchases during the more economical hours of the day.

For any of the restricted fluctuating flow alternatives, the 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 (see "Common Elements").

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 and wildlife 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 because this alternative was intended to preserve the current interim flow operations for which nearly 2 years of data have been collected.

The common elements that are described later in this chapter apply to all restricted fluctuating flow alternatives.

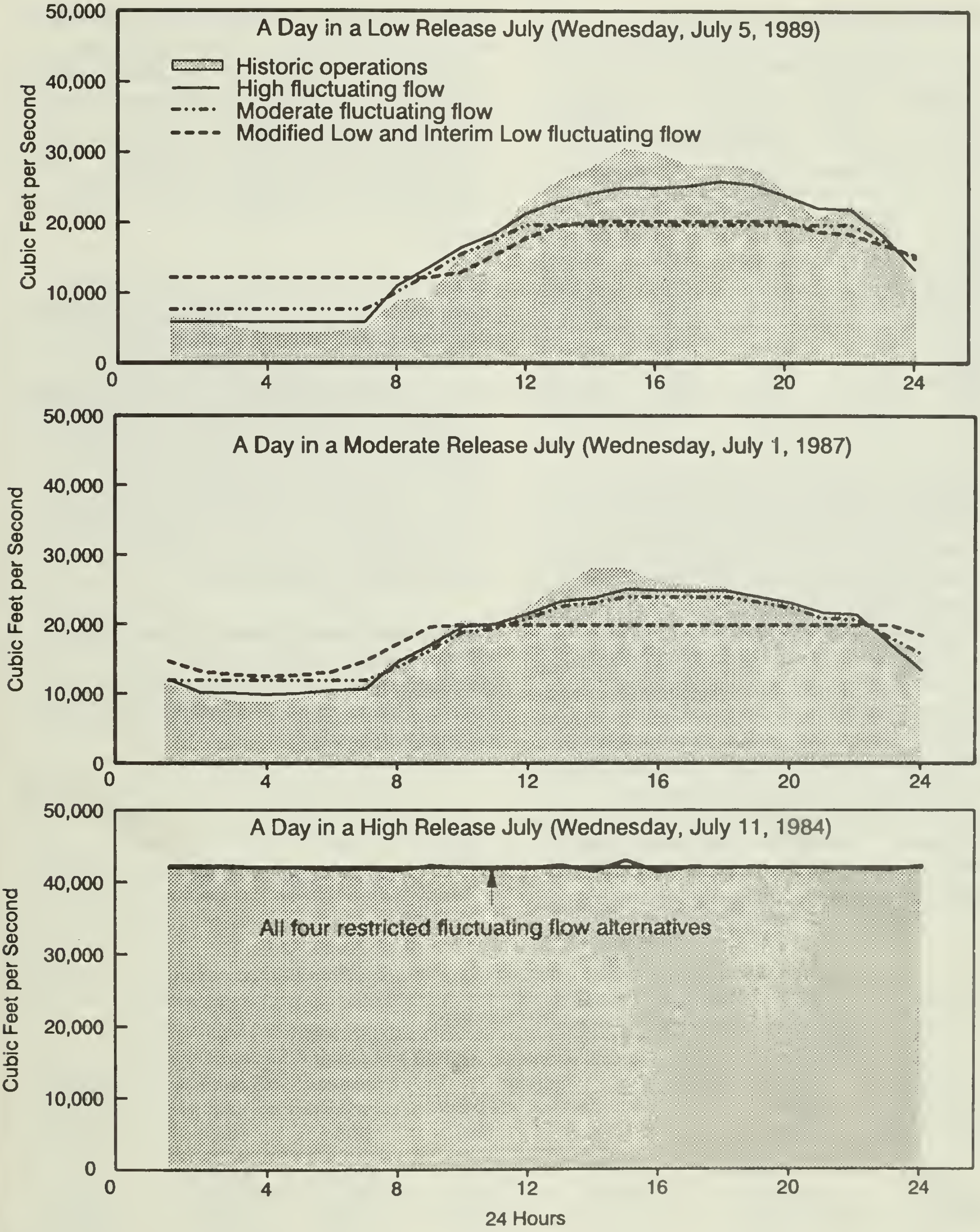

Figure II-7.—Example hourly releases under fluctuating flow alternatives compared to historic operations for low, moderate, and high release days in July. All restricted fluctuating flow alternatives would increase minimum flows and decrease maximum flows when compared to no action.

High Fluctuating Flow Alternative

Minimum releases (cfs)	Maximum releases (cfs)	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	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 market conditions (see table II-3). 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, 20,000, 21,000, or 22,000 cfs over any 24-hour period, depending on the monthly release volume. Under this alternative, adverse market conditions (when power demand is relatively high) are assumed to occur during winter and summer: November, December, January, June, July, and August. All other months are considered favorable market condition months (power demand is relatively low).

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 in winter and summer and 4,000 cfs per hour during spring and fall.

Table II-3.–Flow parameters under the High Fluctuating Flow Alternative

		Minimum flows				
		Favorable market conditions Firm load		Adverse market		
Monthly release volume (1,000 acre-feet)	Mean flow (cfs)	>500 GWh[1] (cfs)	<500 GWh (cfs)	conditions (cfs)	Maximum flow (cfs)	Allowable fluctuation (cfs)
<650	<10,900	3,000	3,000	3,000	31,500	15,000
650-850	10,900-14,300	3,000	5,000	3,000	31,500	20,000
850-1,000	14,300-16,800	5,000	8,000	5,000	31,500	21,000
<1,000	>16,800	8,000	8,000	8,000	31,500	22,000
Down ramp rate		4,000 cfs/hr		5,000 cfs/hr		

[1] Gigawatthour (GWh).

Moderate Fluctuating Flow Alternative

Minimum releases (cfs)	Maximum releases (cfs)	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. Maximum flows during a minimum release year would normally 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.

Approximate minimum and maximum release limits and daily fluctuations are as shown in table II-4. The equations used to determine minimum and maximum flows can be found in attachment 6.

Table II-4.–Flow parameters under the Moderate Fluctuating Flow Alternative

Monthly release volume (acre-feet)	Mean flow (cfs)	Minimum flow (cfs)	Maximum flow (cfs)	Allowable daily fluctuation (cfs)
550,000	9,200	5,100	13,400	±4,150
800,000	13,400	7,400	19,400	±6,000
1,000,000	16,800	10,800	22,800	±6,000
1,500,000	25,200	19,200	31,200	±6,000

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 wildlife habitat. Habitat maintenance flows are high, steady releases within powerplant capacity (33,200 cfs) for 1 to 2 weeks in March, although other months would be considered under the Adaptive Management Program. A more complete description of habitat maintenance flows can be found under the Modified Low Fluctuating Flow Alternative that follows. The monthly release volumes during habitat maintenance flows under this alternative are compared to no action volumes in attachment 6.

Modified Low Fluctuating Flow Alternative (Preferred Alternative)

Minimum releases (cfs)	Maximum releases (cfs)	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 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.

This alternative is essentially the same as the interim operating criteria implemented on November 1, 1991, except for the addition of habitat maintenance flows, endangered fish research, and the common elements. Also, flood frequency reduction would be accomplished by raising the height of the four spillway gates by 4.5 feet to elevation 3704.5 feet (see "Flood Frequency Reduction Measures").

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 could change slightly in the final EIS based on possible adjustment to the interim operations, new information, or public comments.

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.

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. The relationships would be as shown in table II-5.

Habitat Maintenance Flows. Maximum releases under the Modified Low Fluctuating Flow Alternative normally would not exceed 20,000 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 overgrown with vegetation.

Once low elevation sandbars became vegetated, large flows (perhaps greater than 45,000 cfs) would be required to remove vegetation and re-form backwaters. 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 and maintain sandbars, which are important for camping beaches and wildlife habitat.

Table II-5.–Flow parameters under the Modified Low and Interim Low Fluctuating Flow Alternatives

Monthly release volume (acre-feet)	Mean flow (cfs)	Minimum flow (cfs)	Maximum flow[1] (cfs)	Allowable daily fluctuation (cfs)
<600,000	<10,100	5,000/8,000	20,000	5,000
600,000-800,000	10,100-13,400	5,000/8,000	20,000	6,000
>800,000	>13,400	5,000/8,000	20,000	8,000

[1] Does not include habitat maintenance flows.

Habitat maintenance flows are high, steady releases within powerplant capacity (33,200 cfs[1]) for 1 to 2 weeks in March, although other months would be considered under the Adaptive Management Program. March was selected 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 2,500 cfs per hour and would conclude by decreasing flows back to the normal operating range at a rate no greater than 1,500 cfs per hour. The limit on daily change in flow would not apply during these transitions.

Habitat maintenance flows would differ from beach/habitat-building flows (a common element of the restricted fluctuating and steady flow alternatives) because they would be within powerplant capacity and would occur nearly every year when the reservoir is low. Beach/habitat-building flows would be of greater magnitude than habitat maintenance flows and would be less frequent. Habitat maintenance flows would not occur in years when a beach/habitat-building flow is scheduled (see discussion under "Common Elements" later in this chapter). 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. The monthly release volumes under this alternative are compared to no action volumes in attachment 6.

Endangered Fish Research. Endangered and other native fish in Grand Canyon are commonly thought to be limited by cold, clear water releases from Glen Canyon Dam; large daily flow fluctuations; and non-native fish. However, uncertainty remains regarding the impacts of dam operations on fish. Although a considerable amount of research on endangered fish has been conducted, there has been no opportunity to study the effects of low, steady flows in summer and fall combined with higher, steady spring flows—which the U.S. Fish and Wildlife Service (FWS) believes are critical to native fish in the Colorado River. Therefore, endangered fish research flows would be integrated into this alternative during its initial years of implementation. These research flows would be coordinated with the long-term monitoring and research under the Adaptive Management Program.

Through the Adaptive Management Program, a set of research hypotheses and specific flows or experiments to test these hypotheses would be developed. These research flows would be within the flow parameters of this alternative and would 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 about half the time, it is uncertain how many total years it would take to complete the research program. However, it is likely that research flows could be completed within 10 years. The ideal situation would call for uninterrupted research occurring during consecutive low release years.

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[1] Actual powerplant release capacity may be less under low reservoir conditions.

Endangered fish research flows would be between 8,000 and 20,000 cfs with a spring and summer pattern and monthly release volumes similar to the Seasonally Adjusted Steady Flow Alternative. Results from the research program would be monitored, and corrective action would be taken if adverse effects on endangered species were identified. Upon completion of the research flows and analysis of the data, Reclamation would implement any necessary changes in operating criteria to comply with the Endangered Species Act. Any such changes would be implemented through the Adaptive Management Program.

Interim Low Fluctuating Flow Alternative

Minimum releases (cfs)	Maximum releases (cfs)	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 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 under 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). Interim operating criteria were established prior to obtaining results from GCES Phase II. 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 record of decision (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.

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. The relationships would be as shown in table II-7.

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). Figure II-8 compares operations under the steady flow alternatives with historic operations for low (8.23 maf), moderate (13.6 maf), and high (21.1 maf) release years. 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.

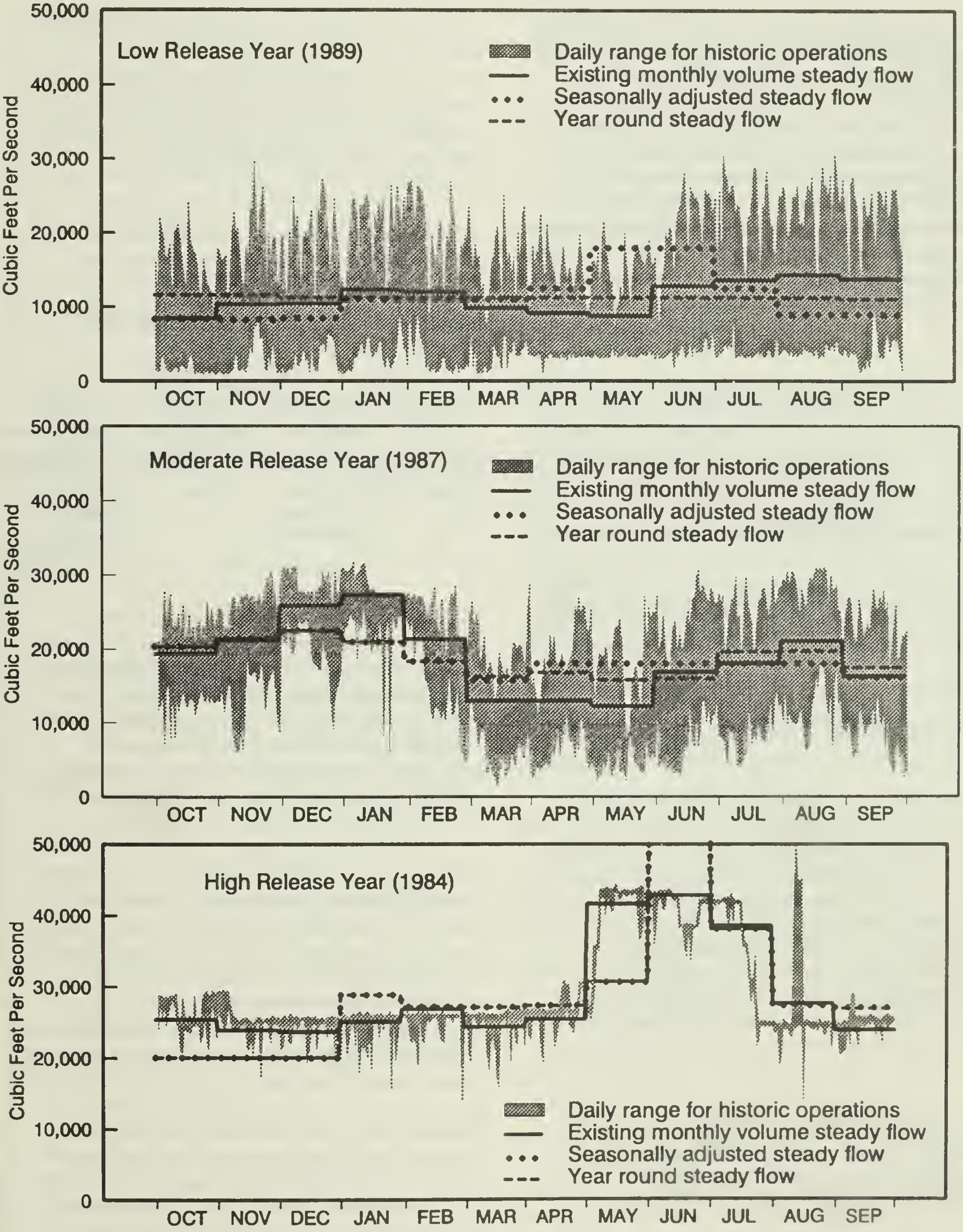

Figure II-8.—Steady flow alternatives compared to no action for low, moderate, and high release years.

Daily variations of plus or minus 1,000 cfs per day (approximately 42 megawatts) would allow some minor flexibility in dam operations to be used 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 (see figure II-9).

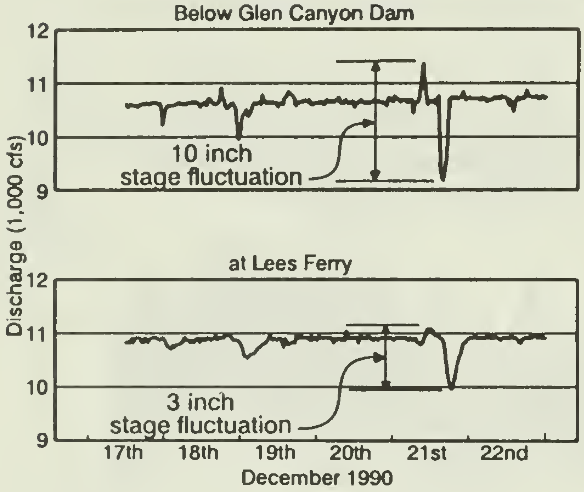

Figure II-9.—Changes in electrical load during steady research flows caused minor discharge fluctuations that were measured at U.S. Geological Survey gauging stations below the dam and at Lees Ferry. On December 21, the 2,170-cfs fluctuation measured 1/2 mile below the dam was reduced to 1,105 cfs at Lees Ferry. This release fluctuation resulted in a river stage fluctuation of 10 inches at the gauge below the dam and 3 inches at the Lees Ferry gauge.

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.

The "Common Elements" described later in this chapter apply to all steady flow alternatives.

Existing Monthly Volume Steady Flow Alternative

Minimum releases (cfs)	Maximum releases (cfs)	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 (see "Common Elements"). See figure II-8 for estimated operations under this alternative, using historic low, moderate, and high annual release situations.

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 would rarely 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)	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. See figure II-8 for estimated operations under this alternative. 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 wildlife habitat. Habitat maintenance flows are high, steady releases within powerplant capacity (33,200 cfs) for 1 to 2 weeks in March, although other months would be considered under the Adaptive Management Program. A more detailed discussion of habitat maintenance flows can be found under the Modified Low Fluctuating Flow Alternative.

The monthly release volumes during habitat maintenance flows under this alternative are compared to no action volumes in attachment 6.

Year-Round Steady Flow Alternative

Minimum releases (cfs)	Maximum releases (cfs)	Daily fluctuations (cfs/24 hrs)	Ramp rate (cfs/day)
Yearly volume prorated	Yearly volume prorated	±1,000	2,000 between months

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. The minimum flow would be determined from the mean monthly release but would correspond generally to the minimum annual release volume of 8.23 million acre-feet, 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.

Common Elements

The elements common to all restricted fluctuating flow and steady flow alternatives are described in detail below. Impact analyses of these alternatives were conducted taking these common elements into account.

Adaptive Management

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

The objective of the Adaptive Management Program would be to develop modifications to Glen Canyon Dam operations and exercise other authorities under existing law—as appropriate—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. These values include but are not limited to natural and cultural resources and visitor use. Long-term monitoring and research are essential to adaptive management and would be implemented to measure the performance of the selected alternative in meeting resource management objectives and to provide additional understanding of resource responses to dam operations (see Appendix A, Long-Term Monitoring and Research).

The Adaptive Management Program, under the direction of the Secretary of the Interior (Secretary), would include an Adaptive Management Work Group (AMWG), a technical work group, and an independent scientific review panel.

Adaptive Management Work Group. The AMWG would be comprised of representatives from at least each of the EIS cooperating agencies, Basin States, contractors for the purchase of Federal power, recreation industry and users, and environmental organizations.

The work group could function as either a single, large forum (anyone can participate) or a two-tiered forum (a large group, with a small group comprised of one representative from each interest to facilitate the process). Either structure may require formal chartering as a Federal Advisory Committee. In any event, all AMWG meetings would be open to public participation. The AMWG would:

- Develop proposals for modifying operating criteria, for research under the long-term monitoring program, and for other mitigation actions, as appropriate
- Facilitate technical coordination and input from interested parties
- Provide an annual report to the Secretary on the current and projected year's operations
- Provide annual budget recommendations

Technical Work Group. This work group would be comprised of technical representatives from Federal, State, and Tribal governments and their contractors. This technical work group would:

- Conduct and coordinate monitoring, research, and inventory programs
- Prepare annual resource report for AMWG

- Maintain scientific information data base
- Prepare and distribute technical and scientific reports
- Coordinate scientific review of the long-term monitoring and research programs
- Propose annual budgets for the long-term monitoring and research programs

Independent Scientific Review Panel. The review panel would be comprised of scientific experts not otherwise participating in the long-term monitoring and research studies. Responsibilities of this review panel would include:

- Annual review of scientific study plan, budget, and resource reports
- Five-year review of scientific logic and protocols

The Adaptive Management Program would continue indefinitely. The action agency would be responsible for any subsequent National Environmental Policy Act (NEPA) compliance and any other required permits prior to implementing significant actions. The program would be implemented consistent with the Grand Canyon Protection Act of 1992 which requires the Secretary to:

> (a) Adopt criteria and operating plans separate from and in addition to those specified in section 602(b) of the Colorado River Basin Act of 1968 and exercise other authorities under existing law, so as to assure that Glen Canyon Dam is operated consistent with section 1802 and to fulfill consultation requirements of section 1804(c) of the Grand Canyon Protection Act
>
> (b) Establish and implement long-term monitoring and research programs and activities that will ensure that Glen Canyon Dam is operated in accordance with provisions of section 1802 and consultation requirements of section 1805(c)

In carrying out such provisions, the Secretary or designee would develop, as appropriate, modifications to operating criteria in consultation with all interested parties and in technical consultation with the AMWG. The process would include formal consultation required in sections 1804(c) and 1805(c) of the Grand Canyon Protection Act, concerning additional operating criteria for Glen Canyon Dam and long-term monitoring and research programs, respectively (see attachment 2).

Consultation would be maintained with appropriate agencies of the Department of the Interior, including the FWS, National Park Service (NPS), and Bureau of Reclamation (Reclamation); the Secretary of Energy; Governors of Arizona, California, Colorado, Nevada, New Mexico, Utah, and Wyoming; Indian Tribes; and the general public, including representatives of academic and scientific communities, environmental organizations, the recreation industry, and contractors for the purchase of Federal power produced at Glen Canyon Dam.

Further development of the adaptive management process would occur between the draft and final EIS.

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 places and sacred sites. Impacts are likely to occur to some of these historic properties regardless of the EIS alternative chosen for implementation.

The National Historic Preservation Act requires Federal agencies to consider measures which would avoid or minimize loss of historic properties resulting from their actions. Due to the potential impact from any dam operation, Federal agency responsibilities for compliance with sections 110 and 106 of the National Historic Preservation Act will be required for each alternative considered in this document.

Given the potential impacts from the existence and operation of Glen Canyon Dam, Reclamation and NPS have complied with documentation requirements in established regulations (36 Code of Federal Regulations 800). The Advisory Council on Historic Preservation, Arizona State Historic Preservation Officer, Reclamation, NPS, and Indian Tribes have completed a programmatic agreement which ensures that both Reclamation's section 106 responsibilities and NPS's section 110 responsibilities are satisfied (see attachment 5). Administration, implementation, and refinement of the program design are detailed in the programmatic agreement and accompanying monitoring and historic preservation plans to be completed by October 1994.

The programmatic agreement and accompanying plans will direct long-term monitoring, which includes continuing consultation, identification, inspection, analysis, evaluation, and remedial protection actions as necessary to preserve the historic properties within Glen and Grand Canyons.

Potential remedial actions would be initiated in consultation with all of the Federal and State agencies and Indian Tribes involved in the agreement. A range of actions are proposed, including:

- Discontinue monitoring
- Monitor with cameras or sensing devices
- Modify trails (obliterations, check dams, etc.)
- Stabilize site
- Partially or completely excavate site
- Close site to visitors
- Develop site for interpretation

These 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 may be damaging. 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 for the 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 to implement this element.

2. Change releases to provide a minimum of 1 maf of space from January 1 through June. This additional space would be nonviolable flood control space and would be used only in years when existing floodflow protection measures are insufficient. As indicated earlier in this chapter, existing practices are to target Lake Powell to reserve 500,000 acre-feet of reservoir space on July 1 (until the runoff peak has clearly passed).

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

Beach/Habitat-Building Flows

Under any EIS alternative, Grand Canyon sandbars that exist above the normal peak river stage would continue to erode, unwatered vegetation may die, and backwater habitat within normal stage would tend to fill with sediment. Therefore, beach/habitat-building flows have been incorporated as an element common to 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, water vegetation and deposit nutrients, restore backwater channels, and provide some of the dynamics of a natural system.

Magnitude. Replenishing sandbars requires both an available upstream sand supply and higher than normal flows to deposit sand at high elevations. Sandbars must be several feet above the water surface to be dry and suitable for wildlife habitat or camping. Consequently, sandbars must be deposited and formed by discharges somewhat higher than the normal operating range.

Magnitudes would be at least 10,000 cfs greater than the allowable peak discharge in a minimum release year for a given alternative but not greater than 45,000 cfs (see table II-6). A single test of a beach/habitat-building flow would be conducted prior to long-term implementation of this element to test the predictions made in chapter IV. This test would have a discharge of about 45,000 cfs and would not set a precedent for future releases. Scheduled flows exceeding powerplant capacity (33,200 cfs) may require legislation to implement.

Ramp Rates. Releases would be increased and decreased at a maximum rate of 4,000 cfs per hour.

Season and Duration. Beach/habitat-building flows could be scheduled in the spring (to coincide with the 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, beach/habitat-building flows would be scheduled in spring for a duration of 1 to 2 weeks. The exact season and duration would be determined through the Adaptive Management Program. Releases would be curtailed if monitoring showed detrimental impacts to the ecosystem. A 10-day flow in March/April is assumed when describing the environmental consequences in chapter IV.

Water Year and Frequency. A recommendation for a beach/habitat-building flow would come from the Adaptive Management Program, and such a flow would be scheduled as part of the Annual Operating Plan (developed in the summer for the following water year). Such flows would be scheduled only in years when the projected storage in Lake Powell on January 1 is less than 19 maf (low reservoir condition). Scheduling beach/habitat-building flows during high reservoir conditions would be avoided because of the increased risk of unscheduled flows greater than powerplant capacity (see attachment 6).

A beach/habitat-building flow would be recommended during years when sufficient quantities of sediment are available, but not

Table II-6.–Example beach/habitat-building peak discharges and monthly volumes

Alternative	Allowable peak discharge[1] (cfs)	Beach/ habitat-building flow (cfs)	Original volume (acre-feet)	Additional volume required (acre-feet per month)	Reductions from other months (acre-feet per month)
Restricted fluctuating flow					
High	31,500	41,500	607,000	627,000	57,000
Moderate	30,000	40,000	607,000	598,000	54,300
Modified low	30,000	40,000	607,000	598,000	54,300
Interim low	20,000	30,000	607,000	399,000	36,300
Steady flow					
Existing monthly volume	14,400	24,400	607,000	288,000	26,200
Seasonally adjusted	30,000	40,000	687,000	572,000	52,000
Year-round	11,400	21,400	695,000	200,000	18,200

[1] Minimum release year (8.23 maf) without a beach/habitat-building flow.

following a year in which a large population of young humpback chub is produced (see chapter III, ENDANGERED AND OTHER SPECIAL STATUS SPECIES). A frequency of 1 in 5 years (when the reservoir is low) was assumed for analyzing the environmental consequences presented in chapter IV. Although these flows would be expected to aggrade many sandbars, these sandbars would be subject to natural erosion. How long these new deposits would last would be determined through monitoring.

Monthly Release Volumes. Additional water would be scheduled in March/April to support a beach/habitat-building flow. This water would be shifted equally from each of the other 11 months. The additional release volumes needed in March/April and the volume to be taken from other months would vary by alternative (see table II-6).

New Population of Humpback Chub

The Grand Canyon population of humpback chub uses habitats in both the Colorado River mainstem and the Little Colorado River (LCR). The only known successful spawning habitat for that population is in the LCR, and individuals move between the mainstem and LCR.

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 chronic incidents that would reduce the viability of this spawning habitat could cause the loss of this population. Conditions in the mainstem (principally water temperatures) are not conducive to humpback chub spawning or survival of eggs and young. Therefore, at least one more population in one or more of the tributaries below Glen Canyon Dam should be established.

In consultation with FWS, NPS, Arizona Game and Fish Department (AGFD), and other land management entities such as the Havasupai Tribe, Reclamation would make every effort—through funding, facilitating, and technical support—to ensure that a new population of humpback chub is established in one or more of the tributaries within Grand Canyon.

Further Study of Selective Withdrawal

Prior to the dam, the water quality (including temperature) of the Colorado River was much different than today. Water temperatures varied seasonally, directly influenced by spring snowmelt and summer warming. Seasonal variations in temperatures ranged from 32 degrees Fahrenheit (°F) to 82 °F. Today, the cold water released from the dam varies only a few degrees year-round.

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 °F.

The nearly constant year-round release temperatures have resulted in conditions "not unlike those found in a well-balanced aquarium" (Carothers and Brown, 1991). Only a few species of aquatic organisms thrive under these conditions, but those few species are abundant. They account for biomass production far exceeding that in more diverse and species-rich environments. However, many native species require thermal changes at certain life-cycle stages and cannot reproduce in these constant temperature conditions.

Except for draining the reservoir, no operational method would 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 selectively withdraw warmer water from upper levels of the reservoir.

The structure would include a series of vertically stacked gates to enclose each penstock intake. Different configurations of gates could be opened to mix water of varying temperatures. Gate control would be automated, and adjustments would be made in relation to reservoir elevation, turbine operation, and water temperature.

Preliminary studies (Ferrari, 1988) 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.

Increasing the temperature of river water may create problems for species currently inhabiting the Colorado River below Glen Canyon Dam. The cold river temperatures may act as a barrier to the upstream migration of non-native predatory fish such as striped bass from Lake Mead. Higher water temperatures may encourage the upstream migration of predatory fish, further endangering humpback chub and other native fish through increased predation or competition.

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.

Many questions will need to be answered before a decision can be made on selective withdrawal. Additional research and analysis could determine whether a selective withdrawal structure would enhance endangered species and other native fish populations in the Colorado River. FWS, in consultation with AGFD, would be responsible for recommending to Reclamation whether or not multilevel intake structures should be built at Glen Canyon Dam.

Upon FWS recommendation, Reclamation would seek congressional authorization and funding. Reclamation also 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. NERC has established guidelines for the emergency operations of interconnected power systems. A number of these guidelines apply to Glen Canyon Dam operations and are described more fully in attachment 6. These changes in operations would be of short duration (usually less than 4 hours) and would be the result of emergencies at the dam 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)

Mitigation

All environmental mitigation has been incorporated into the alternatives identified for detailed analysis; 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.

The manner in which Western markets energy and capacity from Glen Canyon Dam would differ for each alternative (see chapter IV, HYDROPOWER). Some basic options that exist 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 fully implement. Continuing use of the financial exception criteria allowed under interim operations is a potential short-term (5- to 7-year) mitigation measure. These 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 (nonguaranteed) thermal energy is being used to meet those commitments. Under interim operating criteria, 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 making use of unused capacity is unlikely. While Western's customers have benefited from having unused generating capacity available during interim operations, Western has not had to exceed operating criteria for financial reasons.

Environmental resources such as fish and wildlife would be protected by avoiding use of financial exception criteria during specific periods of vulnerability (i.e., during breeding and nesting). If operations to avoid purchases of high-cost power were determined to be occurring too frequently or at inappropriate times, the Secretary of the Interior could suspend those operations and review the matter, making any necessary changes.

If financial exception criteria are part of the selected alternative, the availability of capacity and energy would be maintained, and costs to Western's customers would be expected to increase at a slower rate.

Permits and Regulatory Approvals

No permits or regulatory approvals would be immediately necessary to implement any of the alternatives described in this document. 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.

Implementing multilevel intake structures would require additional NEPA compliance, congressional authorization, and permits. A permit from the U.S. Army Corps of Engineers (Corps) under section 10 of the Rivers and Harbors Act and possibly section 404 of the Clean Water Act might be required, depending on the structure design and the amount of fill material used in construction. The Corps would make a decision on issuing a permit only after a public notice and public interest review. Supplementary NEPA documentation might be required, including a section 404(b)(1) alternatives analysis, if fill material is involved.

ALTERNATIVES CONSIDERED AND ELIMINATED FROM DETAILED STUDY

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

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 natural predam conditions of the Colorado River were characterized by dramatic seasonal fluctuations in flow, sediment, and temperature. Flows typically ranged from less than 3,000 cfs in late summer, fall, and winter to over 80,000 cfs in spring. The river usually was turbid, and peak sediment loads were carried by spring and late summer floods. Water temperatures ranged from near freezing in winter to more than 80 °F in late summer.

Steep sediment deposits were built annually during the sediment-laden spring floods. These deposits later tended to erode following the return to lower flows. Native vegetation existed in the old high water zone but was sparse to nonexistent in the zone of seasonal fluctuations. Native plants and animals were well-adapted to this system of strong seasonal fluctuations.

Non-native species of plants and animals were introduced to Grand Canyon prior to the dam's construction. Lake Powell—formed behind the dam—now inundates all but 16 miles of Glen Canyon. Glen Canyon Dam has replaced seasonal flow fluctuations with daily fluctuations between 1,000 cfs and 31,500 cfs, sediment is supplied only by downstream tributaries, and water temperatures are nearly constant year-round—averaging a cool 46 °F. A naturalized system now exists downstream, and species and communities that were rare or nonexistent before the dam are now abundant: *Cladophora*, *Gammarus*, trout, bald eagles, peregrine falcons, and riparian vegetation and its wildlife in the new high water zone.

The EIS team responded to scoping comments by formulating the Run-of-the-River Alternative. The objective of this alternative was to mimic, as nearly as possible, the natural predam conditions. This would be achieved through operational changes, sediment augmentation, and selective withdrawal.

The historic pattern of high spring flows and low fall and winter flows would be achieved by matching releases from the dam with inflows to Lake Powell. Spring releases would be limited to 48,000 cfs (combined capacity of powerplant and outlet works), unless the spillway could be used; then releases would equal inflow. Under these operating principles and based on predam inflows, flows in May could exceed 45,000 cfs about 40 percent of the time, and June flows could equal or exceed 45,000 cfs about 60 percent of the time. Low steady inflows and the resulting releases as low as 1,000 cfs would occur during late summer and winter.

The frequency of high flows needed to simulate predam conditions would scour most of the sediment along the river corridor in Grand Canyon. Tributaries below Glen Canyon Dam cannot supply large amounts of sediment on an annual basis, so the sediment would not be replaced naturally. The scouring of sediment from Grand Canyon would damage environmental, recreational, and cultural resources in the canyon. Postdam sediment losses have been reduced by regulating the frequency of high-flow releases from Glen Canyon Dam.

For these reasons, the Run-of-the-River Alternative would require massive sediment augmentation (1 to 10 million tons annually) in order to replenish sediments transported out of the system. Several technical issues concerning sediment augmentation were considered, such as sediment quantity and size (sand, silt, clay), source, and type of delivery system. Potential sediment delivery systems considered included a barge and truck operation and a sediment slurry pipeline to Lees Ferry. Sediment would be dredged from a remote source and then continually transported and deposited in the Colorado River. The river would then carry the sediment downstream for deposit in eddies and main channel pools.

Any sediment source would have to be renewable in order to indefinitely sustain the sandbars in Grand Canyon under the suggested water release regime. Therefore, sediment deltas of Lakes Powell and Mead were considered as possible sources for sediment augmentation. The areas of Lake Powell considered as possible sources of sediment were the upstream delta along the mainstem (Cataract Canyon), the San Juan River, and Dirty Devil River.

To more closely approximate predam seasonal patterns, some type of temperature modification was needed in the Run-of-the-River Alternative. To increase river water temperature, multilevel intake structures would be placed on the dam penstocks to draw warmer water from near the reservoir surface for release downstream. This approach would raise downstream water temperatures 5 to 18 °F above current conditions during spring and summer.

Evaluation of Alternative

Evaluation of the Run-of-the-River Alternative focused primarily on flows/sediment, environmental concerns, and compact and treaty requirements.

Flows/Sediment. Sediment augmentation would be required to maintain a sediment balance in the river system when high releases are frequent. Without sediment augmentation, the Run-of-the-River Alternative would eventually erode most of the sediment from Grand Canyon—damaging or destroying the canyon's environmental, recreational, and cultural resources.

A slurry pipeline would likely take at least 15 to 20 years to implement. This timeframe includes necessary research and data collection, NEPA compliance, design, Federal permitting, congressional authorization, land purchase/ easements, implementing mitigation procedures, and construction.

The cost of building a slurry pipeline was estimated at $400,000 per mile. For a completed pipeline to the river deltas of the San Juan, Dirty Devil, or the mainstem (Cataract Canyon), costs were estimated at $50, $80, and $85 million, respectively. Operational costs could be $10 million per year. Other means of sediment transport (barging and trucking) would be more expensive than a slurry pipeline.

Environmental Concerns. Any overland route for sediment transport to the Colorado River below Glen Canyon Dam would cross more than 100 miles of high-desert canyon landscape to reach the nearest renewable source of sediment. Construction would cause adverse environmental impacts to fragile resources. Cultural and archeological impacts on tribal lands could be significant and, in the case of sacred sites, mitigation (avoidance) would significantly increase costs. A submerged pipeline in Lake Powell would affect recreation during construction and would require an overland route to Lees Ferry.

Sediment would be augmented just below Lees Ferry so as not to increase turbidity in the Glen Canyon reach, which would adversely affect the trout fishery. The high spring flows would scour most of the sand deposits from the river upstream from Lees Ferry.

Low flows during the winter spawning season would reduce habitat for rainbow trout, and extended low flows at any time would adversely affect the *Cladophora-Gammarus* segment of the aquatic food chain throughout Grand Canyon.

Important unanswered questions exist concerning the types and amounts of contaminants that may be found in some of the sediment sources identified above and their effects on resources if added to the aquatic system below the dam.

Lastly, modification of water temperature in the Colorado River below Glen Canyon Dam presents both opportunities for enhanced management of some resources and risks associated with unknown responses. Higher water temperature may benefit humpback chub and other native fish but also may improve habitat conditions for competing non-native species and permit an invasion of striped bass from Lake Mead. The current water temperature is below the optimum for rainbow trout growth, but it is unknown how the alga, *Cladophora*, and the shrimp-like amphipod, *Gammarus*—which trout depend on—would respond to higher temperatures.

Compact and Treaty Requirements. Releases from Glen Canyon Dam under this alternative would not meet the annual water release pattern requirements of the "Law of the River," especially the Colorado River Compact, the Colorado River Basin Project Act, the Long-Range Operating Criteria, and the treaty with Mexico. Therefore, this alternative would violate existing laws.

Under the Run-of-the-River Alternative, releases from the dam could only match high spring inflows when Lake Powell was full and the spillways could be used. Because of the way the dam is designed, the spillways cannot be used unless the reservoir is nearly full. Without using the spillways, releases cannot exceed 48,200 cfs. Inflows to Lake Powell in June typically exceed 45,000 cfs, and the excess would have to be stored in the reservoir. Lake Powell could be expected to fill and spill at an average frequency of 1 out of every 4 years under this alternative.

Conclusions

Restricting releases to reservoir inflow during prolonged drought periods would prevent Glen Canyon Dam from meeting its statutory purposes. Requirements under the Colorado River Compact and treaty with Mexico could not be met.

The natural environment along the river corridor has been forever altered with the introduction of non-native species and the construction of Glen Canyon Dam. Under this alternative, the river would be converted into a system very different from existing conditions. Resources associated with the aquatic food chain would be disrupted—*Cladophora, Gammarus*, aquatic insects, trout, swallows, bats, bald eagles, and peregrine falcons.

Most of these impacts would be associated with the massive addition of sediment needed to prevent the net loss of sediment and sediment-dependent resources. Sediment augmentation would cause significant impacts to water quality—most notably increased turbidity. The chemistry of various sediment sources and corresponding impacts to Grand Canyon water quality and aquatic resources are unknown.

The need for sediment augmentation has not been demonstrated under alternatives with reduced daily flow fluctuations. For example, sandbars still exist in Grand Canyon and appear to be stable under the interim operating criteria.

A sediment augmentation delivery system would cause environmental damage along the route during construction and operation and would be expensive to build and maintain.

Some people consider sediment augmentation the ultimate solution for Grand Canyon because a portion of the natural sediment supply could be restored and the life of Lake Powell could be extended. However, others doubt the wisdom of using a major construction project to solve the environmental problems of a previous construction project. In either case, sediment augmentation would take a long time to implement—perhaps 15 to 20 years—and a plan to operate Glen Canyon Dam would still be needed in the interim.

Sediment augmentation would require data collection; research and analysis; an EIS addressing alternate sediment sources and delivery systems; congressional authorization and funding; Federal, State, and tribal permits; land purchases and easements; and construction. A project of this magnitude is beyond the scope of dam operations and would be better addressed in a separate NEPA document.

Without sediment augmentation, the volumes of clear-water releases defined in this alternative would eventually eliminate most sediment deposits along the Colorado River in Glen and Grand Canyons. This loss would affect recreational opportunities, cultural resources, backwaters, marshes, and riparian vegetation. Mitigating these impacts by reducing seasonally high flows creates a flow regime incorporated into the Seasonally Adjusted Steady Flow Alternative.

In conclusion, the EIS team recognized the desire of some to return riverflows to a more historic (predam) pattern. A return to a seasonal streamflow pattern emulating the magnitude of historic spring flows would, however, be very destructive to downstream resources unless a large-scale, long-term sediment augmentation program were added. This program would have significant impacts—all of which are not yet known. If sediment augmentation is desired in the future, this action should be the subject of a separate EIS. The Run-of-the-River Alternative was therefore eliminated from further consideration in this document.

Historic Pattern Alternative

Comments received during the scoping process indicated that many respondents wished to alter dam releases to return to predam flow patterns. The Historic Pattern Alternative attempted to follow predam water flow patterns more closely, while still managing flows within current powerplant capacity.

This alternative was a modification of the Run-of-the-River Alternative. Minimum annual releases of 8.23 maf would be met, and all scheduled releases would be within powerplant capacity. Flows would be steady each month while following a seasonal pattern of higher spring/summer and lower fall/winter flows. Maximum flows would be limited to 33,200 cfs, and minimum flows would be determined by the forecasted annual release remaining after high spring/summer flows were allocated. The Historic Pattern Alternative also included a sediment slurry pipeline and multilevel intake structures for the reasons discussed under the Run-of-the-River Alternative.

Evaluation of Alternative

Although the high flows under the Historic Pattern Alternative would be of less magnitude and perhaps of shorter duration than under the Run-of-the-River Alternative, sediment augmentation would still be required to prevent long-term adverse impacts to downstream resources. Without sediment augmentation, the sediment resources along the Colorado River would be more subject to erosion under the Historic Pattern Alternative than under any of the steady or fluctuating flow alternatives, including the No Action Alternative. The Historic Pattern Alternative was not expected to conflict with the "Law of the River."

Conclusions

This alternative was eliminated from detailed study for most of the reasons given for the Run-of-the-River Alternative. Specifically, sediment augmentation would cause an increase in turbidity and disrupt the aquatic food chain below Lees Ferry, and high and low flows would adversely affect resources above Lees Ferry. Other potentially significant impacts are unknown. Sediment augmentation 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 steady or fluctuating flow alternatives, including no action operations. 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 eliminated from further consideration in this document.

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 to downstream resources by constructing a reregulation dam.

Releases from Glen Canyon Dam under this alternative would be similar to those described under the No Action Alternative, with maximum flows increased to 33,200 cfs and minimum flows of no less than 1,000 cfs year-round. Annual and monthly releases would be based on the following factors: meeting water deliveries to the Lower Basin States, maintaining conservation storage in Lake Powell, avoiding anticipated spills, balancing storage between Lakes Powell and Mead, and seasonal power demand patterns. Daily releases would be patterned to meet power demand within the limits of the required monthly release volume. Ramp rates would be constrained only by physical limitations of the powerplant.

An increase in the magnitude of daily fluctuations would cause additional impacts to downstream resources at levels above those documented for the No Action Alternative at 31,500 cfs. To reduce new and existing impacts, a reregulation dam would be constructed approximately one-half mile upstream of the gauge at Lees Ferry to provide steady flows downstream of the reregulation dam. The top of the dam would extend about 20 feet above the downstream water surface.

Flows below the reregulation dam would follow a daily pattern of steady flows but would be adjusted daily and monthly. Minimum steady flows would be about 8,000 cfs, and maximums would be dictated by the monthly and daily volume to be released. Downstream of the reregulation dam, changes in river stage between weekdays and weekend days would likely occur because the average daily release may be lower on a weekend day than on a weekday; however, the transition between flows would be gradual. Effects of ramping would be virtually unnoticeable below the reregulation dam.

Between Glen Canyon Dam and the reregulation dam (Glen Canyon reach), the river would be converted to a fluctuating reservoir storing water during the day for release later at night. Minimum water elevation at the upstream face of the reregulating dam would increase 4 feet, and the water level would fluctuate up to 17 feet daily. This fluctuating reservoir would act as the damper to accept the fluctuating releases of Glen Canyon Dam and would convert them to nearly steady releases below the reregulation dam.

Evaluation of Alternative

The Reregulated Flow Alternative would provide complete flexibility in power operations at Glen Canyon Dam while providing a mechanism for protecting physical and biological resources downstream from Lees Ferry (260 miles). However, the river reach between Glen Canyon Dam and the reregulation dam (15 miles) would be significantly altered by increased fluctuations.

Flows and Sediment Resources. Steady flows below a reregulation dam would virtually eliminate rapid changes in flows and would reduce the capability of the river to transport sediment. Under these conditions, natural input of sediments from tributaries (Paria and Little Colorado Rivers) would allow sediment to accumulate in the river corridor at relatively low elevations.

Fluctuations in flow above the reregulation dam would be considerably higher than under historic operations. In the Glen Canyon reach, sediment exposed to these higher release fluctuations would continue to be lost. Further, because river stages would be from 4 feet to 20 feet higher in elevation, sediment deposited above historic normal operational ranges would be subject to fluctuations and loss. Because this reach lacks a source of sediment input, these operations eventually would eliminate most of the sand and fine-grained sediment from sandbars and banks in the Glen Canyon reach.

Riparian and Terrestrial Resources. Stabilized flows downstream from the reregulation dam would promote further development of riparian resources on stabilized sandbars in Grand Canyon. Terrestrial wildlife linked to riparian resources would benefit from the stabilized riparian corridor.

The AGFD categorizes the riparian habitat found in the Glen Canyon reach as Resource Category I habitat (of the highest value to wildlife) and recommends that all potential losses of existing habitat values be prevented. Riparian habitat associated with perennial streams in Arizona is considered unique and irreplaceable on a statewide basis.

The loss of sandbars through inundation in the reach above the reregulation dam would result in the direct loss of riparian resources. Riparian vegetation near the reregulation dam would be immediately inundated, and virtually all riparian resources in this reach would be eliminated as sandbars eroded due to rapid fluctuations in water level. Because the endangered peregrine falcon feeds on prey linked to riparian communities, eliminating riparian resources above the reregulation dam would affect peregrine falcons using Glen Canyon.

Aquatic Resources. The placement of the reregulation dam would not directly disturb habitat used by the endangered humpback chub. Reregulated flow to the river reaches below the LCR could stabilize backwaters and promote warming that would provide rearing habitat for larval or juvenile chub. River temperatures would remain cold, thus limiting the movement of larval humpback chub out of the LCR. Stabilized flows would not guarantee that backwaters would be maintained through time. As backwaters developed into riparian areas over time, they would eventually lose their value as fish-rearing habitat. Reregulated flows would not create additional spawning habitat for humpback chub in the main channel nor would they encourage establishment of new spawning populations in tributaries.

The aquatic system above the reregulation dam would be altered. Accelerated sandbar erosion caused by increased fluctuations—combined with lake-like conditions in the reach above the reregulation dam—would favor planktonic algal forms, which could decrease water clarity. Changes in water clarity, combined with weekend minimum stages, could reduce the zone occupied by the alga, *Cladophora*. Reduced *Cladophora* and/or reductions in its transport out of the reregulating reservoir could result in the entire food chain being restructured throughout the river in Grand Canyon.

Restructuring the food chain above and below the reregulation dam would affect the existing trout fishery. This resource would change from a "stream" to a "lake" fishery above the reregulation structure, with very different management needs and expectations. Natural reproduction would be reduced. Impacts to *Cladophora* and the algal/invertebrate community associated with it would reduce the probability of maintaining a blue ribbon trout fishery within the Glen Canyon reach. See chapter III for more information concerning fish needs.

Cultural Resources. More than 40 cultural sites have been documented within the Glen Canyon reach. In addition, two locations currently under evaluation could be Hopi spiritual sites. Greater fluctuations would increase the erosion affecting these sites. Some impacts to cultural sites could be mitigated by collecting data during excavation, but impacts to others cannot be mitigated because of their complexity or traditional nature. If these sites are determined to be sacred to Native Americans, by their very nature they cannot be moved, transferred, or excavated.

The reregulation dam would be built within the historic district of Glen Canyon National Recreation Area. Increased beach erosion and the inundation of additional areas of the Glen Canyon reach would affect the cultural heritage associated with the last remaining miles of Glen Canyon. This registered historic area also contains a National Register property, the Charles H. Spencer Steamboat, downstream from the potential damsite. Activities that may impact sites listed on the *National Register of Historic Places*, especially those that would alter the setting that justified registration, are considered adverse effects.

Recreation. White-water boating would not be inhibited by the near-steady flows below a reregulation dam; steady flows above 8,000 cfs are considered desirable conditions. However, recreation above a reregulation dam would change dramatically. The Glen Canyon reach typically is used by day rafters and sport fishermen. Under the Reregulated Flow Alternative, access to this reach was an unresolved issue. However, the type of access and the recreational fishery undoubtedly would change.

Safety would be a major concern for those using the reregulating reservoir. A policy decision on safety would be required from the NPS. If boating were permitted, a ramp would provide access upstream from the reregulation dam. Sustained high flows above powerplant capacity would overtop the reregulation dam spillway. Therefore, boat launching or operation near the reregulation dam under high flow conditions would be dangerous. Recreational use of this segment of Glen Canyon would likely be prevented for extended periods. Such closures would have exceeded 24 months as a result of the 1983-86 high flows.

Economics. Construction cost of a reregulating dam is estimated at $60 to $110 million. A reregulation dam would permit the powerplant to operate at maximum capacity whenever enough water was available (Lake Powell elevation greater than 3641 feet) and electrical demand was high. Estimates show that, under these criteria, the powerplant would operate at maximum capacity about 25 days per year (7 percent of the time) for less than 4 hours at a time.

Existing Legislation. The Grand Canyon Protection Act directs the Secretary to operate Glen Canyon Dam

> *. . . and exercise other authorities under existing law in such a manner as to protect, mitigate adverse impacts to, and improve the values for which Grand Canyon National Park and Glen Canyon National Recreation Area were established . . .*

The 1916 act establishing the National Park Service defined those purposes generally as being

> *. . . to conserve the scenery and the natural and historic objects and the wildlife therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations.*

Section 3 of the Colorado River Storage Project Act (1956) states: "It is the intention of Congress that no dam or reservoir constructed under the authorization of this Act shall be within any national park or monument." Congress declared in 1970 and reemphasized in 1978 that all National Park Service areas, including Glen Canyon National Recreational Area, are interrelated and part of one national park system.

Public Acceptance. Planning and constructing a reregulating dam would be guided by the Federal Government's *Economic and Environmental Principles and Guidelines for Water and Related Land Resources Implementation Studies* (Water Resources Council, 1983) that govern all implementation studies. These principles and guidelines apply the four tests of completeness, effectiveness, efficiency, and acceptability to all project alternatives that are considered reasonable. Although some segments of the public would find a reregulation dam acceptable, diverse groups have expressed strong opposition to placing a dam in the last remaining reach of the Colorado River in Glen Canyon.

Administrative Clearance. A reregulation dam would take at least 5 to 15 years to construct after the ROD. This estimate includes such activities as research and data collection, additional NEPA compliance, design, Federal permitting, consultation with the Arizona State Historic Preservation Officer and the Advisory Council on Historic Preservation, excavation of cultural sites, consultation under the Endangered Species Act, congressional authorization, implementation of mitigation procedures, and construction. Construction impacts would be irreversible.

Conclusions

Construction of a reregulation dam in Glen Canyon National Recreation Area would require a change in existing law. While most downstream resources would experience improved conditions over the No Action Alternative, resources in the Glen Canyon reach would experience significant negative impacts under the Reregulated Flow Alternative.

Resources in the Glen Canyon reach that would be significantly 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.

In summary, predicted impacts to resources, required changes in existing law, acceptability problems under the principles and guidelines, and the scrutiny required under section 404 of the Clean Water Act combine to render this alternative unreasonable.

Eliminated Concepts

Some comments received during the scoping process suggested concepts that were not formulated into detailed alternatives. A short discussion of those concepts follows.

Sand Pumping

Pumping sand from the river channel to rebuild eroded sandbars on a systemwide basis currently is not necessary and may not be in the future. Also, such an operation is not compatible with NPS management policies for reasons of visitor use and potential wilderness designation. In the future, NPS might decide to consider sand pumping on a site specific basis, if needed. If so, NPS would be responsible for obtaining any required permits and NEPA compliance.

Description of Concept. Sandbars could be built by pumping sand from the river channel to a nearby site during low or normal flow. This could be done at specific locations identified by NPS to protect the base of slopes containing prehistoric or historic resources or to enhance sites for recreational purposes.

This action could be taken only where channel sand deposits are available. A source of river channel sand nearest each selected site would be located. Small portable pumping equipment would be transported downstream by raft, and a temporary, small barrier or berm to contain the pumped sand would be constructed on a site. A sand-water mixture would be pumped into the contained area. Water would then drain back to the river through the barrier or underlying sandbar, and the pumped sand would remain. The barrier would be removed at the end of the pumping operation. The newly deposited sand would form a more natural slope after being reworked by wind and water.

The sand pumping operation would most likely take place during January or February, when recreation use is lowest. This concept would be flexible because both the number of beaches targeted and the frequency of sand pumping could be varied, assuming channel-stored sand is available.

Cost estimates for pumping river bottom sand range from $30,000 to $150,000 per year.

Evaluation of Concept. Grand Canyon sandbars are scarcest in narrow reaches. However, sand pumping in these reaches would be difficult because of strong river currents and may not be possible due to scarcity of riverbed sand.

If long-term net erosion of low elevation sandbars were to occur, it would likely be due to a shortage of sand in the river channel, and sand pumping would not be a feasible method of sandbar restoration because of lack of supply. Results from the long-term monitoring program may identify sites where sand pumping should be considered. The feasibility of sand pumping would have to be evaluated on a case-by-case basis.

Beach management by sand pumping would be a minor project involving only a few beaches but would require a permit from the Corps under section 10 of the Rivers and Harbors Act and section 404 of the Clean Water Act. A formal application must be submitted to the Corps by the agency proposing such work. A separate NEPA document also would be required, which would establish a site-specific project purpose and include a section 404(b)(1) analysis to identify the least-damaging practicable alternative in terms of cost, logistics, and available technology.

Beach Protection

Beach protection on a systemwide basis is not currently necessary and likely will not be needed. NPS will determine if beach protection at certain sites is feasible and appropriate and, if so, obtain any required permits and NEPA compliance.

Description of Concept. Rock jetties or riprap lining (layer of rock) could be placed to protect or rehabilitate existing sandbars. A jetty would be used to divert high velocity flow away from a sandbar and create a small eddy on the downstream side of the structure. Riprap lining of the channel bank would help prevent sandbar erosion by high water velocities and recreational activity. Either of these protection measures would work well in conjunction with a sand pumping operation.

All structures would consist of native rock and vegetation and would be designed to blend with the natural environment. No steel, wires, or concrete would be used. Rock would be obtained from nearby tributary debris fans and not from talus slopes or canyon walls. All rock would be placed by hand or with small mechanized equipment. Because of logistical difficulties, only sites that are within a few hundred yards of a debris fan could be protected this way.

Any necessary equipment and personnel would be transported by raft from Lees Ferry. These structures would require a maintenance program with access by raft. Cost estimates for beach protection have not been determined.

Evaluation of Concept. Grand Canyon sandbars are scarcest in narrow reaches. However, beach protection in these reaches would be difficult due to strong river currents and may not be possible due to the scarcity of nearby debris fans (source of rock).

Due to the unique logistical problems in Grand Canyon, sandbars could be protected with riprap only above the low river stage. High water velocities could scour the sandbar below the riprap and cause the entire beachface to fail. Sandbar erosion due to a rapid drop in river stage during fluctuating flows has been documented (Beus and Avery, written communication, 1992). However, riprap would not be effective against this type of erosion.

Results from the long-term monitoring program may identify sites where beach protection should be considered. The feasibility of beach protection would have to be evaluated on a case-by-case basis.

Beach management by bank protection would be a minor project involving only a few beaches but would require a permit from the Corps under section 10 of the Rivers and Harbors Act and section 404 of the Clean Water Act. A formal application must be submitted to the Corps by the agency proposing such work. A separate NEPA document would be required that would establish a site-specific project purpose and include a section 404(b)(1) analysis to identify the least-damaging practicable alternative in terms of cost, logistics, and available technology.

Remove Glen Canyon Dam

Removal of the dam is considered unreasonable in view of:

- The many established beneficial uses that it now serves
- The legal framework ("Law of the River") that now exists, including the Grand Canyon Protection Act of 1992
- The investment that the dam represents
- The adverse social, economic, and other impacts to the existing human environment that would result from its removal

Most importantly, Reclamation was directed by the Secretary to evaluate alternative operations for Glen Canyon Dam. The concept of removal is an alternative to operating the dam and, thus, does not address dam operations. Since dam removal is outside the scope of dam operations, it violates the Secretary's charge to Reclamation. As a result, this concept was eliminated from further study.

Move Hydropower Peaking From Glen Canyon Dam to Hoover Dam

Both Glen Canyon and Hoover Powerplants already are operated as hydroelectric power peaking plants. 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.

It has been suggested that more units could be added at Hoover to increase capacity and to supply the peaking that now occurs at Glen Canyon. However, Hoover modification is already being considered by the Arizona Power Authority and the Colorado River Commission of Nevada to augment their peaking needs. Therefore, power produced at Hoover may not be available for use in the area served by Glen Canyon power.

It may be possible in the future to apply additional computer technology on a regional or system basis to refine and enhance the efficiency of the power network, including Glen Canyon and Hoover Powerplants. This could facilitate some peaking and spinning reserve adjustments between the two projects.

SUMMARY COMPARISON OF ALTERNATIVES

Table II-7, presented at the end of this section, summarizes the impacts of the alternatives considered in detail on the affected environment. Impacts of the Maximum Powerplant Capacity and High Fluctuating Flow Alternatives would be very similar to those of the No Action Alternative.

Impacts under the Moderate and Modified Low Fluctuating Flow and Seasonally Adjusted Steady Flow Alternatives would be similar for most resources (because they include habitat maintenance flows) except hydropower. The habitat maintenance flows of these three alternatives would provide some ecosystem variability that was characteristic of the predam environment.

Endangered fish research flows would be initially included in the Modified Low Fluctuating Flow Alternative during minimum release years. The extent to which steady flows would be permanently incorporated would depend on evaluation of the research results. Because these 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 table of impacts. Endangered fish research flows (when they occur) would have impacts that fall within the range of impacts between the Modified Low Fluctuating and Seasonally Adjusted Steady Flow Alternatives (see chapter IV).

Impacts under the Interim Low Fluctuating Flow and Existing Monthly Volume and Year-Round Steady Flow Alternatives would be similar for most downstream resources and result in a relatively static environment.

The impacts on each of the affected resources are described in more detail in "Chapter IV, Environmental Consequences." These resources include: water, sediment, fish, vegetation, wildlife and habitat, endangered and other special status species, cultural resources, air quality, recreation, hydropower, and non-use value.

Resource Management Objectives

Federal, State, and Tribal Governments develop management objectives to define the desired condition of specific resources. The attainment or nonattainment of these objectives drive the implementation of management actions intended to maintain or reestablish the resource condition. In some cases, objectives must be reevaluated if they are not achieved.

As outlined in the Grand Canyon Protection Act of 1992, the actions considered in this EIS are intended to protect and mitigate adverse impacts to and improve the natural and cultural resource values for which Grand Canyon National Park and Glen Canyon National Recreation Area were established. Many resources in Glen and Grand Canyons developed in response to conditions created by the dam. Reasonable objectives, developed by the management agencies, are goals for future management of these resources and provide meaning to the terms "protect," "mitigate," and "improve."

Reclamation, NPS, FWS, Western, AGFD, Hualapai Tribe, and Navajo Nation have management responsibilities associated with Glen and Grand Canyons and have developed resource management objectives.

The agency resource management objectives and the potential for the alternatives to meet those objectives are assessed below. Attainment of objectives for all resources will require complex interagency planning and management. Some issues would remain unresolved under any alternative.

WATER: Reclamation's water management objectives are to use Colorado River Storage Project (CRSP) reservoirs for the statutory purposes of flood control, river regulation, beneficial consumptive uses, water quality control, enhancement of fish and wildlife, other environmental factors, and power production. This is to be accomplished consistent with other applicable Federal laws, the Mexican Water Treaty, interstate compacts, and decrees.

The Navajo Nation seeks to ensure that dam operations will not affect existing or future water rights or the use of those rights.

NPS objectives are for releases that have a degree of variability to sustain sediment deposits and promote a dynamic ecosystem. Water released from the dam should meet or exceed State of Arizona standards for full body contact use.

The Hualapai Tribe's objective for water releases is to establish a flow pattern that maintains long-term sustainable and balanced multiple use of its resources which include: cultural resources, fish, wildlife, vegetation, water supply and quality, and recreation enterprises.

Assessment: All of the alternatives would likely accomplish Reclamation objectives for CRSP reservoirs.

Raising the height of the spillway gates to reduce flood frequency would meet Navajo Nation objectives. This is the method chosen in the preferred alternative. The other flood frequency reduction measure (increasing exclusive flood control space) would decrease Upper Basin yield.

NPS and Hualapai objectives would be accomplished under the Moderate Fluctuating, Modified Low Fluctuating, and Seasonally Adjusted Steady Flow Alternatives. Water quality objectives would likely be attained under all alternatives.

SEDIMENT: NPS, Hualapai, and Navajo seek to maintain a long-term balance of river-stored sediment and the entire range of predam sediment deposits—including an annually flooded bare-sand active zone, a less frequently flooded vegetation zone, and predam terraces. They prefer a diversity of dynamic, higher-elevation sediment deposits over stable, low elevation deposits.

Some actions taken to benefit Grand Canyon may have negative consequences in the Glen Canyon reach, and such consequences must be considered. However, NPS gives priority to Grand Canyon objectives over Glen Canyon objectives.

Assessment: All management objectives for sediment (except high terraces) in Grand Canyon would be accomplished under the Moderate and Modified Low Fluctuating Flow Alternatives and the Seasonally Adjusted Steady Flow Alternative. These alternatives provide the greatest cycles of deposition and erosion and maintain sandbars at the highest elevations, since daily release fluctuations would be restricted and seasonal variability would be added—primarily through habitat maintenance flows. However, high terraces would continue to erode under any alternative. Glen Canyon sediment would be subject to long-term net erosion under any alternative.

FISH: NPS, Hualapai, and AGFD objectives for native fish are to ensure viable populations in Grand Canyon. The Hualapai seek to completely eliminate carp from Glen and Grand Canyons. FWS objectives for native fish are to closely mimic the natural, predam ecosystem process under which native fish evolved.

NPS, AGFD, Hualapai, and Navajo objectives for the trout fishery are to provide a recreational resource while maintaining and recovering native fish in Grand Canyon. In the Glen Canyon reach, their objective is to encourage natural reproduction, survival, and growth of trout to blue ribbon quality sizes. In Grand Canyon, the objective is to sustain a wild trout fishery.

Assessment: To assure future accomplishment of agency objectives for native fish, additional research is needed on native and non-native fish interaction, the feasibility of selective withdrawal, the potential for reintroduction of extirpated native fish, and potential for eliminating carp.

Achievement of objectives for native fish vary by species. None of the alternatives appear to increase spawning habitat for native fish in the mainstem. Selective withdrawal may be required to allow warmer releases. Reproduction and recruitment of razorback sucker in Grand Canyon is virtually unknown; it is unlikely that any of the alternatives in and of themselves will reverse this trend.

Flannelmouth sucker appear to be favored by those alternatives that create or maintain rearing habitats in the mainstem (i.e., Modified Low Fluctuating and Seasonally Adjusted Steady Flow Alternatives).

All steady flow alternatives and the Modified Low and Interim Low Fluctuating Flow Alternatives would likely meet AGFD, NPS, Hualapai, and Navajo objectives for the trout fishery and its food base.

VEGETATION: NPS, Hualapai, and Navajo objectives for vegetation in the river corridor are to maintain a dynamic ecosystem made up of diverse groups of native, riparian plant species at different stages of succession and at different elevations above the water line. Emergent marsh vegetation should be sustained as a functioning, dynamic resource providing wildlife habitat that changes in location and extent in response to flow and sedimentation processes.

The Hualapai Tribe seeks to remove non-native vegetation, as necessary, to maintain campsites.

Assessment: Habitat maintenance flows, which are components of the Moderate Fluctuating, Modified Low Fluctuating, and Seasonally Adjusted Steady Flow Alternatives, provide the greatest potential for accomplishing the NPS, Hualapai, and Navajo objective for sustaining a dynamic ecosystem. Other alternatives result in system stability or eventual loss of ecosystem components. Because of the regulated flows, it would be difficult under any alternative to achieve the NPS objective of maintaining dynamic marshes. However, alternatives with habitat maintenance flows and variable water releases among years should maintain some marsh dynamics.

WILDLIFE AND HABITAT: NPS, Hualapai, and Navajo objectives are to provide for diversity of wildlife species, giving priority to native species and associated natural processes.

Assessment: Objectives for vegetation—and thus aquatic and terrestrial habitat—would be best met under the Moderate and Modified Low Fluctuating Flow Alternatives and the Seasonally Adjusted Steady Flow Alternative, therefore providing the greatest potential for accomplishing wildlife objectives.

ENDANGERED AND OTHER SPECIAL STATUS SPECIES: NPS, FWS, AGFD, Hualapai Tribe, and Navajo Nation objectives are to monitor, protect, and recover populations of endangered species, candidate species, and State-listed species.

Recovery plans developed for threatened and endangered species specify FWS and AGFD objectives. Final recovery plans have been approved for the bald eagle, peregrine falcon, and humpback chub; a recovery plan for the razorback sucker is being developed. FWS and Navajo Nation objectives specific to the humpback chub and other native fish are to protect the LCR and restore mainstem populations.

Assessment: It may not be possible to accomplish these objectives for some native fish under any of the alternatives without adopting other measures such as selective withdrawal. Objectives for terrestrial species, including bald eagle, peregrine falcon, and willow flycatcher, would likely be met by sustaining the processes needed to accomplish sediment and ecosystem objectives (i.e., Moderate Fluctuating, Modified Low Fluctuating, and Seasonally Adjusted Steady Flow Alternatives). However, dam operations alone cannot meet some objectives for endangered fish over the long term.

The entire Grand Canyon humpback chub population is in jeopardy, partly because of the limited distribution of the fish. Establishment of a second spawning population of the humpback chub is an express objective of AGFD, FWS, Hualapai Tribe, and Reclamation. This objective may be met by establishing a spawning population either in another tributary or in the mainstem, which is a common element under all restricted fluctuating and steady flow alternatives. Humpback chub would appear to be able to maintain a viable population under all alternatives but only because the LCR provides spawning habitat.

FWS believes that their management objectives can only be accomplished under the Seasonally Adjusted Steady Flow Alternative (see attachment 4).

CULTURAL RESOURCES: NPS, Hualapai, and Navajo objectives are to maintain the integrity of all cultural resources within the river corridor, with site preservation as the optimal condition, and to maintain biological and spiritual resources important in preserving Native American values.

For the Hualapai Tribe and Navajo Nation, preserving traditional cultural properties—including access to cultural properties and perpetuation of cultural practices within Glen and Grand Canyons—is the highest priority.

Assessment: Moderate Fluctuating, Modified Low Fluctuating, and Seasonally Adjusted Steady Flow Alternatives would contribute most toward preserving sites in place. However, management actions other than dam operations may be required to meet NPS, Hualapai, and Navajo objectives over the long term.

The same three alternatives would most likely preserve and maintain biological and spiritual resources important to Native Americans. Objectives for biological resources would not be as well met under the other steady flow alternatives and Interim Low Fluctuating Flow Alternative. Cultural resource objectives, in general, would not be met under the unrestricted fluctuating flows or the High Fluctuating Flow Alternative.

RECREATION: NPS, Hualapai, and Navajo objectives are to provide opportunities for recreational experiences along the river corridor that do not diminish natural or cultural resource values and to protect and preserve environmental and wilderness conditions that contribute to quality recreation experiences. Flows should allow navigation by white-water boats in Grand Canyon and power boats in Glen Canyon. In Glen Canyon, AGFD and NPS seek to maintain a blue ribbon angling opportunity and to provide safe boating and access for boaters, waders, and campers. AGFD seeks to provide access for hunting waterfowl in this reach.

The Hualapai Tribe also promotes motorized white-water boating, hunting, camping, and sightseeing in lower Grand Canyon. The Navajo Nation also seeks to provide recreational opportunities for Navajo people and to support and enhance recreation and tourism industries in northern Arizona.

Assessment: The steady flow alternatives would offer the most immediate benefits for recreation activities and attributes. However, the Moderate Fluctuating, Modified Low Fluctuating, and Seasonally Adjusted Steady Flow Alternatives would best meet the long-term recreation objectives of NPS, Hualapai, and Navajo.

All alternatives except the Maximum Powerplant Capacity Alternative would improve boating access and navigation over no action.

AGFD and Hualapai objectives for fishing, hunting, and safety would be realized most under the steady flow alternatives and, to a somewhat lesser degree, under the Modified Low and Interim Low Fluctuating Flow Alternatives.

HYDROPOWER: Western's objective is to serve the public interest by marketing and delivering the greatest amount of long-term firm power and energy from Glen Canyon Dam Powerplant while striving to protect and enhance environmental values both downstream of Glen Canyon Dam and throughout the Salt Lake City Area marketing area.

Assessment: Western's objective is most readily accomplished under the Moderate Fluctuating Flow Alternative. The Interim Low and Modified Low Fluctuating Flow Alternatives offer approaches to achieving a balance between enhancing benefits to natural resources and reducing impacts to hydropower.

Table II-7.–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
Hourly streamflows can be found in table II-2.				
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	44 to 70	28 to 47
With habitat maintenance flows				41 to 66
Potential height	10 to 15	10 to 16	10 to 15	6 to 10
With habitat maintenance flows				9 to 15
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
Trout	Stocking-dependent	Same as no action	Same as no action	Increased growth potential, stocking-dependent

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	568	568	492	699
899	899	899	688	703
592	592	592	1,106	699
1,045	1,045	1,045	768	699
64	69	71	71	74
73	76	82	82	100
24 to 41	24 to 41	10 to 19	16 to 29	0
41 to 66			37 to 60	
6 to 9	6 to 9	3 to 5	4 to 7	0 to 1
9 to 14			9 to 13	
Potential major increase	Potential major increase	Major increase	Major increase	Major increase
Potential minor increase	Potential minor increase	Potential minor increase	Potential major increase	Potential minor increase
Potential minor increase	Potential minor increase	Potential minor increase	Potential major increase	Potential minor increase
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

Table II-7.-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	Same as no action	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				
Change in maximum stage	No net change	5% increase	Same as no action	29% decrease
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	No effect	No effect	No effect
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	30 to 47% increase	45 to 65% increase	38 to 58% increase	63 to 94% increase
0 to 12% increase			0 to 12% 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
37% decrease	37% decrease	48% decrease	43% decrease	64% decrease
Potential increase	Potential increase	Potential increase	Potential increase	Potential increase
Potential minor increase	Potential minor increase	Potential minor increase	Potential major increase	Potential minor increase
Potential minor increase	Potential minor increase	Potential minor increase	Potential minor increase	Potential minor increase
Potential minor increase	Potential minor increase	Potential minor increase	Potential major increase	Potential minor increase
Potential increase	Potential increase	Potential increase	Potential increase	Potential increase
No effect	No effect	No effect	No effect	No effect
No effect	No effect	No effect	No effect	No effect
Same as no action	Same as no action	Same as no action	Same as no action	Same as no action

Table II-7.–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				
Native American traditional use areas	Major	Same as no action	Same as no action	Same as no action
Native American sacred sites/resources	Major	Same as no action	Same as no action	Same as no action
AIR QUALITY				
Regional air quality				
Total emissions (thousand tons)				
Sulfur dioxide	1,960	Less than ±1% change	Less than ±1% change	Less than ±1% change
Nitrogen oxides	1,954			
RECREATION				
Fishing				
Angler safety	Potential danger	Same as no action	Same as no action	Major 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 daily fluctuations	Same as no action	Minor increase	Moderate increase
Economic benefits				
Equivalent annual net benefits (1991 $ millions)	0	0	0	+0.40

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)
Same as no action	Same as no action	Same as no action	Same as no action	Same as no action
Same as no action	Same as no action	Same as no action	Same as no action	Same as no action
Less than ±1% change	Less than ±1% change	Less than ±1% change	Less than ±1% change	Less than ±1% change
Major improvement	Major improvement	Major improvement	Major improvement	Major improvement
Major improvement	Major improvement	Major improvement	Major improvement	Major improvement
Minor improvement	Minor improvement	Major 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
+3.74	+3.94	+3.94	+4.76	+2.93

Table II-7.–Summary Comparison of Alternatives and Impacts–Continued

	No Action	Maximum Powerplant Capacity	High Fluctuating Flow	Moderate Fluctuating Flow
POWER				
Wholesale and retail rates (1991 mills/kWh)				
Wholesale rates	18.78	18.78	19.38 (+3.2%)	23.18 (+23.4%)
Retail rates (median)	62.17	62.17	62.72	65.77
Annual economic cost (1991 $ millions)				
Hydrology	0	-2	+2	+44
Contract rate of delivery	0	0	+3	+36
NON-USE VALUES	*No data.*			

Modified Low Fluctuating Flow	Interim Low Fluctuating Flow	Existing Monthly Volume Steady Flow	Seasonally Adjusted Steady Flow	Year-Round Steady Flow
23.67 (+26.0%)	23.18 (+23.4%)	25.22 (+34.3%)	28.32 (+50.8%)	26.78 (+42.6%)
66.15	65.77	67.20	69.03	68.09
Not available	+36	+65	+76	+67
+41	+36	+69	+119	+86

CHAPTER III

Affected Environment

CHAPTER III

Affected Environment

This chapter describes the general setting, Colorado River system resource linkages, and resources in the study area that would be affected by any of the alternatives if implemented. The conditions described are those that existed in 1990, prior to the Glen Canyon Environmental Studies (GCES) research flows, under the water and power operating regimes that existed at that time. These conditions establish the baseline for analysis of effects, found in chapter IV. The resources presented are: water, sediment, fish, vegetation, wildlife and habitat, endangered and other special status species, cultural resources, air quality, recreation, hydropower, and non-use value.

SETTING

The affected environment includes two areas: (1) the immediate or Glen Canyon Dam area and (2) the region. The immediate area is the Colorado River corridor through Glen, Marble, and Grand Canyons in Coconino and Mohave Counties in northwestern Arizona. This area extends from Lake Powell downstream into Lake Mead. While the focus of the environmental impact statement (EIS) is on this river corridor, some alternatives may lead to regional impacts outside of the immediate geographic area. The following map shows the regional extent of the Colorado River Basin.

Immediate Area (see frontispiece)

Lake Powell and the first 15.5 miles of the Colorado River downstream of Glen Canyon Dam are part of Glen Canyon National Recreation Area (GLCA). The river flows another 278 miles through Grand Canyon National Park (GRCA) into Lake Mead, part of Lake Mead National Recreation Area. All of these areas are administered by the National Park Service (NPS). The Navajo Indian Reservation is adjacent to GRCA and GLCA. Kaibab National Forest, administered by the Forest Service of the U.S. Department of Agriculture, adjoins GRCA on the north and south. The Hualapai Reservation includes 108 miles of Grand Canyon south of the river from National Canyon (river mile[1] (RM) 166.5) to RM 273. The Havasupai Reservation adjoins GRCA south of the river and west of the Kaibab National Forest.

Between Glen Canyon Dam and Lake Mead, the Colorado River falls about 1,900 feet, or from approximately 3100 to 1200 feet above sea level. More than 100 rapids, some having drops of up to 40 feet, account for most of this elevation loss. Numerous tributaries enter this stretch of river, the principal ones being the Paria and Little Colorado Rivers, and Bright Angel, Tapeats, Kanab, Havasu, Diamond, and Spencer Creeks.

The Colorado River can be reached by two highways: U.S. 89 crosses the river immediately below Glen Canyon Dam, and U.S. 89 Alternate crosses about 20 miles downstream near the community of Marble Canyon (near RM 4). Year-round access to the south rim of Grand Canyon is provided by U.S. 180 and Arizona 64. Access to the north rim is provided by Arizona 67, but the part of that road between the GRCA boundary and the north rim is open only from about mid-May to mid-October.

Access to the south and north rims and the river at other locations is provided by a few unimproved roads and several trails. Some of the unimproved roads and trails access the canyon via the Navajo Indian Reservation, and permits for their use must be obtained from the Navajo Nation in Cameron

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[1] River mile designates distance downstream from Lees Ferry (RM 0), which is located 15.5 miles downstream from Glen Canyon Dam. Negative numbers (i.e., RM -9) indicate distance upstream between Lees Ferry and the dam.

or Window Rock, Arizona. Access to the river is also available from Peach Springs to Diamond Creek via the Hualapai Indian Reservation. An NPS road provides access to Lees Ferry from Marble Canyon.

Two cities in the area are Flagstaff, Arizona, about 50 miles south of the south rim of Grand Canyon, and Page, Arizona, about 2 miles southeast of Glen Canyon Dam. Commercial air service is available at both cities and near Grand Canyon Village on the south rim. Commercial boat trips on the Colorado River begin immediately below Glen Canyon Dam and at Lees Ferry (RM 0); private trips begin only at Lees Ferry. Also, the Hualapai Tribe provides commercial river trips from Diamond Creek to Lake Mead. Mule trips are conducted from Grand Canyon Village and the north rim.

Colorado River Region

The Colorado River has its headwaters in the mountains of Colorado and flows southwestward to its mouth at the Gulf of California. It drains an area of approximately 244,000 square miles, of which 242,000 are in the United States and 2,000 are in northern Mexico. The basin extends from the Wind River Mountains in Wyoming to south of the United States–Mexico border, a straight line distance of approximately 900 miles. Basin width varies from about 300 miles in the upper reaches to more than 500 miles in the lower reaches. It is bounded on the north and east by the Continental Divide in the Rocky Mountains, on the west by the Wasatch Mountains, and on the southwest by the San Jacinto Mountains. Colorado River tributaries drain parts of seven Western States: Arizona, California, Colorado, Nevada, New Mexico, Utah, and Wyoming.

The Upper Colorado River Basin drains an area of 108,000 square miles; its tributaries include the Upper Colorado, Green, Gunnison, San Juan, and Paria Rivers. The Lower Colorado River Basin drains an area of 136,000 square miles, and its tributary basins include the Lower Colorado, Little Colorado, Virgin, and Gila Rivers. The division between the two basins is at Lee Ferry, a reference point in the mainstream of the Colorado River 1 mile below the mouth of the Paria River (not to be confused with Lees Ferry, which is the site of the U.S. Geological Survey (USGS) stream gauge above the Paria River confluence).

Geology

For more than 5 million years, the Colorado River and its tributaries—along with geologic uplift and weathering—have carved the Grand Canyon. The canyon is about a mile deep and varies in width from a few hundred feet at river level to as much as 18 miles at the rim. The river cut only a narrow gorge; running water from the canyon walls, freezing and thawing, and abrasion of rock against rock excavated most of the canyon. The Colorado River is like a huge conveyor belt for transporting finer particles to the ocean, temporarily (geologically speaking) dropping its load into Lake Mead.

In cutting the canyon, the river has exposed rocks of all geologic eras, covering a span of nearly 2 billion years. The rocks of Grand Canyon are part of the Colorado Plateau, a 130,000-square-mile area covering most of the Colorado River Basin. The elevation of the Grand Canyon area varies between about 5000 and 8000 feet above sea level, with the north rim about 1,000 feet higher than the south rim.

A river trip starting at Glen Canyon Dam is a trip backward through geologic time (Beus and Morales, 1990). Glen Canyon is cut through the massive Navajo Sandstone of the Mesozoic era—about 200 million years old. Downstream from Lees Ferry, the great sequence of nearly horizontal sedimentary rocks of the Paleozoic era appear at river level in descending order, beginning with the Kaibab Formation that caps much of the canyon rim. In Marble Canyon, river runners pass through the cavernous Redwall Limestone. The river is narrower here and in other places where the Paleozoic rocks are relatively hard and wider through more easily eroded formations. The shelves of the Tapeats Sandstone (more than 500 million years old) at the base of the Paleozoics appear near the mouth of the Little Colorado River (LCR). For the rest of the trip, the narrowest reaches are cut through the

Colorado River Basin Location Map

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 III-1). 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 Little Colorado River.

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 inconsistent 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 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 annual flows ranged seasonally from spring peaks sometimes greater than 100,000 cfs to winter lows of 1,000 to 3,000 cfs. The way water is now released varies on a daily or even hourly basis. 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 change by 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.

Photo by Gary Ladd

Figure III-1.—Photograph of Colorado River corridor looking downstream from Nankoweap Creek.

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, particularly temperature and water clarity. 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

Exposed sediment deposits (including beaches) through 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.

The river's capacity to transport sediment has been reduced along with the sediment supply. 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 transported sand stored within the river channel, eroded low elevation sandbars, and aggraded high elevation sandbars. 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. 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 resulting system can be described as "naturalized," meaning a mixture of native and non-native plant and animal communities supported by postdam conditions. The river is forever changed. That change—brought about by Glen Canyon Dam—permitted this naturalized ecosystem to exist.

Aquatic Resources

The biological foundation of the aquatic system in the postdam Colorado River below Glen Canyon Dam is *Cladophora glomerata*, a non-native 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 single-celled 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 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, 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 (figure III-2).

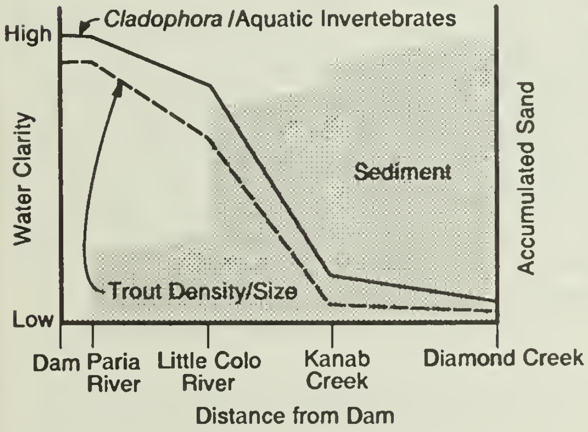


Figure III-2.—As the river's sediment load increases downstream, the abundance of Cladophora, aquatic macroinvertebrates, and rainbow trout decreases.

Before the dam, eight native fish species inhabited the river. Now several species face survival problems, and only three native fish species remain relatively common in tributaries and certain sections of the river. The reasons for these survival problems are undoubtedly complex, but principal known factors are the introduction of non-native fish and habitat changes brought about by construction of Glen Canyon Dam. The following linkages are believed related to changes in water quality.

- Low water temperature prevents mainstem spawning and threatens survival of young fish.
- Low water temperature may affect food consumed during certain fish life stages.
- Increased water clarity may make some native fish more vulnerable to competition and predation from non-native fishes.

Because of cold water temperatures, suitable habitats for reproduction and development of the remaining native fish in Grand Canyon are confined to tributaries, tributary mouths, and backwaters. Reproduction of native fish species is restricted to within the tributaries, which are mostly outside the influence of the dam.

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 water 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, extended periods of exposure can adversely affect *Cladophora* and its associated invertebrates. 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 those sites that remain continuously inundated. Insect larvae are uncommon in the fluctuating zone.

Flow fluctuations affect the spawning attempts of trout and native 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 native 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 at Nankoweap Creek during the winter to feed on spawning trout and fish stranded by fluctuating flows (figure III-3).

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. Rapid reductions in 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.

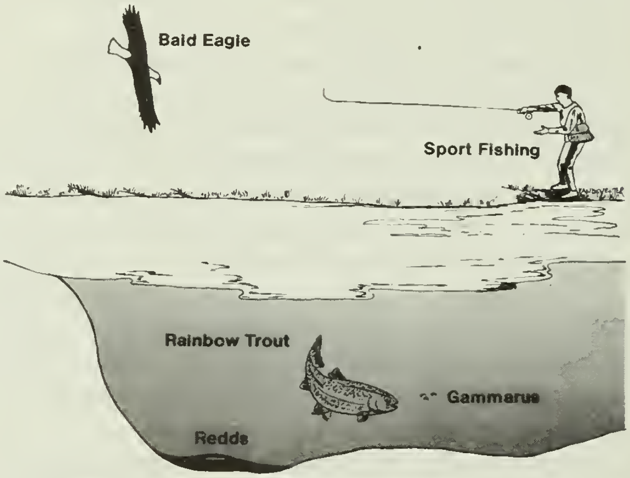


Figure III-3.—The effects of dam operations on linkages between aquatic and terrestrial resources is exemplified by the trout fishery. Fluctuating flows can affect food abundance (Cladophora/Gammarus), trout spawning in the river and tributaries, the availability of trout as prey for eagles, and the sport fishery. These resources were not found in the Colorado River corridor through Grand Canyon before construction of Glen Canyon Dam.

Following dam construction, riparian vegetation developed below the OHWZ in what has become known as the new high water zone (NHWZ). Today, this new zone of vegetation provides several hundred acres of habitat for native wildlife. Riparian vegetation reflects water flow pattern and is an excellent example of how resources are linked in the terrestrial system. A mixture of native and non-native plant species helps stabilize sediment deposits and 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.

Emergent marsh vegetation, such as cattails, often develops in areas with low water velocity and high concentrations of silt and clay. Even though emergent marsh vegetation makes up less than 2 percent of the total riparian vegetation, it greatly enhances diversity in the river corridor.

While riparian vegetation supports its own insect populations, it also provides habitat for insects emerging from the river. Structural 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. One of the highest known densities of peregrine falcons in North American resides in Grand Canyon, feeding on the swallows, swifts, and bats there (figure III-4).

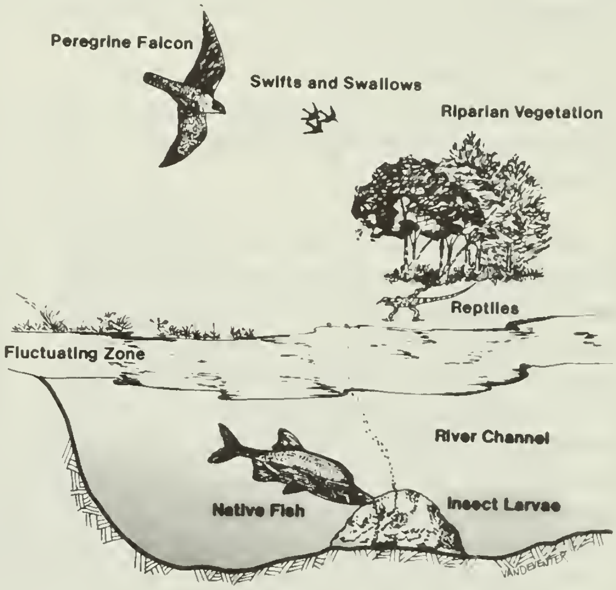


Figure III-4.—Insects are an important linkage between aquatic and terrestrial systems in Grand Canyon. Some insects emerge from the river as adults and become food for various wildlife species using the river corridor. For example, swallows, swifts, and bats feed on emerging insects; peregrine falcons, an endangered species, feed on these foraging species.

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.

Summary

As described above, the processes (water releases and sediment transport) that control downstream resources and the resources themselves (water, sediment, fish, vegetation, and wildlife and their habitat) are interconnected within a system operationally defined as the Grand Canyon ecosystem.

The reader should keep in mind that this naturalized system exists within the boundaries of conditions dictated by Glen Canyon Dam. None of the alternatives considered in this EIS has the potential to return the system to predam conditions. Well-defined volumes of cold, clear water annually pass through Glen and Grand Canyons. Native fish that could not tolerate these conditions have declined or disappeared from the canyon. Other species and communities that were rare or nonexistent before the dam are now abundant: *Cladophora*, *Gammarus*, trout, bald eagles, peregrine falcons, and riparian vegetation and its wildlife in the NHWZ. The following discussions present the details surrounding the affected resources necessary to understand and evaluate the effects of each alternative.

WATER

Colorado River water flowing into Lake Powell and ultimately released into Glen Canyon comes principally from the Rocky Mountains. During April, May, June, and July, runoff is high, and the Colorado River above Lake Powell is at maximum flow. Before Glen Canyon Dam existed, the river gained volume from the spring snowmelt and reached a maximum flow in May or June, then receded during the remainder of the year—except when flash flooding in the late summer resulted in a second peak. Since Glen Canyon Dam was completed in 1963, riverflows below the dam have been almost completely dependent on water releases from Lake Powell.

The regulation of flow by Glen Canyon Dam has resulted in a slight increase in median flows and a great decrease in the number of flood peaks. Frequent flash flooding from tributaries during summer thunderstorms still produces temporary uncontrolled peak flows. Since demands for hydroelectric power determine the hourly schedule of discharges, water releases vary over a 24-hour cycle. The peak daily discharge generally occurs in the daytime, and the minimum discharge occurs at night.

In addition to reservoir capacity, annual runoff, and discharge capacity, Glen Canyon Dam operations also are affected by legal and institutional constraints specified in various Federal laws, interstate compacts, international treaties, and Supreme Court decisions—the "Law of the River."

Section 602 of the Colorado River Basin Project Act (Public Law 90-537) directed the Secretary of the Interior to develop operating criteria to comply with and carry out the provisions of the Colorado River Compact, the Upper Colorado River Basin Compact, and the Mexican Water Treaty. This resulted in the 1970 Criteria for Coordinated Long-Range Operation of Colorado River Reservoirs (Long-Range Operating Criteria). These Long-Range Operating Criteria cover the coordinated operations of the Upper Basin reservoirs and Lake Mead and are reproduced in attachment C.

The Long-Range Operating Criteria are subject to review at least every 5 years. The most recent review was completed in 1993. As part of the review process, comments are invited and received from numerous individuals and groups. In 1985, the Colorado River Management Work Group was formed to "seek consensus regarding operating flexibility available in the existing operating criteria and to develop procedures and analytical tools to be used for formulating future annual operating plans" (Bureau of Reclamation, 1986). Since formation, the work group has met several times each year to develop annual operating plans and to conduct studies with the objective of improving overall operations. Until recently, the work group has consisted principally of representatives of the Basin States, Bureau of Reclamation (Reclamation), and the Western Area Power Administration (Western). In 1991, additional resource management agencies and organizations were invited and became involved.

This section provides historic perspectives on the following water issues:

- Streamflows
- Floodflows and other spills
- Reservoir storage
- Water allocation deliveries
- Upper Basin yield determination
- Water quality

Streamflows

The closure and water release management of Glen Canyon Dam have affected Colorado River flows below the dam. Figure III-5 illustrates the changes in the pattern of annual flows at Lees Ferry for the predam period (from 1922, when continuous records were first kept, through 1962) and postdam period (1963-89).

Predam Streamflows

The predam period was characterized by frequent, very high flows in the late spring and early summer and by very low flows during the late summer, fall, and winter. In spring and early summer, average daily flows greater than 80,000 cfs were not uncommon; they occasionally were greater than 100,000 cfs. In contrast, flows less than 3,000 cfs were frequent during the fall and winter months. Figure III-6 shows predam

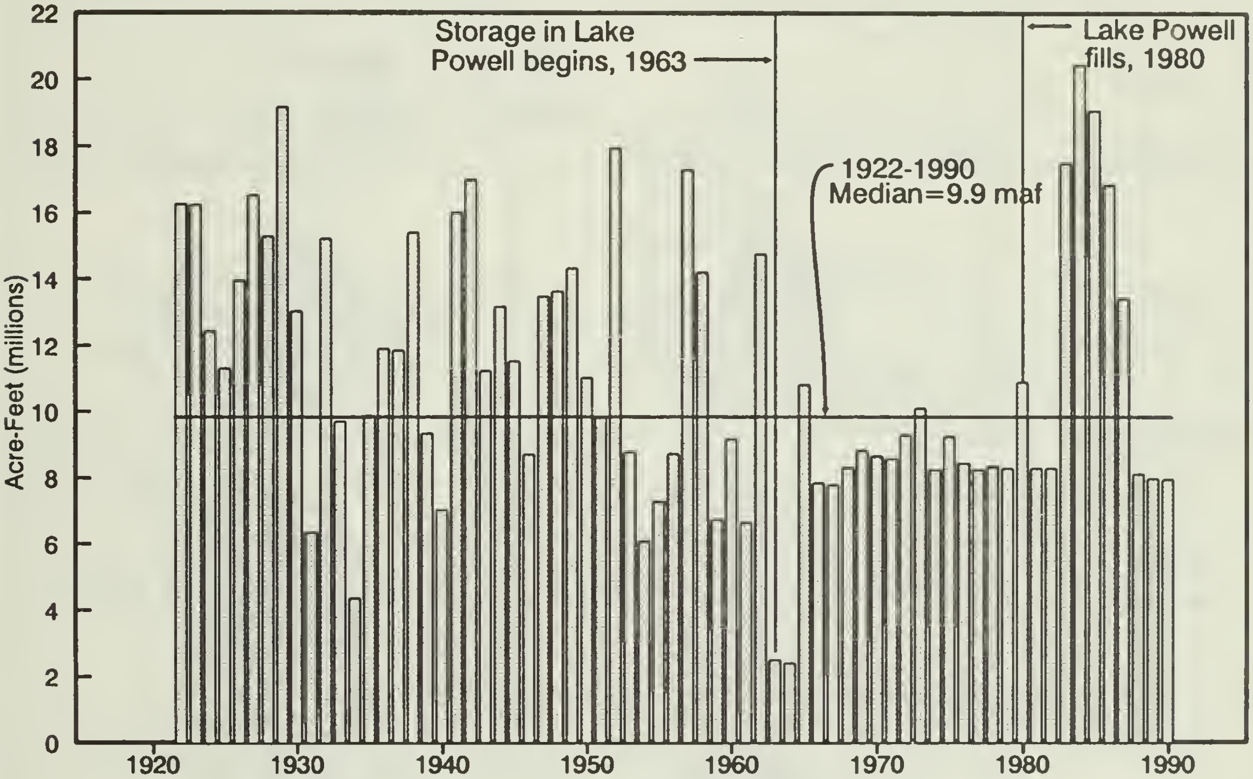


Figure III-5.—The pattern of annual flows at Lees Ferry changed with completion of Glen Canyon Dam in 1963.

and postdam daily flows for 4 representative months (the higher flows are shaded darker) and illustrates that predam spring flows were much higher and predam winter flows much lower than postdam.

In the period of record before closure of Glen Canyon Dam (1922-62), flows below the damsite typically exceeded 33,200 cfs (powerplant capacity) in the months of April through July. On rare occasions, flows exceeded 33,200 cfs in August and into the fall. Table III-1 summarizes maximum predam and postdam flows and the frequency with which powerplant capacity was exceeded. These data show that high flows were more frequent and more severe before the dam.

Table III-1.—High predam and postdam Colorado River flows below Glen Canyon Dam (daily values)

	Percent of days 33,200 cfs exceeded		Maximum flows (cfs)	
Month	Predam (1922-62)	Postdam (1963-89)	Predam (1922-62)	Postdam (1963-89)
April	16	0	75,000	—
May	61	9	119,000	48,000
June	77	13	124,000	93,000
July	17	7	119,000	88,000
August	3	2	65,000	45,000

Postdam Streamflows

Historic operations (prior to existing interim flows) are described under the No Action Alternative, chapter II. Additional historical perspective on monthly and hourly releases is provided here.

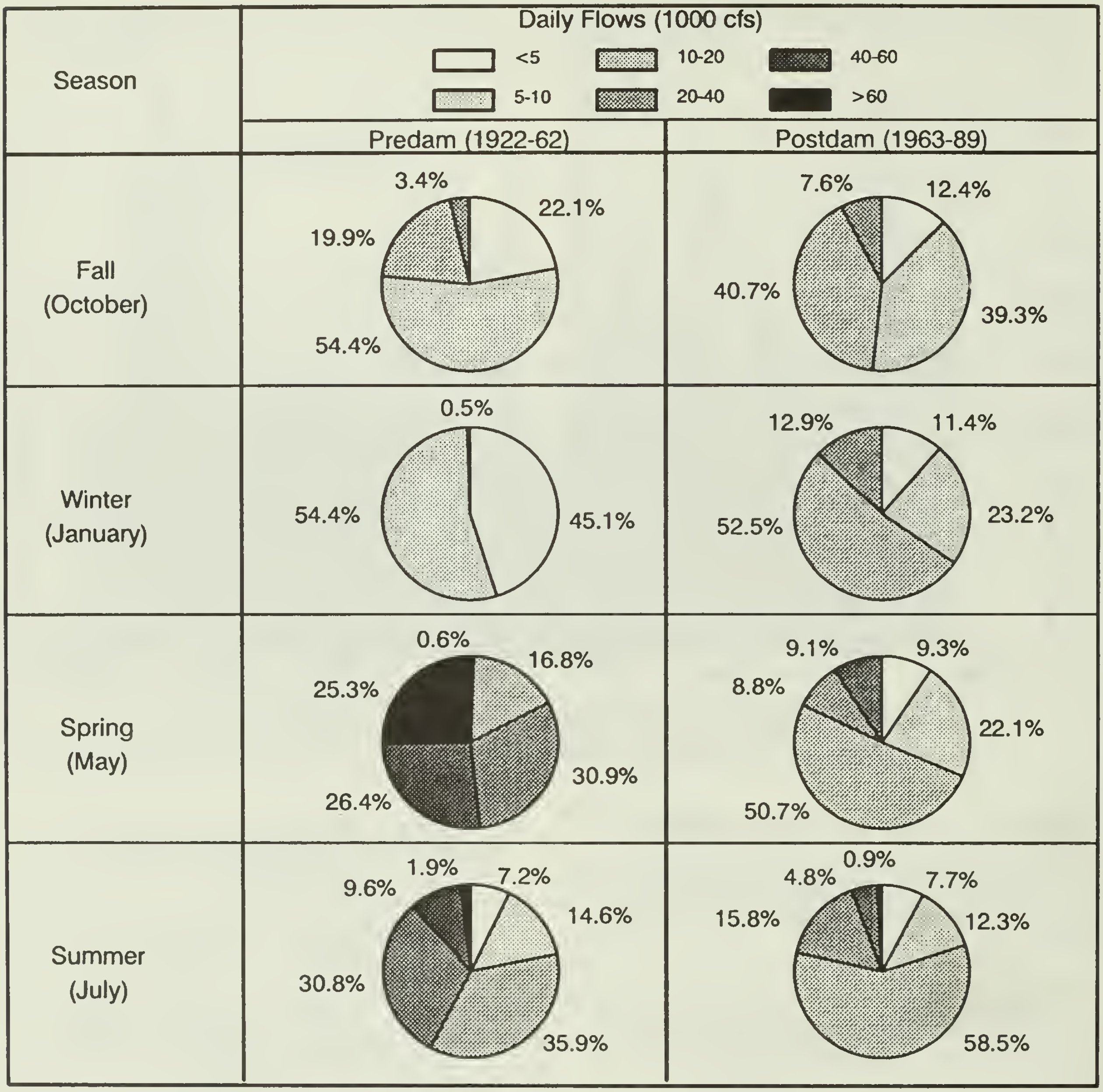


Figure III-6.—Predam and postdam daily flows at Lees Ferry (percent of days that the specified flows occurred).

Lake Powell began storing water in March 1963 and filled in June 1980. Very little water was released through Grand Canyon for the first 2 years after dam closure (about 2.5 maf each year). In 1964, Lake Powell achieved the minimum elevation necessary for power production (3490 feet). Since 1965, the minimum annual release from Glen Canyon Dam has been about 8.23 maf, and variability in annual releases has been reduced. Figure III-6 compares the postdam daily flows with predam flows. Of particular note is the substantial reduction of high spring flows in the postdam period.

Monthly Streamflow. Predam monthly flow volumes reflect high spring flows and low winter flows. Table III-2 presents predam and post-dam median monthly volumes for representative months of the four seasons. Postdam volumes have been much less extreme than predam volumes.

Table III-2.—Median predam and postdam monthly flows at Lees Ferry (1,000 acre-feet)

	Predam (1922-62)	Postdam (1963-89)
Fall (October)	412	609
Winter (January)	319	745
Spring (May)	2,805	845
Summer (July)	1,357	827

Hourly Streamflow. Figure III-7 shows the daily range in flows for low, moderate, and high water release years. The range is represented by a plotting of the lowest and highest hourly releases for each day of the water year. Greater fluctuations occur in years with low and moderate release volumes. See chapter II (figure II-4) for typical daily fluctuations during 24-hour periods with high, moderate, and low daily release volumes.

Daily flow maximums, minimums, and fluctuations are important when comparing EIS alternatives. Figure II-5 in chapter II shows historic daily occurrences of these parameters by month. Table III-3 provides such historic daily occurrences by season.

Table III-3.—Historic minimum and maximum hourly releases and daily fluctuations, 1965-89 (percent of days)

Minimum hourly releases

	<5,000 cfs	<8,000 cfs
Fall (October)	70	81
Winter (January)	54	76
Spring (May)	44	64
Summer (July)	49	66

Maximum hourly releases

	>20,000 cfs	>25,000 cfs
Fall (October)	32	11
Winter (January)	64	39
Spring (May)	99	96
Summer (July)	70	47

Daily fluctuations

	>8,000 cfs	>12,000 cfs	>20,000 cfs
Fall (October)	77	49	7
Winter (January)	83	69	23
Spring (May)	74	49	10
Summer (July)	83	67	22

Rate of Change in Streamflow (Ramp Rate). The ramp rate is the rate of change in instantaneous discharge to achieve either higher or lower releases in responding to electrical load. The principal times of change are in the morning, when the releases are ramped upward to respond to the peak daytime demand, and at night, when releases are ramped downward as the electrical demand diminishes. Ramp rates are of concern because of their possible effects on sediment and aquatic resources downstream of the dam. The historic down and up ramp rates are shown in chapter II (figure II-6).

Downstream Transformation of Fluctuating Releases

Daily fluctuations in releases from Glen Canyon Dam produce long waves that travel the length of the canyon. To an observer at a fixed location, these waves resemble ocean tides. The waves produced by fluctuating releases transfer the energy of the released water downstream by continuously displacing an equivalent amount of water. As a wave passes a fixed location, an observer sees displaced water, not the released water that initially formed the wave.

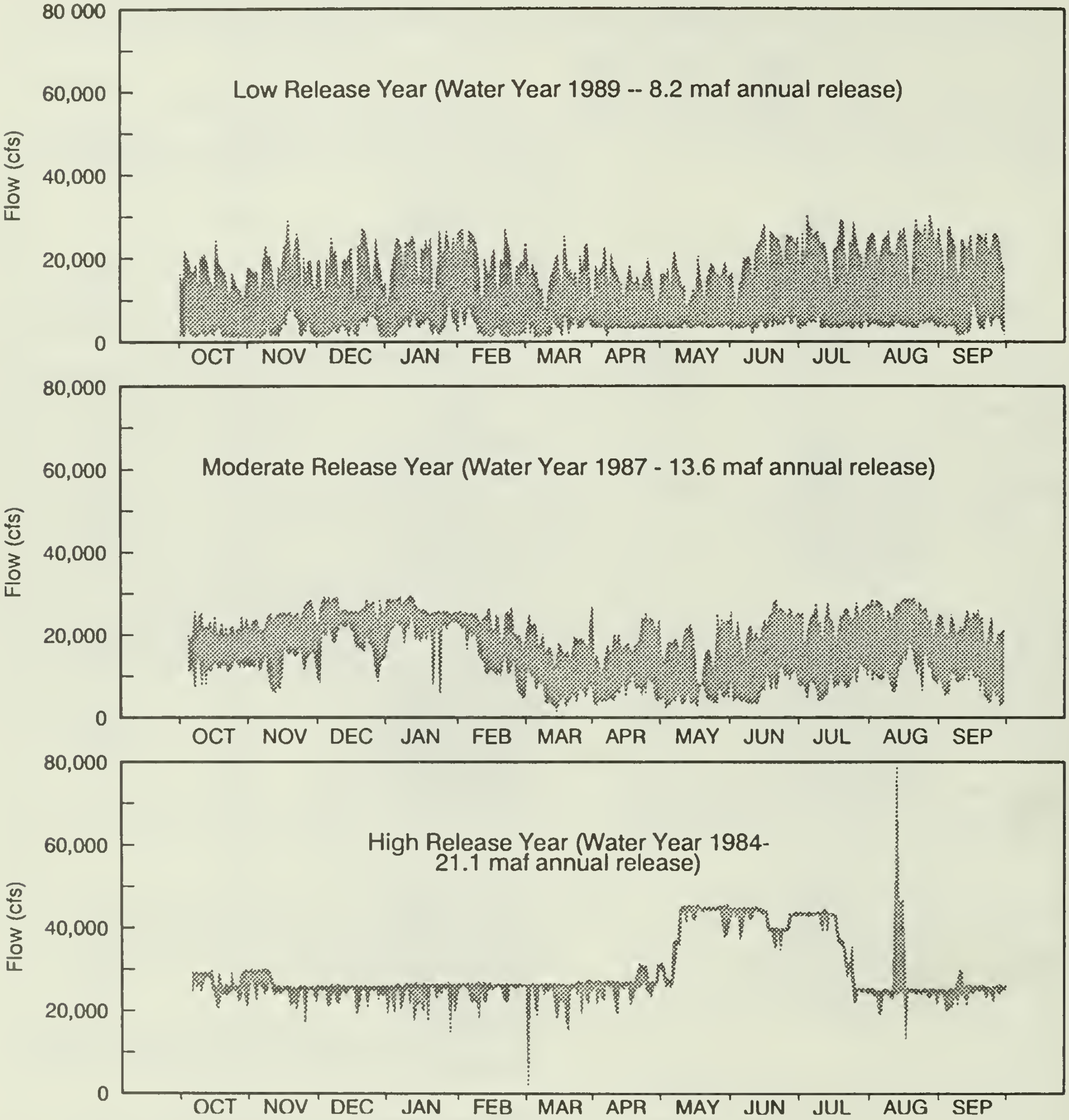


Figure III-7.—The magnitude of daily fluctuations has been greater for low to moderate release years than for high release years.

The size and shape of the waves change as the waves travel downstream. Such changes are important considerations for determining impacts on sediment resources, fish habitat, riparian habitat, and recreation. Scoping revealed that there are many misconceptions regarding changes in river level resulting from daily flow fluctuations. See Appendix B, Hydrology, for additional information about wave transformation.

Travel Time of Water

Information about travel time of water released from the dam to sites of interest downstream is important for assessing water quality. Travel time is determined by water velocity, which varies with discharge. Dissolved constituents travel at the same velocity as the water, suspended materials travel somewhat more slowly, and floating materials travel more rapidly. The energy waves produced by fluctuating releases from the dam, however, travel at substantially greater velocities than the water that initially forms them, so wave travel times through a given reach are much shorter than travel times of the released water. Additional information about travel time of water is provided in appendix B.

Tributary Flows

Principal tributaries to the Colorado River below Glen Canyon Dam are the Paria and Little Colorado Rivers, and Bright Angel, Tapeats, Kanab, and Havasu Creeks. Streamflow records are available for the Paria River (at Lees Ferry), the LCR (near Cameron, Arizona), and Bright Angel Creek (near Grand Canyon). Table III-4 presents USGS water records for maximum and minimum flows by day, month, and year for each of these tributaries.

Floodflows and Other Spills

Floodflows are defined in this EIS as flows in excess of the powerplant capacity of 33,200 cfs. Spills other than floodflows are excess annual release volumes greater than legally required owing to scheduling difficulties.

The ideal operating plan would enable Lake Powell to fill each year without risking floodflows. Floodflows are undesirable because they move sediment out of the system, they bypass the powerplant, and they exceed diversion capacities (often causing loss of downstream water uses). Unfortunately, inflow forecasts have a large degree of uncertainty, which increases the risks of either flood releases or not filling the reservoir. Since the closure of Glen Canyon Dam, floodflows (releases in excess of powerplant capacity—33,200 cfs) have occurred almost exclusively in the months of May, June, July, and August.

The present methods of scheduling releases to avoid floodflows are discussed under the No Action Alternative in chapter II. These operating measures are thought to provide protection against floodflows for all years except those with extreme inflows compounded with a high forecast error. If the reservoir was near full when such hydrologic events occurred, floodflows would be difficult, if not impossible, to avoid.

Table III-4.—Recorded flows of principal tributaries to the Colorado River in Grand Canyon through 1990

	Paria River (1924-90)	Little Colorado River (1947-90)	Bright Angel Creek (1923-74)
Minimum day (cfs)	1	0	10
Maximum day (cfs)	6,750	18,400	2,500
Minimum month (acre-feet)	119	0	795
Maximum month (acre-feet)	24,596	257,766	30,019
Minimum year (acre-feet)	8,280	16,873	10,562
Maximum year (acre-feet)	45,900	815,855	62,845

Reservoir Storage

If monthly release volumes were altered, storage patterns at Lake Powell within the year could be affected. Further, if annual release volumes were changed (such as by increasing or decreasing spills), carryover storage from one year to the next could be affected. Storage amounts in Lakes Powell and Mead are operationally tied together because the Long-Range Operating Criteria require storage equalization between the two reservoirs under certain conditions. Figure III-8 presents the end-of-month storage in the two reservoirs since 1963.

Since first reaching storage equalization with Lake Mead in 1974, Lake Powell has had two significant periods of drawdown due to drought—one beginning in 1976 and a more recent one that started in 1988. Lake Powell first filled in 1980 and, under historic and present operations, is not allowed to exceed 22.6 maf on January 1 to allow receiving spring inflows. A typical storage pattern is to draw the reservoir down beginning in July or August through February or March of the next water year. With spring inflow beginning in March or April, Lake Powell begins to rise to its maximum storage in June or July. During drought periods, its annual increase in storage is very slight or nonexistent.

Lake Mead is somewhat insulated against dramatic drawdowns due to drought because of the minimum annual release requirement from Lake Powell under the Long-Range Operating Criteria. Also, annual fluctuations at Lake Mead are smaller than those at Lake Powell. Storage in Lake Mead rises and falls as a result of scheduled releases from Lake Powell and Lake Mead releases to meet downstream demands or to comply with flood control regulations.

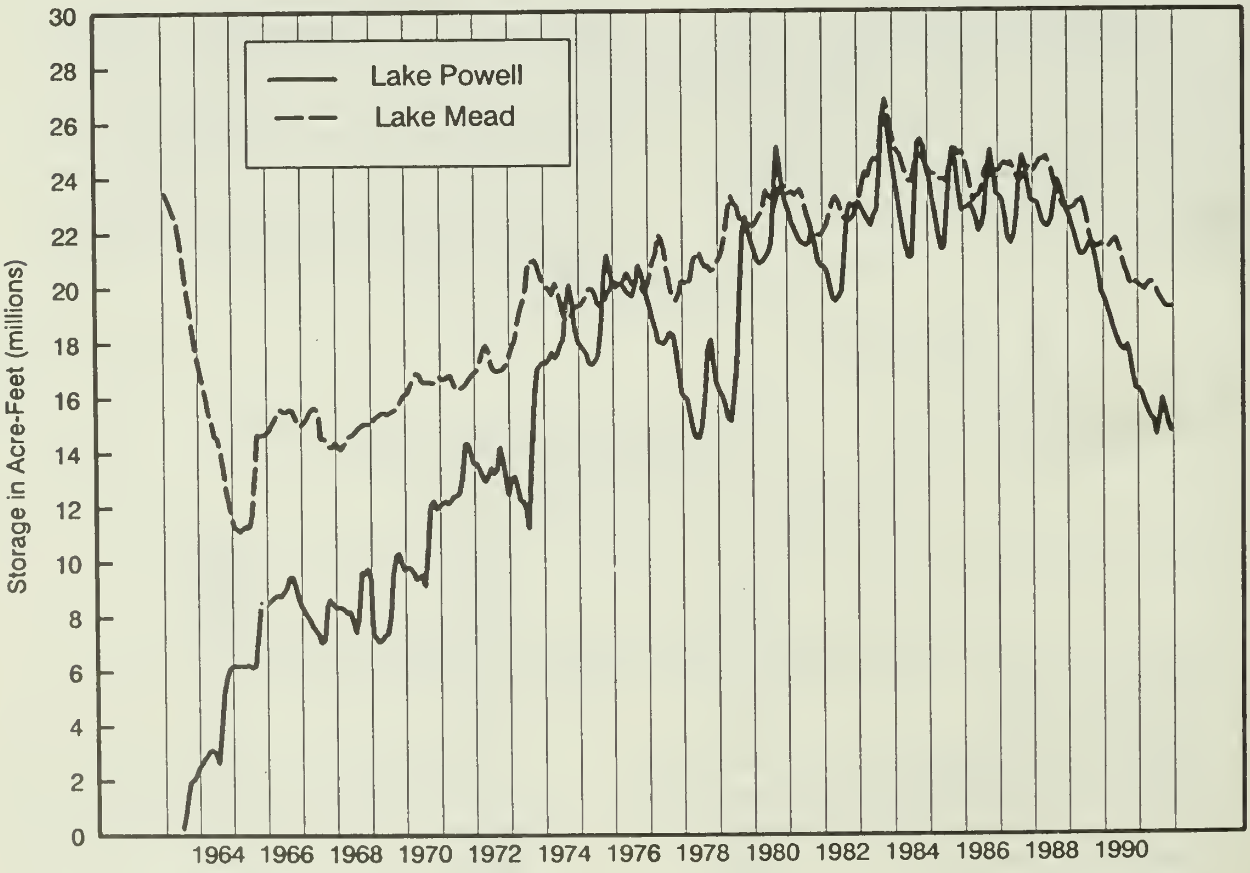


Figure III-8.—End-of-month storage in Lakes Powell and Mead since 1963.

Water Allocation Deliveries

Water allocation deliveries are the deliveries of Colorado River water to entities in the seven Colorado River Basin States and Mexico, in accordance with the "Law of the River."

In recent years, Lower Basin water demands have approached their 7.5-maf entitlement, thus requiring rationing and innovative solutions to anticipated future shortages. California's water use has been exceeding its 4.4-maf entitlement, until Arizona's capability to use its full 2.8 maf is developed. Lower Basin consumptive water uses and deliveries to Mexico for 1986 through 1991 are shown in table III-5.

The most recent official records of Upper Basin consumptive water use are contained in *Colorado River System Consumptive Uses and Losses Report, 1981-85* (Bureau of Reclamation, 1991e). The estimated uses in that document are presented in table III-6.

These historic and projected consumptive water uses are considered in the chapter IV analysis of alternatives. In that analysis, projected future water deliveries under each action alternative are analyzed and compared with projected future deliveries under historic operations.

Upper Basin Yield Determination

In 1988, a determination was made of water availability under long-term contracts for municipal and industrial uses from Navajo Reservoir on the San Juan River in New Mexico. This hydrologic determination required an

Table III-5.—Historic Colorado River consumptive water use, Lower Basin[1]
(in 1,000 acre-feet)

Year	Arizona	California	Nevada	Total	Mexico Basic	Mexico Excess[2]
Basic apportionment	2,800	4,400	300	7,500	1,500	—
1986	1,357	4,804	112	6,273	1,700	9,224
1987	1,734	4,891	109	6,734	1,700	3,044
1988	1,923	5,040	129	7,092	1,700	759
1989	2,230	5,144	156	7,530	1,500	228
1990	2,260	5,219	178	7,657	1,542	134
1991	1,864	5,006	180	7,050	1,521	141

[1] Published in accordance with the Supreme Court decree in Arizona vs California.
[2] Includes amounts ranging from 98,000 to 148,000 acre-feet per year pursuant to minute No. 242 of the Mexican Water Treaty.

Table III-6.—Colorado River consumptive water use, Upper Basin
(in 1,000 acre-feet)

Year	Arizona	Colorado	New Mexico	Utah	Wyoming	Total
Basic apportionment[1]	50	3,079.5	669.5	1,368	833	6,000
1981	42	2,086	342	782	341	3,551
1982	40	2,106	425	746	330	3,607
1983	42	1,920	426	718	346	3,410
1984	44	1,865	417	762	307	3,351
1985	44	1,994	401	879	336	3,610

[1] In accordance with 1988 hydrologic determination.

assessment of the total water depletion that can ultimately be allowed in the Upper Basin. The analysis is summarized in *Hydrologic determination, 1988, water availability from Navajo Reservoir and the Upper Colorado River Basin for use in New Mexico* (U.S. Department of the Interior, 1989).

The determination concluded that annual water depletion for the Upper Basin reasonably can be allowed to increase to 6 maf. The determination further certifies the availability of interim excess supplies of 69,000 acre-feet annually through year 2039 for marketing in New Mexico. Subsection (b) of article II of the Upper Colorado River Basin Compact permits New Mexico (or any other Upper Basin State) to use water in excess of its percentage allotment, provided such excess does not prohibit any of the remaining States from using their allotment.

Any reduction in the 6-maf determination (as a result of implementation of an alternative or otherwise) would cause a corresponding reduction in the 69,000 acre-feet determined to be available to New Mexico through 2039.

Water Quality

The study area for evaluation of water quality includes Lake Powell and the Colorado River and its tributaries between Glen Canyon Dam and the inflow area of Lake Mead. This section describes chemical, physical, and biological characteristics of the study area and their influence on river system water quality. More detailed information can be found in Appendix C, Water Quality.

Lake Powell

Lake Powell limnology—or water quality and aquatic ecology—is a story of change, both over years and seasons. Changes include:

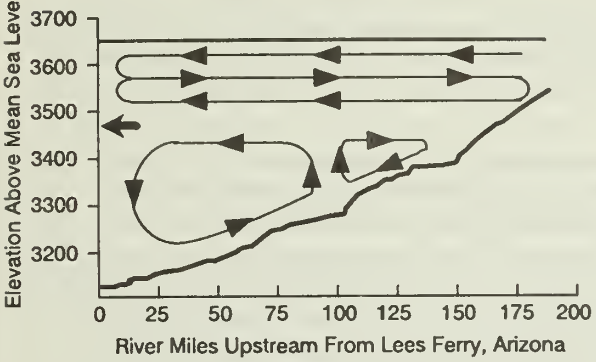
- The reservoir's stages of development, from initial filling to a full reservoir, and subsequent stages of drawdown and refilling
- Seasonal changes in climate
- Variable quality and quantity of reservoir inflow

Lake Powell was filling nearly continuously from 1963 until 1980. Through 1982, the reservoir periodically stratified into chemical layers through most of the year and thermal layers from spring through early fall. The depth of stratification was to about the penstocks. The reservoir completely filled and spilled for the first time in 1980 and remained full through 1987. Releases through the river outlets and spillways during the 1983-84 high flows helped flush out the reservoir and mix the layers, forestalling stratification for over a year. The major drought in the Southwest that began in 1987 caused the elevation of Lake Powell to drop over 80 feet from full pool between 1988 to 1992. Lake Powell has reestablished its stratifications, but winter vertical mixing has not been strong enough to mix as thoroughly.

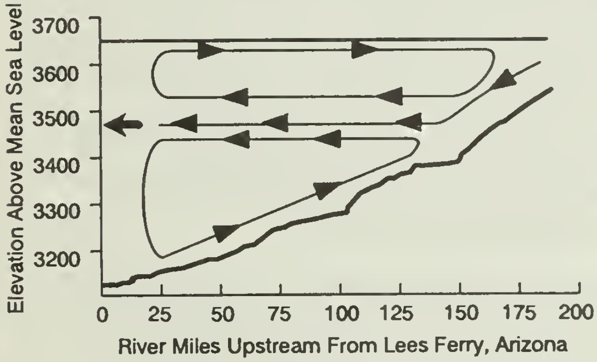
Long-term hydrologic cycles cause large changes in reservoir depth and volume which influence the vertical mixing, nutrient distribution, sedimentation patterns, and circulation in the reservoir.

Inflows. The Colorado River is the major tributary to Lake Powell, followed by the Green River—which joins the Colorado River upstream of Lake Powell—and the San Juan River. Together, the three tributaries contribute about 95 percent of the total reservoir inflow. Each tributary has a unique chemical, physical, and biological composition stemming from diverse basin geology, development, and seasonal and annual hydrologic variations, among other factors.

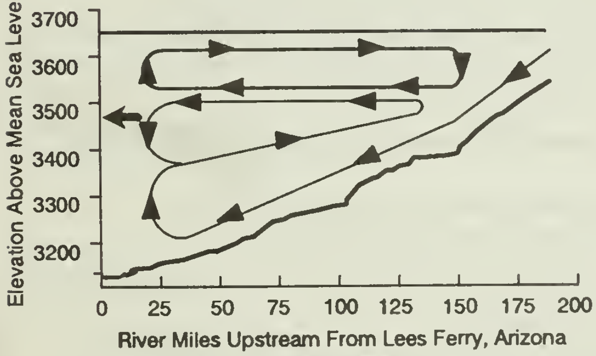
Three distinct seasonal inflows from the Colorado River form currents which travel in different ways through Lake Powell. Spring inflows are warm and less dense than the cold reservoir water, allowing the inflow to flow over the top of the reservoir surface. These inflows may reach the dam in 2 to 7 months, depending on the volume of water in the reservoir and amount of spring inflow. In contrast, winter inflows are cold and saline, so they are denser than reservoir water. Thus, winter inflows travel primarily along the bottom of Lake Powell, pushing oxygen-poor, saline water up toward the penstock intakes. Late summer inflows are intermediate in density and travel about mid-depth in Lake Powell. Figure III-9 illustrates these general current patterns.



April - July



Aug - Oct



Nov - Mar

Figure III-9.—Generalized seasonal circulation patterns in Lake Powell (modified from Merritt and Johnson, 1977).

When reservoir water is drawn through the penstock intakes at elevation 3470 feet—or about 230 feet below full pool—a withdrawal current forms, which further influences other currents in Lake Powell. The vertical extent of the withdrawal current increases with the amount of discharge and reaches a maximum of about 100 feet above and below the intakes (Johnson and Merritt, 1979). The intakes usually withdraw water from within the bottom layer of the lake, the hypolimnion, which is discussed later in greater detail.

Studies. Lake Powell limnology has been studied at various levels of detail since about 1968, providing a basic background of some limnological components and processes at particular stages of reservoir development. Reservoir fisheries have been studied in greatest detail. Since about 1972, Reclamation's water quality data collection program has focused on salinity and temperature; dissolved oxygen (DO), circulation, and other data also were collected. Recently, the Lake Powell Monitoring Program has been gathering data at more regular intervals. Short-term and single-event studies, often not conducted reservoir wide, have provided additional information on nutrients, plankton, sediment chemistry, and pH trace elements such as mercury, selenium, and lead. The U.S. Fish and Wildlife Service (FWS) also has collected fish samples for trace chemical analysis, and NPS conducts bacteriological studies in recreation areas for human health concerns.

Since data was not collected at regular intervals, limited comparisons may be made between seasons and years. Accordingly, general statements characterizing all components and processes of reservoir limnology and quantitative predictions of future changes cannot be made with confidence. In the absence of a complete data history, alternate means were used to assess past and future conditions, such as comparing the characteristics of Lake Powell with other reservoirs and lakes.

Temperature. Most of Lake Powell is extremely clear; sunlight penetrates to depths of 82 to 113 feet. Sunlight's ability to warm water decreases with depth, so Lake Powell is thermally stratified through much of the year. The epilimnion is the topmost and warmest layer, ranging from 30 to as much as 80 feet in depth (Johnson and Merritt, 1979). However, the thickness varies with seasons and location (Hammer and MacKichan, 1981). Summer temperatures in this layer reach about 80 °F, and winter temperatures may drop to 45 °F. Temperatures of 45 °F or less can be lethal to the threadfin shad. The metalimnion, or the middle layer, often ranges from 30 to as much as 80 feet in depth. Here sunlight is limited, and water temperatures decrease with depth. The hypolimnion, or bottom layer, is too deep for sunlight to reach, and water temperatures remain nearly constant at about 46 °F. This uneven heat distribution also creates circulation in the reservoir.

Nutrients. Most of the incoming nutrients to Lake Powell are associated with or attached to sediments. Lake Powell retains over 97 percent of the inflowing phosphorus, primarily with sediments (Miller et al., 1983). Algae cannot readily consume nutrients attached to sediments. Nutrient concentrations near the surface are highest during June and July, stimulating growth of plankton. As plankton populations grow, the nutrient supply diminishes. Typically, planktonic algal blooms occur in the summer, mainly in shallow, sunny inflow areas where tributaries enter the reservoir carrying nutrient-rich sediments.

Other Characteristics. Other water quality characteristics also vary with reservoir depth. Atmospheric reaeration and wind-induced mixing of reservoir water is limited to the epilimnion, thus restricting reaeration of deeper water throughout the summer. The shallow epilimnion is generally well-oxygenated, averaging over 8 milligrams per liter (mg/L). DO concentrations in the metalimnion may range between 5 and 10 mg/L, except when associated with the summer development of the minimum DO layer, described below. Concentrations of DO deep in the hypolimnion can be as low as 2 to 3 mg/L, and overall water quality remains nearly constant in this layer. Salinity, nutrients, selenium, and mercury concentrations are highest in the hypolimnion and lowest in the epilimnion.

A DO minimum layer periodically develops in the metalimnion between 45 to 60 feet below the reservoir surface during the summer with concentrations as low as 2 mg/L (Johnson and Page, 1981). Its formation results from DO consumption by algae, bacteria, zooplankton, fish respiration, and the chemical processes of organic decay. The DO minimum layer typically begins forming in tributary inflow bays and may extend over most of the reservoir by September.

A water quality inventory conducted for Lake Powell analyzed tributary delta sediments and surface and bottom waters for lead, mercury, selenium, and other trace elements primarily associated with sediments (Kidd and Potter, 1978). This study concluded that Lake Powell traps most of the elements investigated, except lead. More dissolved lead left the reservoir than came in, attributable to gas spills from boating. Based on a limited number of samples, results indicated higher concentrations of mercury and selenium in Lake Powell sediment than the combined tributary sediments. Mercury and selenium occur naturally in the Colorado River Basin and accumulate in tissues of living organisms in the lake (Wood and Kimball, 1987).

Lake Powell also traps sediment. It is estimated that within about 300 to 500 years, sediment will fill the reservoir to near the elevation of the penstocks. As the lake fills with sediment, the reservoir will shrink—affecting changes in temperature distribution, DO and nutrient content, circulation, plankton communities, and other reservoir components.

Colorado River Below Glen Canyon Dam

Two major influences on Lake Powell and downstream water quality are:

- Reservoir elevation (the amount of water in Lake Powell)
- The intake level where water is withdrawn

The intakes withdraw water mostly from the hypolimnion when Lake Powell's elevation is above about 3590 feet. As Lake Powell is drawn down (below 3590 feet), the reservoir surface drops, and water may be withdrawn from the metalimnion and epilimnion, where reservoir water differs in quality.

Most of Lake Powell's influences on the Colorado River below the dam center on flow, sediment, and water quality. Reservoir releases have changed variation and magnitude of downstream riverflow, turbidity, temperature, salinity, nutrients, and other water quality characteristics. Below the dam, both temperature and salinity change little with the seasons. Salinity fluctuations downstream now vary less over several years than the predam cycles changed in months. Downstream salinity is of major economic significance to water users in the Lower Colorado River Basin because high salinity causes problems, such as damage to irrigated crops.

River temperatures at Lees Ferry are inversely related to Lake Powell water surface elevations. Releases from Glen Canyon Dam have ranged between 43 and 54 °F and average about 46 °F. River temperatures increase slowly downstream of the dam but seldom exceed 60 °F at Diamond Creek, about 240 miles downstream (Sartoris, 1990). The greatest warming occurs during June through August. The average river temperature below the dam is about 55 °F, and actual river temperatures have deviated very little in recent years (Sartoris, 1990). As the reservoir surface elevation falls below 3590 feet, release temperatures, and thus river temperatures, begin to rise measurably.

DO concentrations below Glen Canyon Dam range from approximately 6 mg/L in the winter to 9 mg/L in the summer. Concentrations generally increase slightly with distance downstream, depending on the season.

SEDIMENT

> *Sediment is literally the foundation of the riparian environment and recreation along the Colorado River in Grand Canyon National Park.* (U.S. Department of the Interior, 1988, page A-7.)

In this EIS, sediment is defined as unconsolidated material derived from weathering of rock and transported and deposited by water or wind. Although occasionally used synonymously with "sand," the term "sediment" generally refers to the full range of sediment sizes found in Grand Canyon.

Glen Canyon Dam has caused three major changes related to sediment resources downstream in Glen and Grand Canyons. The first is reduced sediment supply. Because the dam traps virtually all of the incoming sediment in Lake Powell, the Colorado River—which once flowed red from high concentrations of sediment from the Upper Basin—is now released as clear water from Glen Canyon Dam. The second major change caused by the dam is reduced capacity of the Colorado River to transport sand and other sediment. The natural peak flows that occurred annually prior to dam construction had a tremendous capacity to transport sediment. Maximum releases from the dam are substantially less than those historic annual peak flows. The third major change is the reduction in the high water zone from the level of predam annual floods to the level of powerplant releases. Thus, the height of annual deposition and erosion of sediment has been reduced.

Through the scoping process, the public identified sediment and beaches as major issues of concern. The following categories of sediment resources are affected in some way by the dam and its operation; some also are affected by natural processes or human use:

- Riverbed sand
- Sandbars (beaches and backwaters)
- High terraces
- Debris fans and rapids
- Lake deltas

Background

Sediment along the Colorado River below Glen Canyon Dam is an important and dynamic resource. Many of the other resources discussed in this EIS depend on sediment to varying degrees.

Although some sediment is derived from the canyon walls, most sediment enters the regulated Colorado River from the tributaries downstream from Lake Powell. Through complex processes, sediment in the river is transported, deposited, and eroded again for further transport. The quantity of sediment in motion at a given time and location depends on the amount and particle size of sediment available, the dimensions and slope of the channel, and the magnitude of flow.

Sediment-dependent resources in Grand Canyon can be related to four general size classes of sediment particles:

- Silts and clays (finer than 0.062 millimeter (mm))
- Sand (0.062 mm to 2 mm)
- Gravels and cobbles (2 mm to 256 mm)
- Boulders (greater than 256 mm)

Sediment transport and deposition varies with particle size. Silts and clays are easily transported and generally pass through the system in a relatively short time, although some may be deposited in low velocity areas on sandbars and in backwaters. Silt- and clay-sized particles provide important nutrients for vegetation, and clay also provides cohesion for deposits of coarser sediment.

The most abundant sediment size class found along the river is sand. Many sandbars are used as campsites by boaters and are substrate for vegetation and wildlife habitat. Next in size are the gravels and cobbles, which—together with small boulders—armor the streambed in some places. Some fish species use shallow gravel beds for spawning.

The largest particles are boulders, some larger than automobiles, which fall from the canyon walls or reach the river in debris flows from steep tributary canyons. Boulders create and modify most of the major rapids and are a major factor in the creation of sandbars. Although its riverbed is bedrock in some places, the Colorado River generally is a cobble- and gravel-bed stream, through which sand is transported. Sand is stored throughout Grand Canyon in "patches" on the riverbed and in eddies.

The river's capacity to transport sediment increases exponentially with the amount of water flowing in the river. All sediment particles weigh more than water, so they tend to settle to the bottom. The turbulence of flowing water is the uplifting force that causes sediment particles to be carried in suspension or roll along the streambed. The greater the river's flow, the greater the velocity and the greater the turbulence. Clay and silt particles commonly are carried in suspension by nearly all dam releases. Flows in the river often are large enough to carry sand grains in suspension or to roll them along the riverbed, depositing the grains temporarily in areas where water velocity is insufficient to move them. Even larger flows and velocities are needed to move gravel and cobbles. The largest boulders remain in place for decades or more, awaiting the rare flood large enough to move them short distances along the riverbed.

Riverbed Sand

The decreased annual peak flows reduced the river's capacity to transport sand (figure III-10). Measured suspended sediment loads (sand, silt, and clay) at Phantom Ranch averaged 85.9 million tons per year during 1941-57. Since construction of Glen Canyon Dam, this average has been reduced to an estimated 11 million tons per year, approximately 70 percent of which comes from the Paria River and the LCR. Together these rivers have delivered an average of 12 million tons per year of sediment to Grand Canyon since 1941 (Andrews, 1991a).

Most of the sediment delivered to and transported by the Colorado River is silt and clay. Because these finer particles can be carried in suspension by most dam releases, the quantity of silt and clay transported depends mainly on tributary supply. Although sandbars along the banks of the Colorado River contain some silt and clay, their existence primarily depends on the transport of sand.

As bed-material load (mainly sand and gravel) enters the Colorado River from the tributaries, it begins the long and slow journey to Lake Mead. During the course of this journey, sand particles may go through numerous cycles of temporary deposition and transport. The riverbed is made up of bedrock, boulders, cobbles, gravel, and sand. The location of these materials depends on the local geology, river velocity, and the supply of incoming sediment. The riverbed is highly

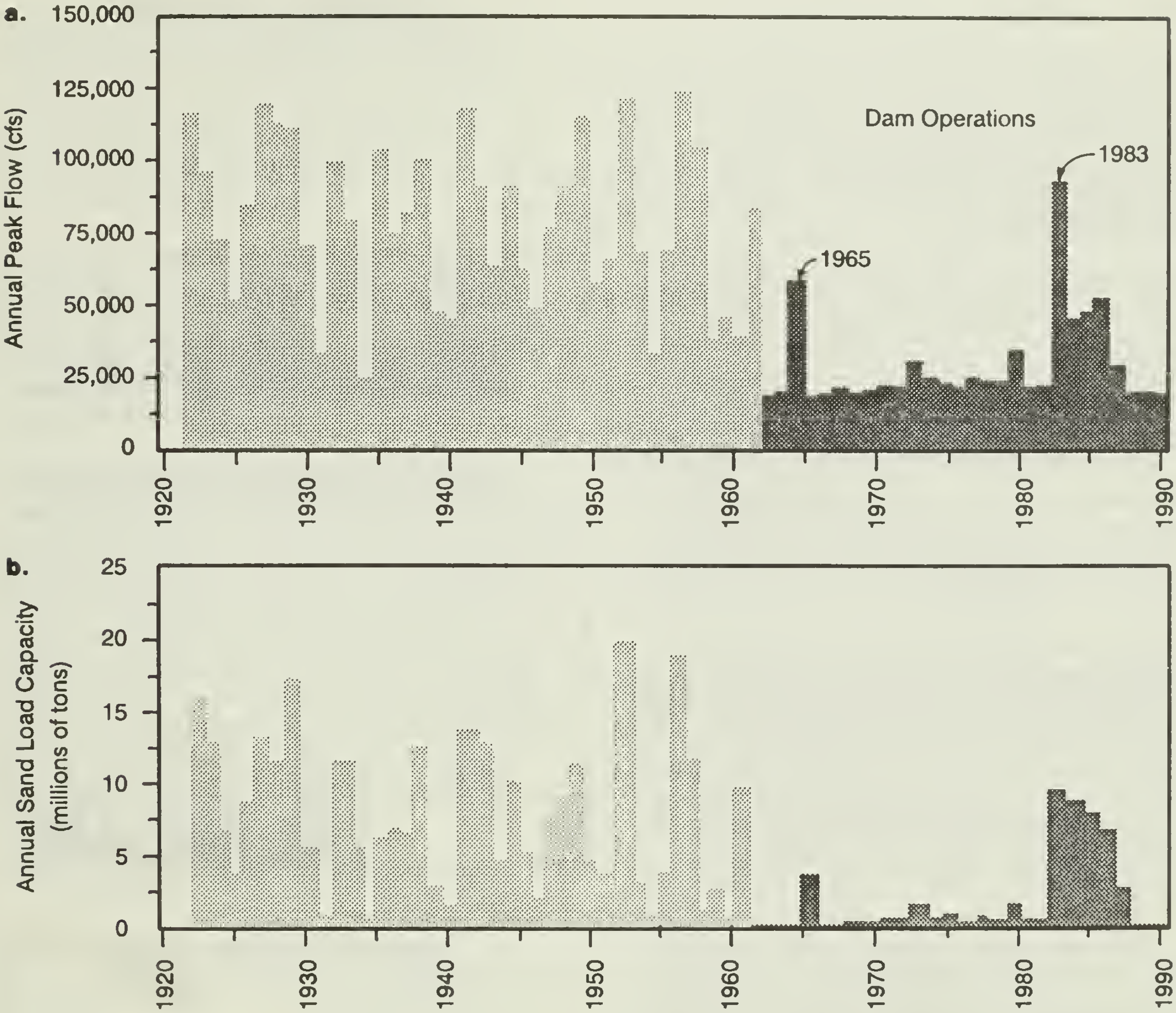


Figure III-10.—Annual peak flows (a) and estimated sand transport capacity (b) for the Colorado River at Lees Ferry from 1922 to 1990, both of which have been substantially reduced since dam closure. Sand transport capacity was estimated from an accumulation of daily sand loads. Daily loads (both predam and postdam) were determined from mean daily flow at Lees Ferry, using the Pemberton (1987) sand load equation for Phantom Ranch. Actual predam loads may have been greater than those computed, and actual postdam loads much smaller than computed. Postdam transport capacity at Lees Ferry is much greater than sand supply.

irregular and contains many deep pools, rapids, and eddies, where sands, gravels, and cobbles are stored during periods of low discharge.

Because of reduced capacity to transport sand, the Colorado River now can store more sand and larger-sized sediments in low velocity areas. The amount of sand stored within the riverbed each year depends on the tributary sand supply (which is highly variable), the pattern of water release, and the amount stored at the beginning of the year. Sand stored on the riverbed is the principal source for building sandbars during periods of high releases. The probability of net increase in sand stored in the river channel is used as an indicator of impacts of the alternatives.

Delivery to the Colorado River

The quantity of sand stored in a given reach—and thus available for deposition on sandbars—depends upon the supply of sand from the upstream channel and tributaries and the rate at which sand is removed from the reach by transport downstream.

Many tributaries supply sediment, including sand, to the Colorado River downstream from Glen Canyon Dam. The Paria and LCR are estimated to supply over 70 percent of the total sediment (sand, silt, and clay) entering Grand Canyon. Other tributaries typically deliver sediment during flash floods or debris flows. There are no tributaries that deliver substantial quantities of sediment between the dam and the Paria River, although sediment occasionally is delivered to that reach by side-canyon flash floods.

Gauged Tributaries. Sediment contribution from the Paria and Little Colorado Rivers and Kanab Creek, estimated at USGS gauging stations, varies greatly from year to year (see figure III-11) but generally has decreased in the 20th century. Sand delivery is subject to long-term climate variations that affect sediment storage in the flood plains of these streams (Hereford and Webb, 1992; Graf et al., 1991).

In spite of the reduced sand-transport capacity of the Colorado River, there has been a net decrease in sand storage between the dam (RM -15.5) and the LCR (RM 61) since closure of the dam. Most of the decrease has occurred since the floods of 1983-86. Also, annual sand deliveries from the Paria River (RM 1) have been below average since 1980 (figure III-11; also see Graf et al., 1991). Downstream from the LCR, there has been a net increase in sand storage.

Under normal fluctuating flows, a long-term sand balance is likely downstream from the LCR but may not be achieved upstream. Smilie, Jackson, and Tucker (1993) analyzed the frequency of annual sand delivery from the Paria River (1949-76) in relation to Colorado River transport capacity. Their results for a minimum release year (8.23 maf) suggest that, when the range in daily flow fluctuations exceed about 18,000 cfs on an annual basis, transport capacity exceeds the

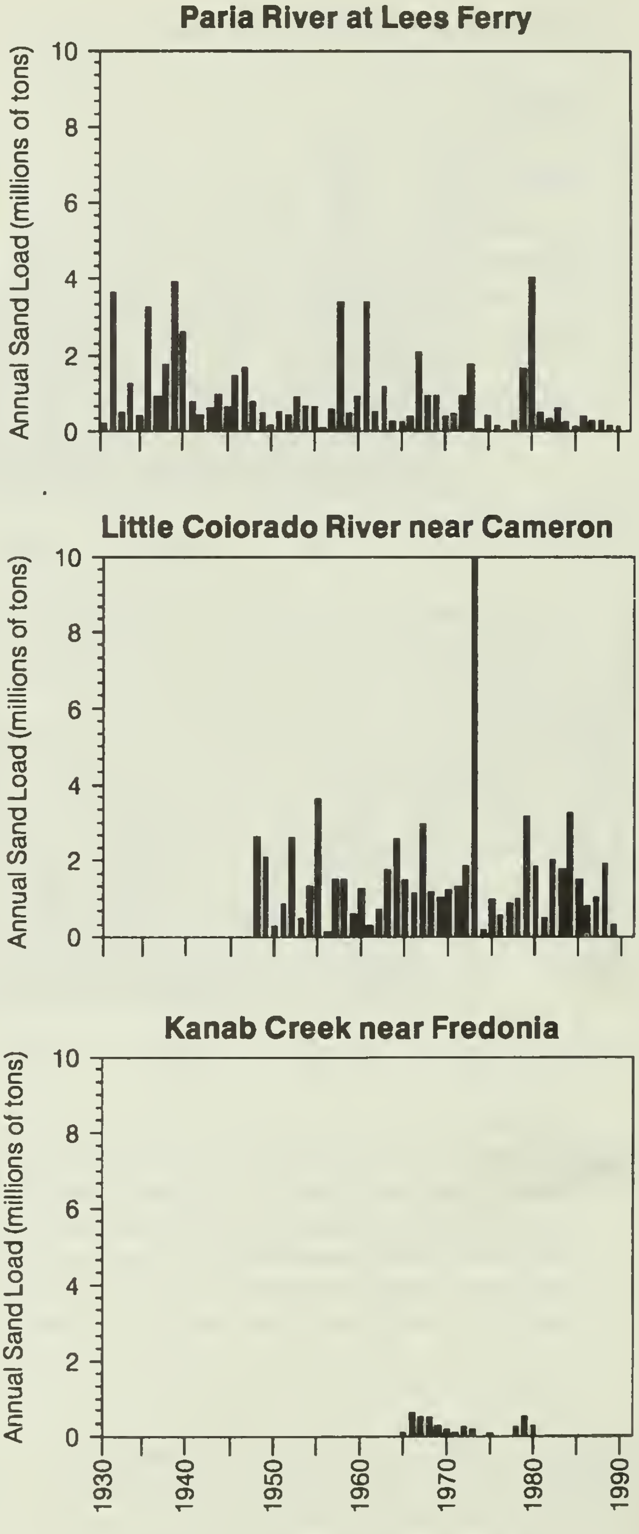


Figure III-11.—Annual sand contributions from the Paria River, Little Colorado River, and Kanab Creek. Computed from mean daily flows, using sand load equations of Randle and Pemberton (1987).

long-term supply from the Paria River (about 790,000 tons) in the reach between the Paria River and LCR . Even when transport capacity and long-term sand supply are in balance, however, there would be periods of fairly substantial short-term losses and gains in sand storage between the Paria River and LCR.

Ungauged Tributaries. Smaller tributary canyons typically form along faults or joints in the rocks (Dolan et al., 1978). Much of the sand and coarser debris (gravel, cobbles, and boulders) from these ephemeral tributaries is delivered to the river by debris flows and flash floods.

The quantity of sand supplied from ungauged tributaries is not well known and is difficult to estimate due to the variability of debris flows and flash floods. However, Randle and Pemberton (1987) made a rough estimate of 0.7 million tons per year based on the relationship between drainage area and sediment yield derived for the semiarid United States. The long-term cumulative average annual sand delivery from all tributaries, gauged and ungauged, is shown in figure III-12. The amounts are listed by reach in appendix D, table D-1.

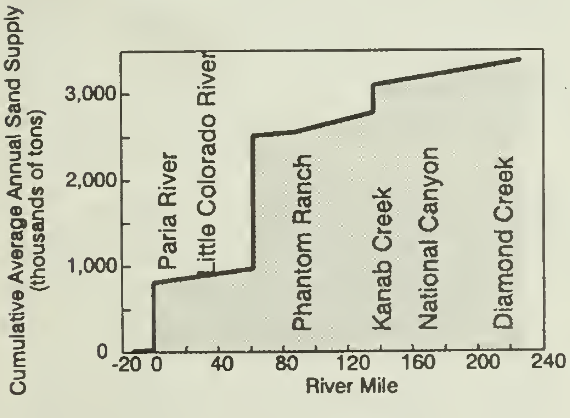


Figure III-12.—Cumulative sand supply increases with river mile, with large increases at the confluences of the Paria and Little Colorado Rivers.

The occurrence and size of both debris flows and flash floods are influenced by geologic and geomorphic conditions within the watershed and prior history of flows, as well as by rainfall amount and intensity. For example, Havasu Creek has not had a debris flow in recent geologic time, but it had a spectacularly destructive flash flood in September 1990. Slope failures in the steep tributary valleys commonly trigger debris flows. Geologic conditions favor- able for debris flows from side canyons vary throughout Grand Canyon. Therefore, the potential for sand delivery from these tributaries to the river also varies throughout the canyon (Webb et al., 1989).

The major points concerning sediment delivered to the Colorado River by ungauged tributaries are summarized below (Webb and Melis, written communication, 1992).

- Flash floods, including debris flows, periodically occur in about 500 tributaries of the Colorado River in Grand Canyon.

- On the average, debris flows occur once in 30 to 50 years for any given tributary. This occurrence can range from once in 10 years to once in more than a century.

- Debris flows are initiated by high-intensity precipitation and failure of either bedrock or rock fragments that accumulate on steep slopes or at the foot of cliffs.

- Debris flows in Grand Canyon are high-magnitude, short duration events. They contain an average of 20 to 30 percent sand and are capable of transporting extremely large boulders into the Colorado River.

- The 500 tributaries are sources of sand to replenish sandbars in Grand Canyon.

- Debris flows create and maintain the rapids that are the hydraulic controls of the Colorado River. They also control the sizes and locations of eddies.

- Tributary flash floods, including debris flows, have directly affected numerous sandbars. Some flash floods completely erode sandbars, while debris flows may cover sandbars with gravel, cobbles, and boulders.

Main Channel Transport and Storage

Sand transport capacity of the Colorado River is the amount of sand that the river could transport if sufficient sand were available. The amount of sand actually transported (sand load), therefore, may be less than the transport capacity, which mainly depends on the velocity of the water. Velocity, in turn, varies with riverflow and local channel characteristics. For a given riverflow, velocities—therefore, transport capacities—are greater in narrower, steeper reaches than in wider, flatter reaches. Narrow and wide reaches alternate throughout the length of the canyon (table III-7 and figure III-13). Where the rocks are very resistant to erosion, the river flows between the rock walls of a narrow gorge. Where the rocks are more easily eroded, the river has a relatively wide channel bounded by deposits of sand, gravel, and cobbles.

The narrowest, steepest, and shallowest places of all are the rapids, which account for about 90 percent of the river elevation drop through the canyon but only about 10 percent of the length (Leopold, 1969). Water velocities typically are

Table III-7.—Hydraulic characteristics of geologic reaches within Grand Canyon (modified from Schmidt and Graf, 1990)

Reach number	River miles[1]	Reach name	Width type	Average channel width[2] (feet)	Average depth[2] (feet)	Channel slope[3] (feet per mile)	Percentage of bed composed of bedrock and boulders[4]
0	-15.5–0	Glen Canyon	Wide	450	27	1.4	>80
1	0–11.3	Permian Section	Wide	280	24	5.2	42
2	11.3–22.6	Supai Gorge	Narrow	210	27	7.4	81
3	22.6–36	Redwall Gorge	Narrow	220	24	7.9	72
4	36–61.5	Lower Marble Canyon	Wide	350	18	5.3	36
5	61.5–77.4	Furnace Flats	Wide	390	15	11.1	30
6	77.4–117.8	Upper Granite Gorge	Narrow	190	27	12.1	62
7	117.8–125.5	Aisles	Narrow	230	21	9.0	48
8	125.5–140	Middle Granite Gorge	Narrow	210	26	10.6	68
9	140–160	Muav Gorge	Narrow	180	23	6.3	78
10	160–213.8	Lower Canyon	Wide	310	19	6.9	32
11	[5]213.8–236	Lower Granite Gorge	Narrow	240	30	8.4	58
12	236–278	Lake Mead			[No data]		

[1] See figure III-13.
[2] Average of cross-section data at about 1-mile intervals at 24,000 cfs (Randle and Pemberton, 1987).
[3] Based on predicted water-surface elevations at 24,000 cfs (Randle and Pemberton, 1987).
[4] From channel-bed material maps (Wilson, written communication,1987).
[5] Results from miles 213.9–225.

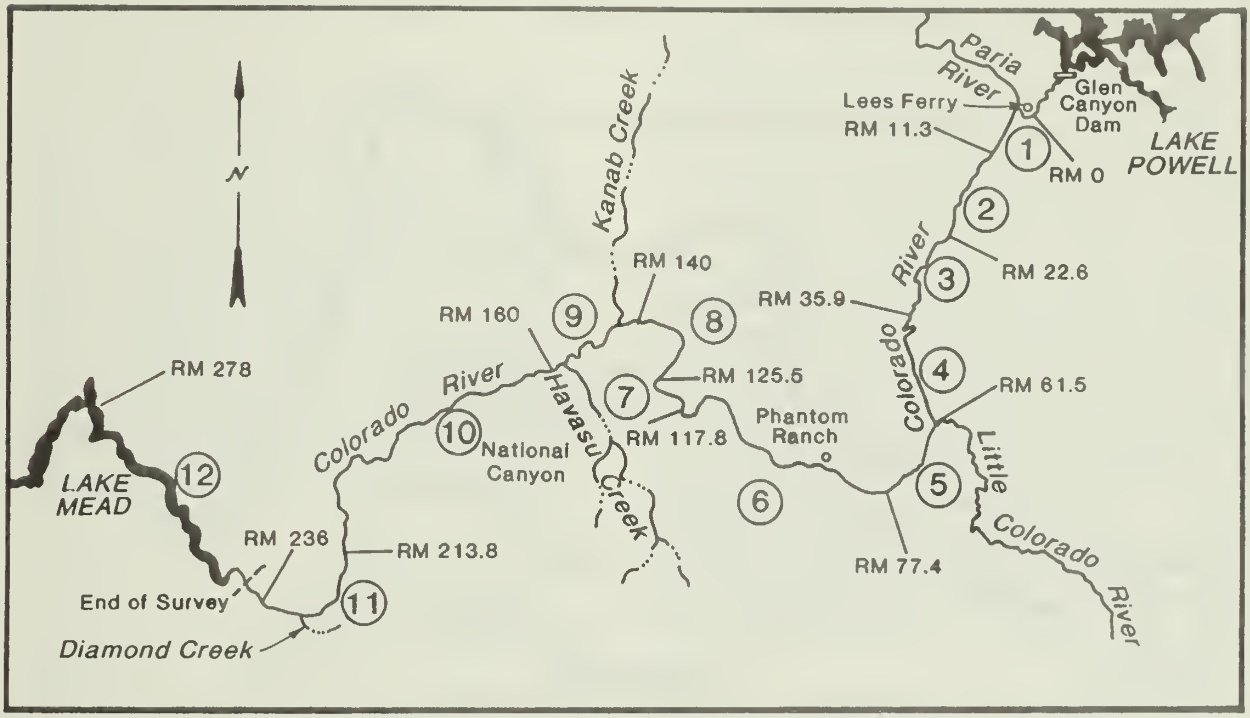


Figure III-13.—Geologic reaches within Grand Canyon (modified from Schmidt and Graf, 1990). Reach characteristics are listed in table III-7.

10 times greater in the largest rapids than in the long pools that extend upstream from the rapids (Kieffer, 1988, 1990). Thus, while nearly all sediment particles but the largest boulders can be transported quickly through high velocity rapids, much of the sand is stored temporarily in low velocity pools and eddies.

Essentially all sand in the main channel between Glen Canyon Dam and Lees Ferry was deposited before the dam was closed. Since closure, the channel has degraded (Pemberton, 1976; Burkham, 1987). Loss of sand from this reach is irreversible without artificial resupply of sand, because contribution from tributaries is very small, and transport capacity of the river is large.

During the initial filling of Lake Powell, sand scoured upstream from Lees Ferry and sand contributed by tributaries downstream from Lees Ferry accumulated in the river channel. The cumulative storage of sand between Lees Ferry and Phantom Ranch, shown in figure III-14, was calculated as the sum of computed inputs from the Paria and Little Colorado Rivers minus the computed transport past the Phantom Ranch gauge. The sand transport equations of Randle and Pemberton (1987) and Pemberton (1987) were used for these computations. The high flows of 1983-86 removed most of the sand that had accumulated during Lake Powell filling. Most of this sand was transported downstream to Lake Mead. Some sandbars within Grand Canyon aggraded as much as 10 feet, while others eroded—some substantially.

The amount of stored sand available for transport, therefore, depends on both preceding flow and sand delivery, as indicated by bed elevation. Before Glen Canyon Dam was constructed, bed elevation in pools decreased as sand and gravel were scoured from the bed during annual snowmelt runoff. Sand and gravel were deposited during lower flows at other times of the year, increasing bed elevation (Burkham, 1987). Burkham reported that bed elevation in pools

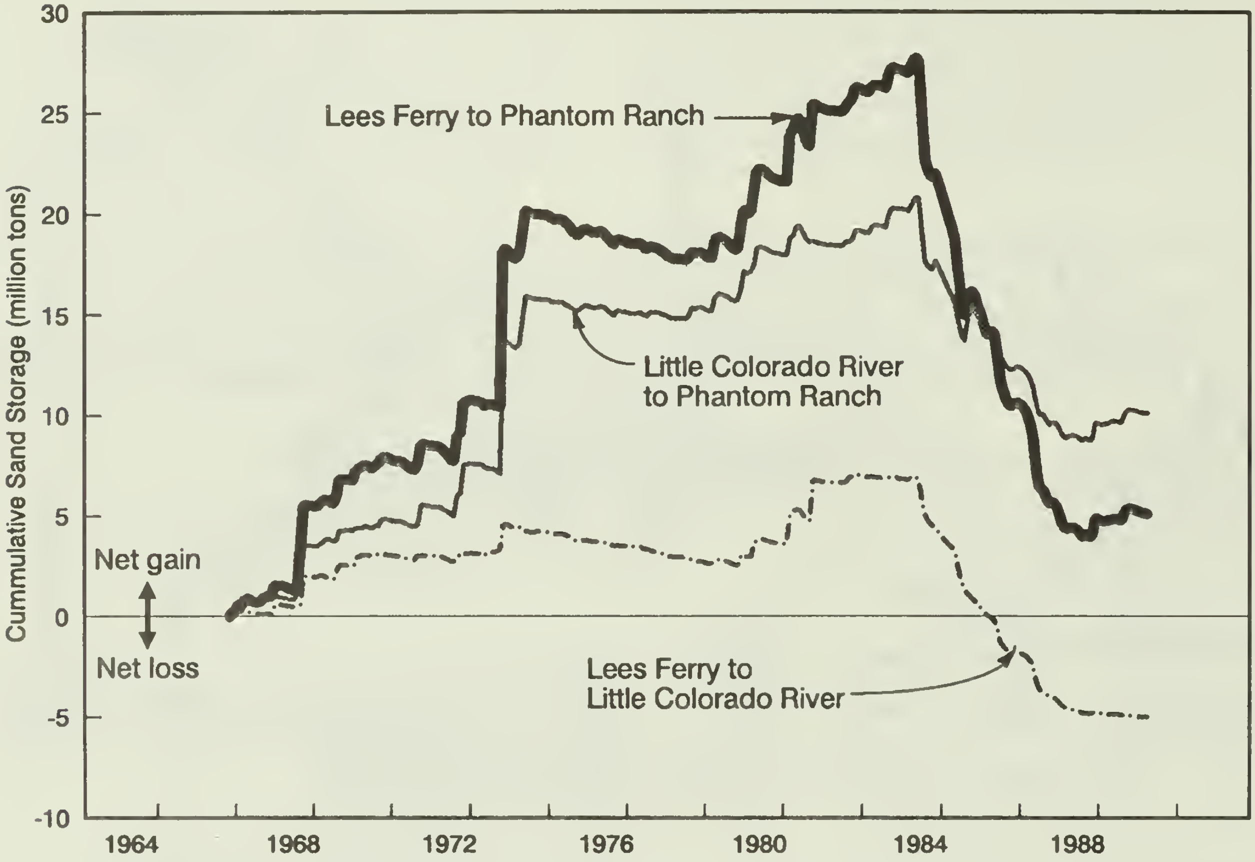


Figure III-14.—Cumulative sand storage between Lees Ferry and Phantom Ranch. Sand accumulated in the river during the relatively low releases while Lake Powell was filling, coupled with large sand contributions from the Paria and Little Colorado Rivers in 1972, 1979, and 1980. Sand was eroded from the channel during the 1983-86 high water years. Computation method is described in text.

before flow regulation changed as much as 30 feet annually at the USGS gauging station at Lees Ferry and as much as 8 feet at the gauge near Phantom Ranch. Daily discharges of 40,000 to 60,000 cfs for more than 40 days in 1965 degraded the bed at Lees Ferry about 27 feet. Because there is essentially no supply of sand and gravel from upstream, the bed has not aggraded since then. It would take an estimated 70,000-cfs flow to initiate further degradation at this site (U.S. Department of the Interior, 1988).

Degradation (scouring) of the riverbed in some places, such as at the Lees Ferry gauging station, is self-limiting by a progressive decrease in velocity and a corresponding increase in the size of bed material (Burkham, 1987). As degradation progresses and velocity decreases, bed material coarsens (Randle and Pemberton, 1987). Eventually, the bed material may become so coarse that flow is no longer capable of moving it, so degradation stops. This process, called armoring, has happened in the Glen Canyon reach (Pemberton, 1976).

If the supply of sand is sufficient, the amount transported by the river is exponentially proportional to the riverflow (i.e., the rate of increase in sand load is much greater than the rate of increase in flow). Fluctuating flows, therefore, will transport more sediment than steady flows of the same volume, because the fluctuating flows are higher than steady flows during part of each day. As the wave shape changes downstream (see WATER in this chapter), sediment transport capacity is reduced.

Computed sand loads at the gauge above the LCR for steady and fluctuating water releases of the same volume for 1 day are compared in figure III-15. Computed sand loads are based on the river's transport capacity. Actual sand loads may be smaller than computed loads when the tributary supply is less than transport capacity. As the bed elevation continues to increase, the annual transport through Grand Canyon will approach the amount delivered annually by tributaries. The sand that accumulates during low release years may be available to build sandbars during periods of sufficiently high discharge.

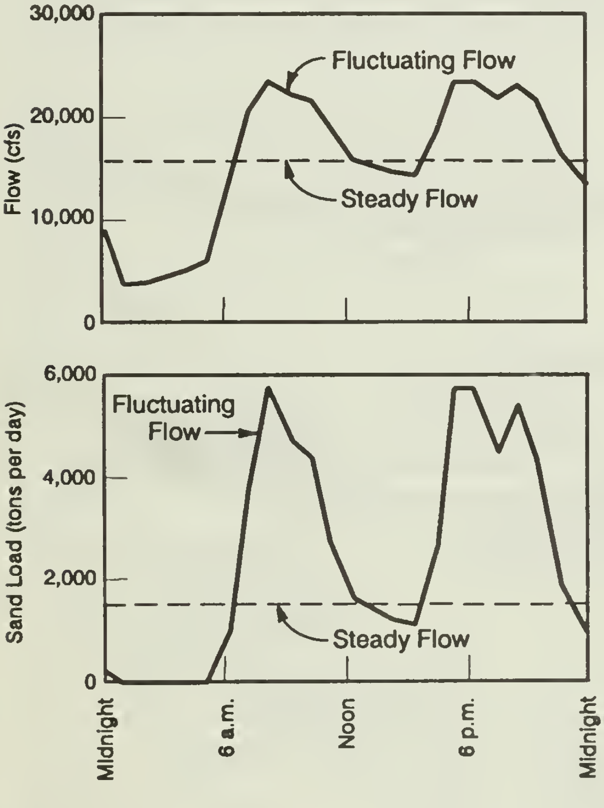


Figure III-15.—Comparison of riverflow and computed sand load at the gauge above the LCR under steady and fluctuating flows within a 24-hour period. Cumulative sand loads in this example are 1,500 tons for the steady flow and 2,500 tons for the fluctuating flow. At Phantom Ranch, the cumulative loads increased to 3,100 tons for the steady flow and 5,100 tons for the fluctuating flow.

Sandbars (Beaches and Backwaters)

Sandbars commonly found along the banks of the Colorado River in Grand Canyon are dynamic. Sandbars are derived from sediment transported by the river and exchange sediment with the river. These bars are composed mainly of sand; however, they may contain some silt, clay, or gravel. In this EIS, the term "sandbar" is used to mean any of the fine-grained alluvial deposits that intermittently form the banks of this otherwise talus- and bedrock-lined river. A greater number of sandbars used as campsites exists in wider reaches than in narrower reaches (U.S. Department of the Interior, 1988; Kearsley and Warren, 1992). Sandbars are important for vegetation, riparian habitat for fish and wildlife, and recreation. Beaches are sandbars that have recreational value. Backwaters are low velocity areas formed by low elevation sandbars and may be important for fish.

Sandbar deposition and erosion, both predam and postdam, are natural processes. Rates and amounts of deposition and erosion vary with:

- Flow magnitude and duration
- Tributary sediment supply
- Amount of sand stored in river channel pools and in eddies
- Local channel hydraulics

The pattern of sandbar deposition and erosion has been altered by Glen Canyon Dam. Before completion of the dam in 1963, sandbars in Glen and Grand Canyons were aggraded and eroded cyclically by seasonal and long-term variation in flow and sediment transport (U.S. Department of the Interior, 1988; Howard and Dolan, 1981). During 1965-82 (following the flood release of 1965), high elevation sandbars generally eroded, and low elevation bars generally aggraded; erosion rates decreased with time (Schmidt, written communication, 1992). During the floods and prolonged high releases of 1983-86, sand was deposited on higher sandbars but removed from lower bars. Generally, high rates of erosion were observed during the nearly steady high releases and during the return to normal fluctuating releases between October 1985 and January 1986 (Schmidt and Graf, 1990). Between 1987 and 1991, aggradation and erosion patterns were similar to those of 1965-82, but erosion rates were greater (Schmidt, written communication, 1992).

Since implementation of interim flows, sandbars have cyclically aggraded and eroded, with negligible net change overall (Beus and Avery, written communication, 1992). Also, sandbars between the 20,000- and 30,000-cfs levels have eroded and not been rebuilt, riparian vegetation is encroaching into the 20,000-30,000-cfs zone, and backwater habitats have filled with silt (Patten, written communi- cation, 1993).

Recirculation Zones (Eddies)

Nearly all sandbars in Grand Canyon are associated with recirculation zones that consist of one or more eddies. As the river flows around an obstruction, such as protruding bedrock or a debris fan, the flow becomes constricted, and the downstream-directed current becomes separated from the riverbank (figure III-16). Downstream from the constriction, the channel is wider, the main current reattaches to the riverbank, and some of the water is redirected upstream. This change in flow direction forms a zone of recirculating water and sand between the points of separation and reattachment and between the main channel and the riverbank. The location of the reattachment point and length of the recirculation zone vary with riverflow. The recirculation zone lengthens with increasing discharge and shortens with decreasing discharge.

There is great potential for sand deposition within a recirculation zone, where water velocities are much lower than velocities in the main channel

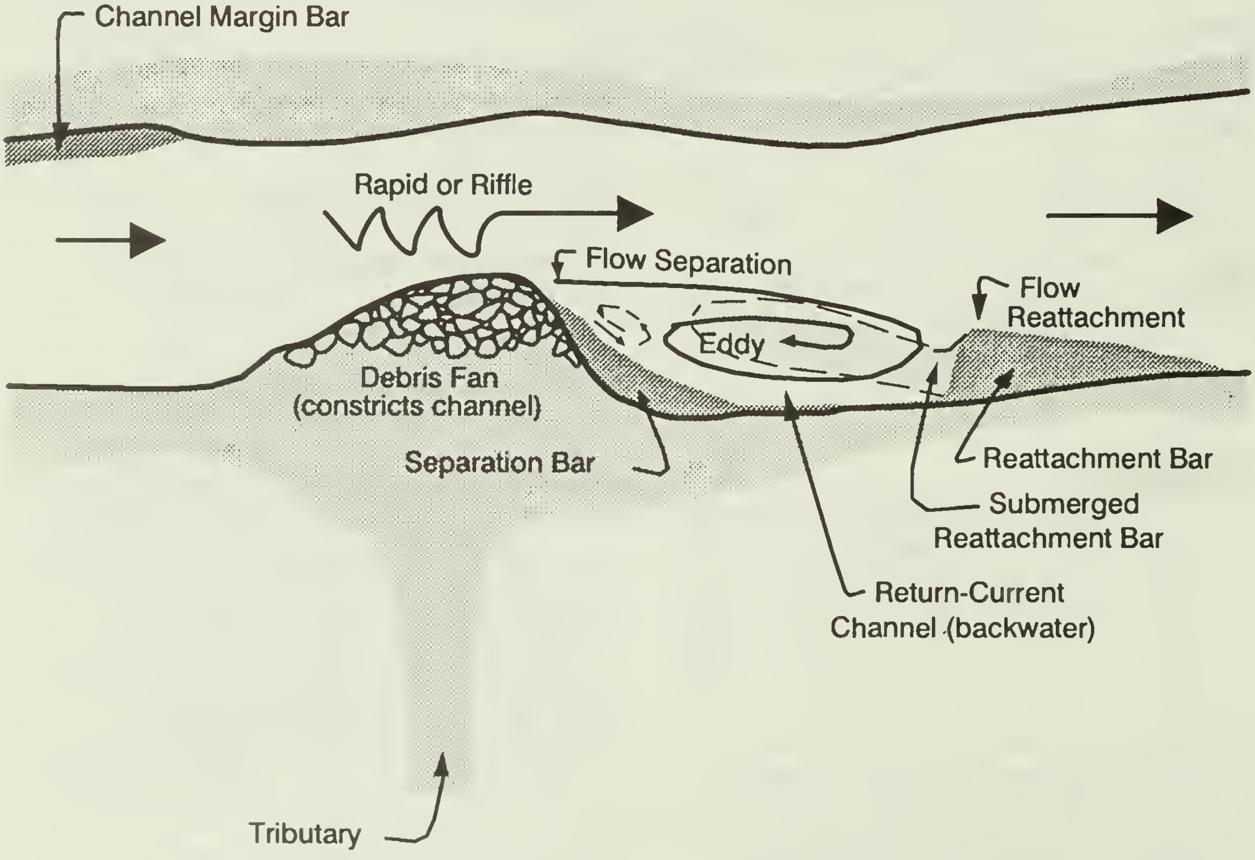


Figure III-16.—Relationship of sandbars and flow patterns. Riverflow is constricted in a rapid, causing an eddy downstream. Sediment is suspended in the highly turbulent currents of the rapid and deposited on bars associated with the relatively tranquil currents of the eddy.

(Schmidt, 1990). Figure III-17 shows that water with relatively high sand concentration moves into the eddy near the streambed, and water with relatively low sand concentration moves out of the eddy near the surface (Nelson, 1991). Sandbars form in low velocity areas at the downstream and upstream ends of the recirculation zone. These bars usually are continuous deposits, although the return-current channel connecting them may be submerged at most riverflows. Sand deposition and erosion in recirculation zones is dynamic, varying with changes in riverflows and the dimensions of debris fans.

Sandbars are classified as reattachment bars, separation bars, or channel-margin bars, according to their position in a recirculation zone or location along the river (Schmidt, 1990; Schmidt and Graf, 1990).

Reattachment bars, formed in low velocity areas near the downstream end of recirculation zones, extend upstream from the point of flow reattachment and typically are broader but lower than the other types of sandbars (figure III-16). They are inundated more frequently and have been subjected to a greater range of aggradation and degradation (Schmidt, written communication, 1992). Reattachment bars and the return-current channels directly associated with them are important for backwaters and emergent marshes. Boaters use these sandbars for campsites where they are high enough to avoid inundation—mostly in wide reaches. In the narrowest gorges, reattachment bars may be submerged by all but the lowest flows.

Return-current channels, whether submerged or exposed, are components of reattachment bars. Return-current channels are excavated when the velocity of recirculating flow is strong enough to transport more sand from behind the reattachment bar than is being transported across the bar face. Responses of return-current channels to various flow-release patterns are not well understood; however, there is general agreement that they are destined to fill with sand and silt unless flushed occasionally by high flows—probably greater than powerplant capacity.

Backwaters, which may be important for rearing fish, are open return-current channels connected to the river characterized by little or no velocity and potential for warming by exposure to the sun (see FISH in this chapter). The channel must be inundated, but the crest of the reattachment bar must be above water. Suitable backwaters are formed within certain ranges of riverflow; higher flows inundate the reattachment bar, and lower flows may leave the channel dry or disconnected

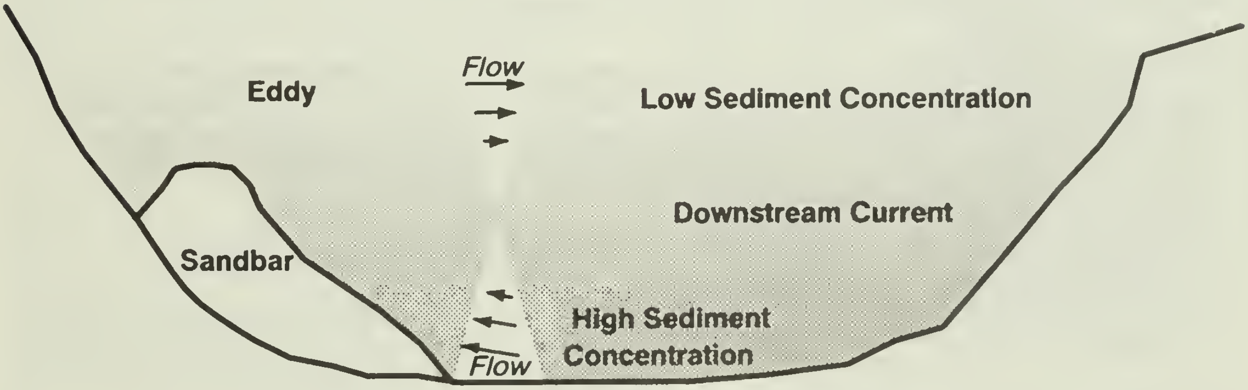


Figure III-17.—Cross section of the Colorado River. Eddies are very efficient sediment traps. Water with relatively high sediment concentration (near the streambed) moves toward the eddy and builds a sandbar. Water with relatively low sediment concentration (near the surface) moves from the eddy back to the main channel.

from the river. According to Schmidt (verbal communication, 1992), floods increase the number of backwaters by removing vegetation and scouring the return-current channels; the number of backwaters decreases between floods as they fill with sediment (figure III-18).

Marshes became established along wide reaches of the Colorado River in Grand Canyon after flow regulation began in 1963, developing where large reattachment bars became overgrown by cattails and other marsh vegetation. The 1983-86 floods scoured the marsh vegetation and probably eroded several vertical feet of sand from these reattachment bars (Stevens et al., 1991). Since that time, emergent marsh vegetation has reestablished on many new reattachment bars. Vegetation becomes established on stable sandbars; however, the vegetation apparently does not prevent erosion (Stevens and Ayers, 1993).

Deposition of silt and other fine sediment by all riverflows is important for establishment and maintenance of marshes (see VEGETATION in this chapter). Silt and clay are delivered by the tributaries and transported by the river under almost any discharge. The height of the deposition, however, depends on maximum river levels, which vary with riverflow.

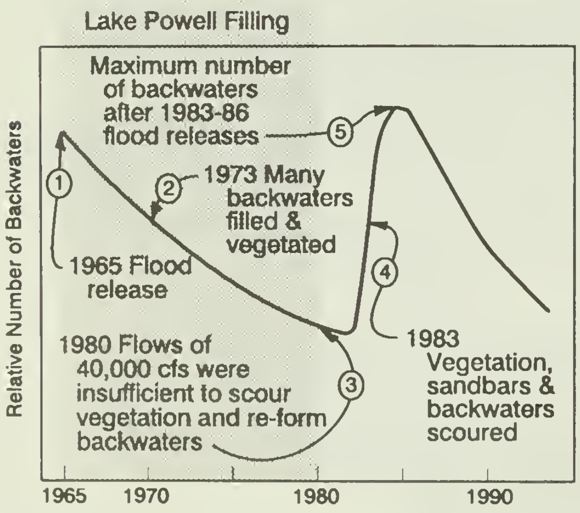


Figure III-18.—Change in general number of backwaters (open return-current channels) during low flow seasons since the 1965 flood release, based on interpretation of aerial photographs (source: Schmidt, verbal communication, 1992).

Separation bars (typically high elevation bars) are formed in the low velocity areas near the upstream ends of recirculation zones and commonly mantle the downstream surface of debris fans (figure III-16). They generally are steeper and higher than reattachment bars; many extend above the level of 30,000 cfs. Usually associated with eddies, separation bars are built with sand transported upstream from the reattachment point. Therefore, separation bars are composed of finer-grained sand than reattachment bars. They are preferred as campsites because they are less likely to be inundated by rising river levels, and because the low velocities in the upper ends of eddies make it easier to moor boats (see RECREATION in this chapter).

Channel margin bars are elongated sand deposits along the margins of the Colorado River that have the form of terraces. Channel margin bars are not directly associated with large eddies; instead, they typically form in small eddies related to some sort of flow obstruction, such as a large boulder (Schmidt and Graf, 1990). Typically, channel margin bars cover bedrock or talus. In some reaches, particularly where the channel is wide, these bars line the channel from a few hundred feet to nearly a mile and often are heavily vegetated.

Downstream from RM 236, riverflow and sediment deposition and erosion are affected by the level of Lake Mead (see discussion of Lake Mead delta later in this section).

Sandbar Deposition and Erosion

Deposition requires high flows, whether annual or daily; erosion occurs following the return to lower flows (Jackson, written communication, 1992). Without occasional periods of sustained high releases (above powerplant capacity), high elevation sandbars eventually will erode and not rebuild (Andrews, 1991a). Sandbars typically were not vegetated prior to the dam. Unvegetated sandbars are dependent on cycles of deposition and erosion. Active erosion is a part of this natural process.

Comparison of photographs taken of the same sites in 1890 and in 1990 provides some information about the long-term change of sandbars (Webb, written communication, 1992). In eastern Grand Canyon (RM 0-126), a relatively high percentage of sandbars had eroded between 1890 and 1990. In western Grand Canyon (downstream from RM 126), more sandbars were about the same size or had aggraded than had eroded. This comparison, however, does not take into account the short-term variability of sandbars, which could affect the conclusions.

Short-term changes in sandbars have been documented since completion of the dam. During periods of low releases (1966-82 and 1987-90), channel banks in wide reaches aggraded while high elevation bars used as campsites eroded. Erosion rates decreased with time. During periods of relatively high discharge (1983-86), reattachment bars eroded, but high elevation bars aggraded. Although aggradation rates in 1987-90 were equivalent to those of 1966-82, erosion rates were about twice as great (Schmidt, written communication, 1992).

Normal Operations. Sandbars experience cycles of deposition and subsequent erosion during normal operations. Generally, net erosion decreases downstream, with the attenuation of the daily extremes in river stage and the addition of sand from tributaries.

Sandbar erosion can result from any of three mechanisms: main-current erosion, seepage-induced erosion, and wave-induced erosion. At a particular sandbar and at a particular time, one of these mechanisms may be predominant. Although up ramp rates may affect other resources, they have not been linked to sandbar erosion.

Main-current erosion is caused when the main channel current is in direct contact with part of a sandbar. Exposure of sandbars to this type of erosion may be increased by the contraction of the recirculating zones during periods of low discharge or when debris fans are overtopped during periods of high flow. Main-current erosion is believed to cause greater net loss of sand from recirculation zones to the river than the other types of erosion, but this has not been documented quantitatively.

Seepage-induced erosion affects most sandbars in Grand Canyon and is responsible for rivulet formation, slope failures, bank cuts, and piping and tunneling (Budhu, written communication, 1992). Seepage-induced erosion is affected by fluctuations in river stage, down ramp rates, and the duration of minimum flow.

Wave-induced erosion is caused by turbulence in nearby rapids, wakes from motor boats, and wind. At each sandbar, effects of wave-induced erosion are concentrated at a specific river stage under steady flow but are distributed over the range of river stages under fluctuating flow.

During increasing flow, eddies expand downstream, and sediment deposition rates within the eddy systems increase (Andrews, 1991b). During decreasing flow, the downstream areas of eddies shift upstream (contract), and sediment deposition rates within the eddy system decrease. Sand deposited near the reattachment point during higher flows is subjected to main-current erosion by the river. Water stored within the sandbars begins to flow toward the river.

Ground-water processes occur on every sandbar during daily and hourly fluctuations. Ground-water levels within exposed sandbars rise and fall with increases and decreases in river stage (Werrell et al., 1993; Carpenter et al., 1991; Budhu, written communication, 1992). If river stage decreases rapidly, seepage-induced erosion may occur. Water table fluctuations within sandbars attached to the bank are greatest near the river and decrease with distance from the river. When river stage declines faster than the ground water can drain from the sandbar, the exposed barface becomes saturated. Water seeping from the saturated barface forms rills that move sand particles toward the river (Werrell et al., 1993). When the rate of river stage decline is equal to or less than the rate at which ground water naturally drains from the barface, a seepage face will not form.

The sandbar slope stability model of Budhu (written communication, 1992) is applied in this EIS (see figure III-19). The slopes of sandbars are initially deposited at angles ranging from 20 to 45 degrees with an average of 26 degrees. As the river stage recedes, this slope may be unstable. Seepage-induced erosion tends to reduce the slope of new deposited sands to about 11 degrees. On some sandbars, a rapid decrease in river stage sets up conditions for bar failure. The next rising river stage (at almost any ramp rate) could easily cause a failure to occur.

Sandbar height and active width for the range of daily and annual flow fluctuations are used as indicators of impacts of the alternatives. These are the height and width of the inundated zone (figure III-19).

Unanticipated Floods. Large unanticipated floods of sediment-free water generally have a much greater effect on sandbars than releases under normal operations. The magnitude and extent of the effects depend on the magnitude and duration of the flood and the supply of sediment in eddies and the main channel prior to the flood. Floods may be beneficial to backwaters by removing vegetation and re-forming return-current channels. Floods occurring when sand storage in the main channel is low probably would cause more extensive loss of sand-dependent resources than when pools and eddies are relatively full of sand. The 1983 flood, with plenty of stored sand available, aggraded many sandbars. However, Schmidt and Graf (1990) reported evidence that the floods of 1984-86 did not deposit as much as the flood of 1983 and caused greater erosion. If sand contribution from tributaries is sufficient to balance the sand removed from Grand Canyon over the long term, the net change in sandbars would be small.

The number of sandbars used as campsites increased between the inventories of 1973 and 1983 in both narrow and wide reaches as a result of the 1983 flood (Kearsley and Warren, 1992). The floods and prolonged high releases of 1984-86, followed by fluctuating releases in 1985-86, caused net erosion of many campsites. The 1991 inventory indicated that erosion has reduced the number of campsites to slightly more than the 1973 count in wide reaches and less than the 1973 count in narrow reaches (see figure III-20). Vegetative overgrowth further reduced the number of campsites in all reaches.

Other Factors. Sandbars also are eroded by natural forces not influenced by dam operations, such as wind, waves, rainfall, flash floods, and

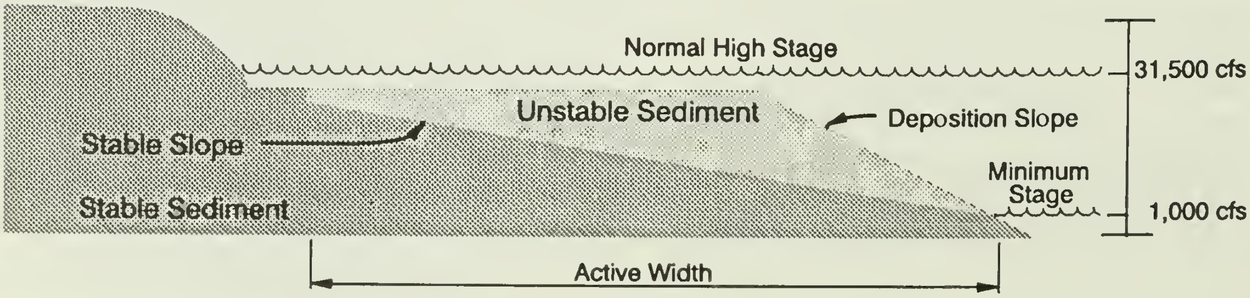


Figure III-19.—Conceptual cross section of a sandbar affected by fluctuating flows. Daily fluctuations create an unstable zone within the sandbar. The minimum stage determines the boundary between the stable and unstable zones.

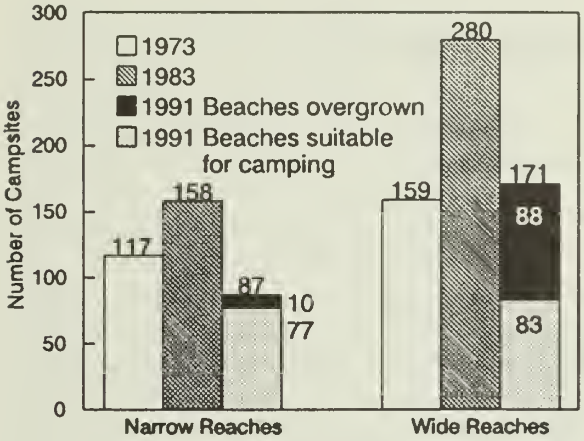


Figure III-20.—Comparison of sandbars used as campsites based on inventories conducted in 1973, 1983, and 1991. The number of campsites increased in both narrow and wide reaches as a result of the 1983 flood. By 1991, erosion reduced the number of campsites to slightly above 1973 levels in wide reaches and below 1973 levels in narrow reaches; vegetative overgrowth further reduced the number of campsites (source: Kearsley and Warren, 1992).

debris flows. Sandbars that are not inundated by dam releases are susceptible to erosion by wind and the effects of camping use.

Recreation causes sandbar erosion, but this erosion is primarily limited to camping beaches. The amount of erosion is thought to be minor in comparison with other causes of erosion, but this has not been documented.

High Terraces

High elevation alluvial terraces in wide reaches of Grand Canyon support native vegetation and may contain buried or partly buried archeological remains. The archeological remains are susceptible to exposure and loss by erosion. Most of this discussion of high terraces is based on the work of Hereford et al. (1993). The high terraces were deposited by large floodflows (100,000 cfs and greater) prior to the dam and commonly have been reworked by wind and runoff from local rainfall. The larger the floodflow, the higher the terrace and the older the deposit (see figure III-21). The highest terraces are more than 1,000 years old, while the lowest terrace is about 30 years old.

Many high terraces are eroded by runoff from local rainfall resulting in networks of deep water-carved gullies (arroyos). Such erosion was extensive during the heavy rainfall of 1978-85, one of the wettest periods on record. This erosion does not occur if runoff filters into the ground before draining to the next lower terrace. However, if runoff drains to the next lower terrace, arroyos will erode to that level, exposing or eroding archeological remains, if present. Arroyo-cutting of even the lowest terraces indirectly causes erosion of higher terraces. In some cases, windblown sand may refill the arroyo.

The oldest and highest terraces eroded prior to the dam and will continue to erode. However, predam annual floodflows maintained the lowest high terrace and prevented some arroyos from cutting all the way to the Colorado River (see figure III-21). The lower peak discharges and smaller sediment concentrations of postdam flows are not sufficient to maintain even the lowest high terrace. Erosion of high terraces will continue through rilling and arroyo-cutting regardless of dam operations, except where site-specific protection may be implemented.

High terraces can be directly eroded by floodflows. Predam floods in some locations caused the river to shift laterally and erode terraces. The 1983 flood caused additional erosion of terraces in some locations, mainly between the dam and RM 36. The frequency of floods greater than 45,000 cfs is used as an indicator of impacts to those terraces.

Debris Fans and Rapids

Formed at the mouths of tributary canyons, debris fans are sloping deposits of poorly sorted sediment ranging in size from clay and silt to large boulders. Deposited by debris flows (see section on riverbed sand), debris fans are important geomorphic features in Grand Canyon; without them, there would be few rapids or sandbars (see Webb et al., 1988).

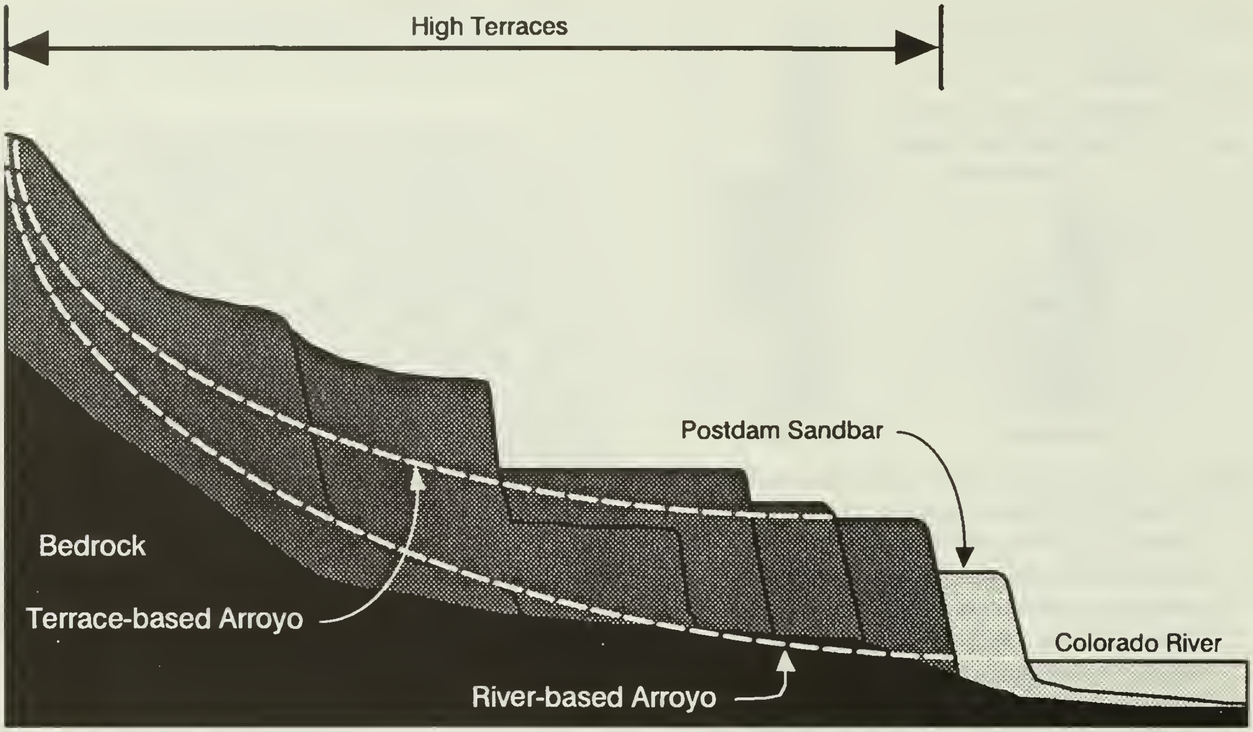


Figure III-21.—Conceptual cross section of arroyos draining high terraces typically found in a wide reach of Grand Canyon. The larger the floodflow, the higher the terrace and the older the deposit. Some arroyos drain to a lower terrace (terrace-based arroyo). Since construction of the dam, some arroyos have cut to the Colorado River (river-based arroyo) (modified from Hereford et al., 1993).

Where debris fans extend into the Colorado River, they obstruct the channel, making it narrower and raising the bed elevation; and rapids or riffles are formed (see figure III-16). As the river reworks a debris fan, debris bars—consisting of well-sorted cobbles and boulders mixed with sand—may form downstream (Webb et al., 1989). Some debris bars form secondary rapids.

Webb, Pringle, and Rink (1989) state that "large rapids may be the most obvious geomorphic manifestation of sediment transport from small drainages in Grand Canyon National Park." Deep pools that form upstream from rapids provide space for temporary storage of substantial amounts of riverbed material—mostly sand and gravel. As discussed in the section on riverbed sand, debris fans that constrict the river channel also create downstream eddies in which most of the camping beaches used by river runners are deposited.

For a given flow, the constriction width and riverbed elevation at a rapid control the velocity and water-surface elevation of the upstream pool, which in turn control the amount of sand and gravel that can be deposited in the pool. Aggraded debris fans will allow the channel to store more sand in the associated pools and eddies.

More than 100 rapids and numerous riffles between Lees Ferry (RM 0) and Bridge Canyon (RM 235) were documented by Stevens (1983). The debris fans that form rapids will continue to be replenished and enlarged by infrequent debris flows, but Glen Canyon Dam has greatly reduced the magnitude and frequency of floodflows and, thereby, the capability of the river to move boulders from the rapids.

Formation of new rapids and steepening of existing ones will continue. Debris flows created rapids at RM 127.6 in 1989 and at RM 62.5 in 1990, and recent debris flows steepened 24-Mile, Specter, and Bedrock Rapids (Webb, written communication, 1992). In the absence of floods, future debris flows will cause the channel to become more constricted, resulting in steeper rapids. Such rapids could become more dangerous to navigate. Constriction ratios and elevation drops at rapids can be used as measures of long-term hydraulic effects of changes in debris fans that intersect the river. The constriction ratio described by Kieffer (1985, 1987, 1990) is the ratio of channel width at the narrow part of the rapid to the channel width of the pool upstream. Many rapids have a constriction ratio of 0.5, which may be an indicator of equilibrium (Kieffer, 1985, 1987, 1990).

As future debris flows deposit new material in a rapid, riverflows within the operational range of Glen Canyon Dam Powerplant will remove some of the new material. However, floods of 100,000 to 200,000 cfs or more probably would be necessary to remove the largest boulders from some debris fans, to increase the constriction ratio, and to decrease the elevation drop (Kieffer, 1985). For example, the 1966 debris flow on Bright Angel Creek (Cooley et al., 1977) deposited material in Bright Angel Rapid (RM 87.9) that could not be reworked completely by riverflows in the range of powerplant releases. The 1983-86 floods and sustained high releases returned this rapid to its pre-1966 condition but could not do the same at Crystal Rapid.

In 1966, a debris flow in Crystal Creek (RM 98.1) changed this previously minor rapid to one of the largest in the canyon. The debris fan temporarily dammed the river completely, and the channel that subsequently was cut through the debris fan was constricted to 25 percent of the upstream width. The 1983 flood release of nearly 100,000 cfs increased the constriction to about 40 percent (Kieffer, 1985). Thus, Crystal Rapid will remain a formidable obstacle for river runners in the foreseeable future. It serves as an example of what may happen at other rapids when they aggrade with new debris flows in the absence of large floods in the Colorado River. For purposes of this EIS, relative capacity to move boulders from debris fans will be used as an indicator of impacts.

Lake Deltas

The ultimate destiny of all reservoirs is to be filled with sediment. The coarser particles (mostly sand) carried into the reservoirs by tributaries are deposited as deltas in the tributary arms. Most of the finer particles (silt and clay) are carried far into the reservoir, where they settle out as lakebed deposits. Deltas fill the upstream parts of the tributary arms first, building toward the submerged mainstem channel and eventually the dam. Some sediment deposited in upstream parts of deltas may be transported downstream by floodflow when the reservoir is low.

The characteristics of a delta depend on such variables as quantity and size of inflowing sediment, reservoir operations, and hydraulics in the tributary arms. Other factors include erosion and vegetative growth along the margins of the tributary arms and turbulence and density currents in the reservoir. The longitudinal profile of a delta depends primarily on lake levels (determined by hydrology and reservoir operations) and the slope of the channel through the delta (Strand and Pemberton, 1982).

Lake Powell Deltas

Large deltas have formed in the major tributary arms of Lake Powell—Colorado, Dirty Devil, Escalante, and San Juan Rivers and Navajo Canyon (figure III-22). The upper surfaces of the deltas are important substrate for vegetation and riparian habitat and can affect recreational navigation and reservoir water quality. The shape and location of the deltas are affected mainly by the changing water surface elevation of Lake Powell. Sand and larger-size sediments generally settle in the upstream shallow parts of the tributary arms, forming deltas, while most silt and clay deposit in deeper areas downstream.

Lake Powell is located in the Colorado Plateau province, an area characterized by broad, cliff-edged mesas separated by narrow,

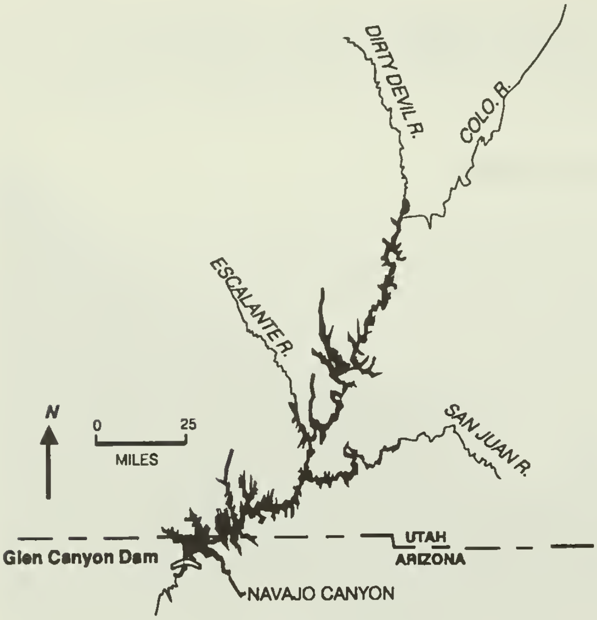


Figure III-22.—Lake Powell and major tributaries.

steep-walled canyons. The lake occupies a long, narrow canyon of the Colorado River and the many slender arms of the tributaries. When Lake Powell is full (at elevation 3700 feet above sea level), the reservoir extends 186 miles up the Colorado River and 75 miles up the San Juan River, creating 1,960 miles of winding canyon shoreline. In 1986, Lake Powell had a total storage capacity of 26.2 maf and a surface area of 161,000 acres (Ferrari, 1988).

Longitudinal profiles of the original river bottom and the 1986 average bottom of the Colorado River are shown in figure III-23 and for the other major deltas in appendix D. Plots of delta profiles in reservoirs commonly exhibit a definite break at the delta crest. For purposes of this EIS, changes in elevation of the major delta crests will be used as indicators of impacts of the alternatives on Lake Powell deltas. Delta crest elevations and other characteristics of the major deltas, last measured in 1986 (Ferrari, 1988), are listed in table III-8.

Table III-8.—Major Lake Powell sediment deltas

Tributary arm of Lake Powell	Delta crest elevation (feet)	Length upstream from delta crest (miles)	Maximum delta depth (feet)
Colorado	3670	19	170
Dirty Devil	3685	11	95
Escalante	3685	4	50
San Juan	3690	20	80
Navajo Canyon	3690	3.2	50

The length of a delta exposed above the water surface can change dramatically with changes in lake elevation. For example, when Lake Powell elevation decreased 10 feet (from 3700 to 3690 feet), the length of the San Juan delta exposed above the water surface increased by more than 7 miles.

Each year from 1980 through 1987, Lake Powell filled or nearly filled (above elevation 3682 feet) but fluctuated 25 feet or more during the course of the year. During this period, sediments were deposited in the lake at relatively high elevations. Since 1987, the level of Lake Powell has receded, vast areas of the deltas have been exposed, and vegetation has become established. Vegetation tends to stabilize deltas by reducing the velocity of tributary floodflows which, in turn, causes more silt and clay deposition than would occur during normal flows.

In 1991, the San Juan River changed course through its Lake Powell delta. The river now has a waterfall (15- to 18-foot fall) near Piute Farms Wash (approximately 53 miles upstream from the mouth of the San Juan River). The rock outcropping that creates this waterfall effectively prevents erosion of the delta upstream, even though the reservoir elevation has receded.

Estimates of the time required for complete reservoir sedimentation are best expressed in hundreds of years. The 1986 survey results indicated that about 868,000 acre-feet of sediment had been deposited below elevation 3700 feet since dam closure in March 1963. This total sediment volume represents a 3.2-percent decrease in total storage capacity in 23 years. At that rate, the estimated time to completely fill the

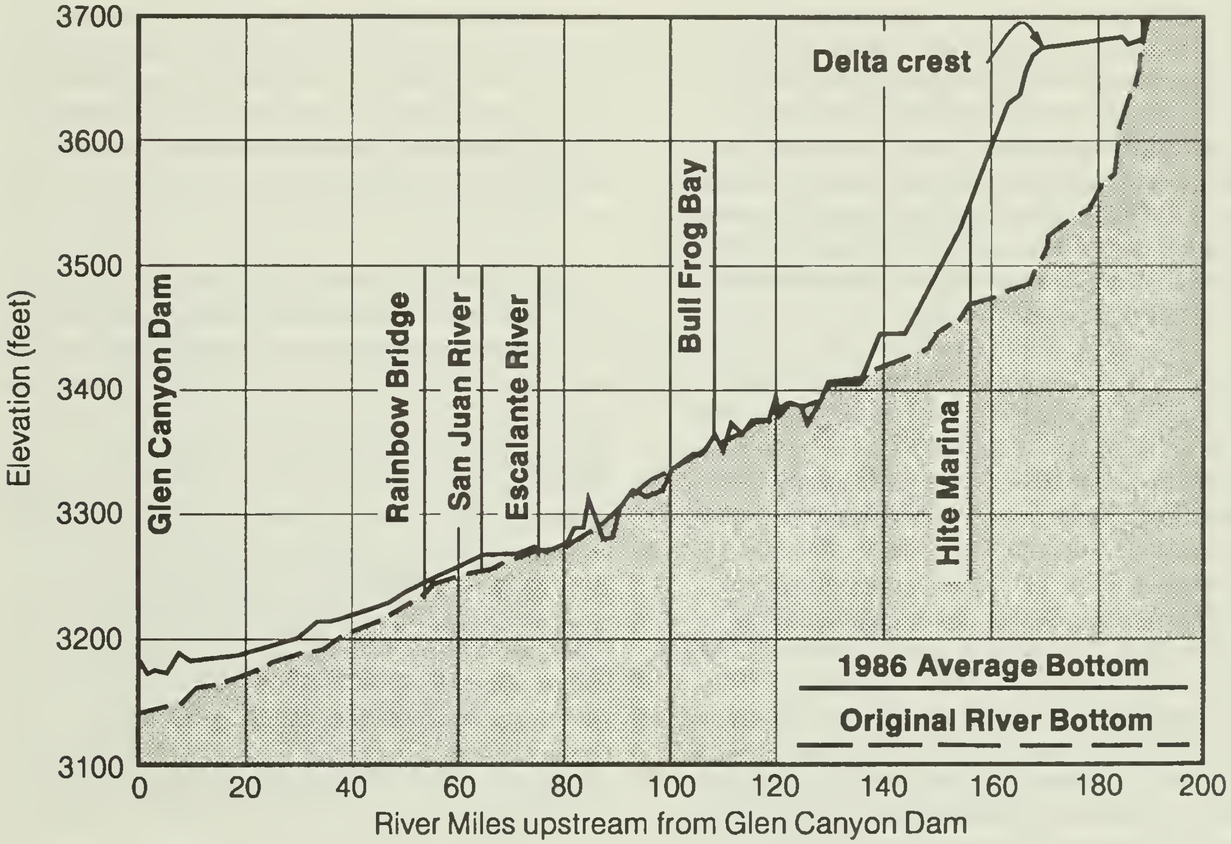


Figure III-23.—Profile of Colorado River bed in 1958-59 and 1986 (source: Ferrari, 1988b).

reservoir with sediment would be more than 700 years; however, sediment would reach the level of the penstocks at the dam in about 300 to 500 years.

Of the 868,000 acre-feet of sediment in Lake Powell, 54 percent was estimated to be in the Colorado River arm, 32 percent in the San Juan River arm, and 14 percent in the remaining tributary arms. Rising water in Lake Powell has caused some slumping of formerly stable cliffs and slopes. The total volume of slumped material is difficult to measure, but it is estimated to be small compared to the volume of sediment carried by the major tributaries.

The chemical quality of sediments deposited in Lake Powell is not well known. See the discussion of water quality in the preceding WATER section.

Lake Mead Delta

All sediment transported into Lake Mead by the Colorado River and tributaries is trapped in submerged canyons and valleys as deltas and lakebed deposits. The magnitude and pattern of dam releases and tributary floodflows may affect the rate of aggradation and the configuration of the deltas. If changes are large enough, marsh and riparian habitat and navigation may be affected (see VEGETATION and RECREATION in this chapter).

The coarsest sediment (mainly sand) begins to drop out of suspension at the point where the Colorado River intersects Lake Mead. The location along the river where this occurs depends on the level of the lake, which is controlled primarily by releases from Glen Canyon Dam and Hoover Dam. The maximum recorded lake level, about 1220 feet above sea level, corresponds approximately to the elevation of the riverbed downstream from RM 235 (Bridge Canyon) in Lower Granite Gorge. River mile 236 is the approximate upper end of the Colorado River delta, which presently extends past Pierce basin to about RM 290. River and lake currents carry large volumes of fine sediment far into Lake Mead. Lakebed deposits extend all the way to Hoover Dam at RM 355 (figure III-24).

Downstream from RM 236, riverflow and sediment deposition and erosion are affected by the level of Lake Mead. Ranges in stage for daily and annual flow fluctuations are substantially less than those upstream. All former rapids have been submerged. Recirculation zones that create and maintain sandbars and return-current channels upstream generally are absent in this reach at flows within powerplant capacity. The backwater effect of the lake causes river velocities to decrease, and more of the finer-size sediment settles out. Channel margin deposits have larger percentages of silt and clay than upstream sandbars. Sediment deposited when the lake level is relatively high is exposed to erosion during subsequent periods when the lake level is lower. Exposed deposits tend to have steep faces (many are nearly vertical), which are more susceptible to erosion; bank caving is common. In the absence of replenishing flood releases, predam flood deposits of sand and finer sediment above high lake level are subject to long-term erosion by wind and local runoff.

The shape of the Colorado River delta profile is affected mainly by lake level. The delta surface in Lower Granite Gorge and upper Lake Mead is relatively flat and is mostly sand. The delta face dips steeply, constantly building towards Hoover Dam as new sediment arrives. The elevation of the delta crest where the slope changes from relatively flat to relatively steep (see figure III-23) can be used as an indicator of changes in the delta. According to a 1948-49 survey of the delta deposits (Smith et al., 1960), the delta crest was at RM 278; by 1963-64 (Lara and Sanders, 1970), it had progressed to RM 286. In 1963-64, the maximum thickness (depth) of the delta was about 250 feet. The lakebed deposits consisted of 12 percent sand, 28 percent silt, and 60 percent clay (Lara and Sanders, 1970). The delta contains a much higher percentage of sand.

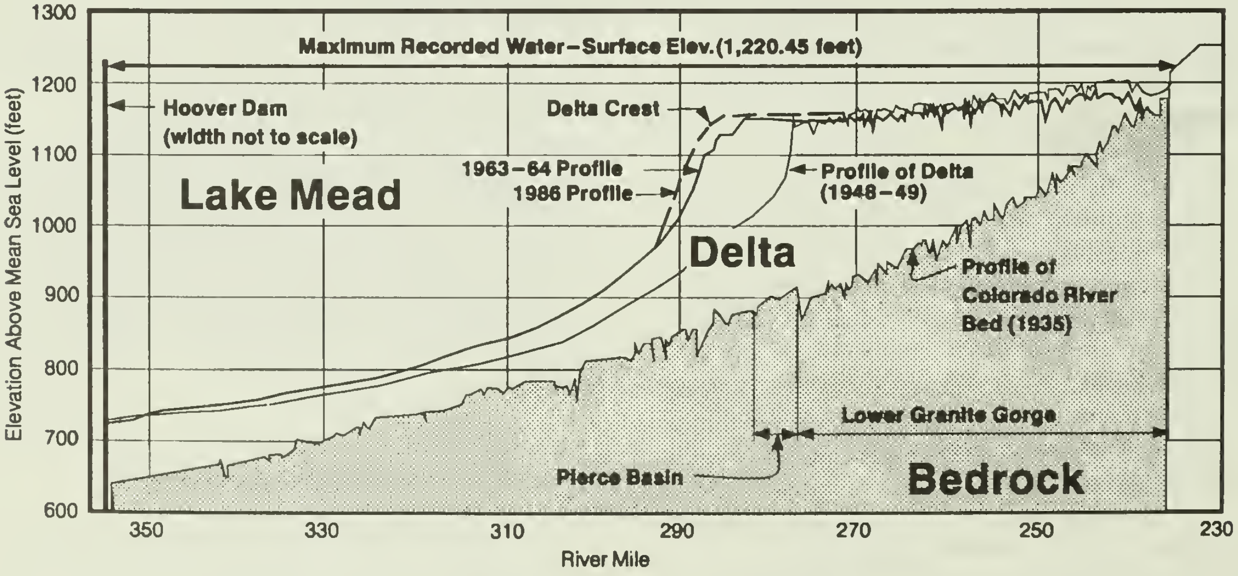


Figure III-24.—Profile of Colorado River bed and sediment deposits in Lake Mead. Vertical scale is exaggerated (modified from Lara and Sanders, 1970).

Lara and Sanders (1970) estimated that the closure of Glen Canyon Dam extended the life of Lake Mead to about 500 years. Average accumulation of sediment in Lake Mead was estimated by Smith et al., (1960) to be about 100,000 acre-feet per year during the first 14 years after closure of Hoover Dam in 1936. Lara and Sanders (1970) estimated about 91,000 acre-feet per year during the first 30 years, for a total accumulation of about 2.72 maf. Since construction of the dam, the rate of accumulation has declined substantially.

FISH

Because the Glen Canyon Dam EIS deals with water release patterns and to some extent water quality, aquatic biological resources will be directly affected by decisions based on EIS findings. Relatively subtle changes can have direct and indirect effects on native fish, coolwater and warmwater non-native fish, and trout below Glen Canyon Dam.

The ability of fish populations to persist and thrive depends on how well their life requirements are met for each life stage. Life stages include newly spawned eggs, embryos, fry and larval stages, juvenile, and adult—including the ability of adults to successfully reproduce. Important life requirement factors include:

- Availability of appropriate food
- Physical characteristics of the underwater environment that affect physiological processes (like water temperature and velocity)
- Presence of competitors and predators

The size and health of fish populations of Glen and Grand Canyons are a result of how well the life requirements of each life stage are met. Of the three life requirement factors, the availability of food (aquatic food base) is one that is common to all fish of Glen and Grand Canyons. Therefore, a discussion of the aquatic food base is presented first in the following section.

Aquatic Food Base

The physical characteristics of water in Glen and Grand Canyons have changed considerably since closure of Glen Canyon Dam because of the effects of Lake Powell and reservoir water releases (see discussion of water quality under WATER). Previously, the aquatic food base of Glen and Grand Canyons was based on coarse organic material carried into the river from the drainage basin. Today, that coarse material is trapped in Lake Powell, and the benthic alga in the river is an important part of the aquatic food base. Productivity of the aquatic food base in the river downstream of the dam is now determined by how and when water is released and by what that water carries in it.

Releasing water from deep below the surface of Lake Powell reduces variation in temperature, water clarity, total dissolved solids, nutrients, and seasonal discharge typical of the Colorado River prior to dam construction (Maddux et al., 1987). Nutrient concentrations and proportions in the river through Glen and Grand Canyons are determined largely by the depth from which water is released from the dam. Therefore, the productivity of the Glen Canyon tailwater is largely dependent upon Lake Powell.

In general, Lake Powell traps important nutrients like phosphorus as it traps incoming suspended sediments. But phosphorus flowing in from the huge drainage basin of the Colorado River above Lake Powell is one of the keys to biological productivity of the reservoir and the river below it (Maddux et al., 1988). Organisms that inhabit Lake Powell also consume a portion of incoming available phosphorus. Some phosphorus, either dissolved or as part of the minute planktonic plants and animals of Lake Powell, is released into the river below the dam. The concentration and proportion of this important nutrient in relationship to other nutrients is influenced by the depth from which water is released (Angradi et al., 1992). It has been suggested by several authors that phosphorous is the limiting plant nutrient in the system (Maddux et al., 1988; Angradi et al., 1992).

Cladophora and Associated Diatoms

Cladophora, along with the organisms that live in or on it, forms the basis of a highly productive food chain below Glen Canyon Dam. Because of the increased water clarity of the discharge from the dam, light penetrates deeper into the water and permits the filamentous green alga *Cladophora glomerata* (Angradi et al., 1992; Pinney, 1991) to capitalize on the available nutrients released through the dam. *Cladophora* and groups of single-celled algae (diatoms) that live on it form the habitat for an important community of aquatic invertebrates dominated by the shrimp-like amphipod, *Gammarus lacustris*, and chironomid and fly larvae.

The importance of *Cladophora* is increased by the diatoms that encrust it. These diatoms carry the important nutritional material that benefits invertebrates like *Gammarus*, which selectively consume some diatoms without consuming the *Cladophora* (Pinney, 1991). Fish like rainbow trout and humpback chub appear to consume *Cladophora* and benefit directly or indirectly from the energy-rich diatoms that live on it.

Among other variables, the distribution of *Cladophora* depends on light penetration, exposure to air, and available substrates (exposed rock such as cliff faces and large cobbles where *Cladophora* can attach itself) (Pinney, 1991). At flows of 5,000 cfs or less, enough light penetrates to the bottom of the river channel to allow *Cladophora* to photosynthesize (Yard et al., 1993). As river stage increases, the depths where *Cladophora* can thrive may decrease. Tributaries contribute turbid inflows, which also affect the zone where *Cladophora* can live. As a result, this zone is measurably narrower in the mainstem below the confluence of the LCR than it would be above the confluence with the Paria River.

The general trend in the distribution of *Cladophora* suggests that the upper reaches of the river are very productive, while production declines downstream (Usher et al., 1988; Angradi et al., 1992). This may be explained by a combination of factors:

- Increased turbidity below the Paria and Little Colorado Rivers
- Declining available phosphorus as waters pass downstream

The prolific growth of *Cladophora* has established the upper portion of the river as an important production area that feeds downstream reaches with particulate organic matter in the form of *Cladophora* and aquatic invertebrates entrained in current as drift, particularly during increasing flows or up ramping (Leibfried and Blinn, 1987). As a result of these relationships, the productive capacity of the clear water reaches above the LCR also becomes the basis of the food chain in the lower portion of the river (Maddux et al., 1988; Angradi et al., 1992).

Cladophora is the dominant alga in the reach below the dam (Blinn et al., 1992). Algal production is maintained because of the clear, cold releases from the dam. Downstream, a blue-green alga (*Oscillatoria* sp.) becomes codominant in the middle canyon and dominant in the lower canyon (figure III-25). Habitat parameters for *Cladophora* are not well understood. Inundation with cold, nutrient-carrying water permits abundant growth of this alga, while exposure can cause mortality.

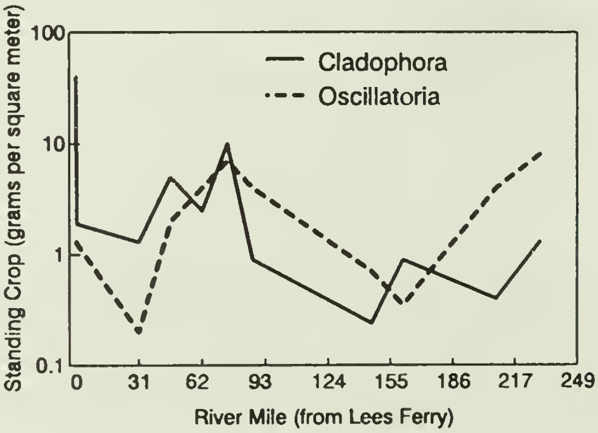


Figure III-25.—Cladophora declines with distance from the dam and Oscillatoria becomes codominant (source: Blinn et al., 1992).

For example, Pinney (1991) recorded highest biomass of *Cladophora* from areas beneath the zone of fluctuation and less biomass from areas exposed by large daily fluctuations. The reverse is true under steady discharges (less than 5,000-cfs daily fluctuation). Exposure of more than 12 hours can cause decreases in *Cladophora* biomass from drying (summer), freezing (winter), or ultraviolet light damage (Usher and Blinn, 1990).

Once affected, *Cladophora* is not very resilient. Pinney (1991) suggested recovery times of 2 weeks to 1 month. Other researchers have suggested that "disturbances severe enough to destroy the periphyton (*Cladophora*) will have protracted (probably greater than 1 year) ecosystem level effects under fluctuating flows" (Angradi et al., 1992).

In summary, *Cladophora* depends on and is susceptible to influences of dam operations. The cold, clear water released from the dam sets the stage for its establishment, but fluctuating river stages result in stranding of some *Cladophora* for varying periods of time. The GCES (Leibfried and Blinn, 1987; Usher et al., 1988; Blinn et al., 1992; Angradi et al., 1992) showed that *Cladophora* isolated out of the water for more than 12 hours would dry out and die. *Cladophora*—either dead from drying or scoured loose by waterflow—and the invertebrates that are forced to move to avoid drying make up much of the drift that feeds fish and other aquatic organisms. That drift also settles to the bottom in eddies and backwater areas where it is fed on by organisms and recycled through the food chain.

Other Aquatic Food Sources

The drift also contains zooplankton that, at least originally, came directly from Lake Powell (Haury, 1988), which may reflect the level at which water is withdrawn from the reservoir. Years in which the reservoir is quite low may see shifts in the composition and density of these plankton as waters are withdrawn from layers closer to the surface. These microscopic animals are important food sources for fish and other aquatic organisms. They typically are quite important to recently hatched larval fish (trout, flannelmouth sucker, and bluehead sucker) (Haury, 1988; Maddux et al., 1987).

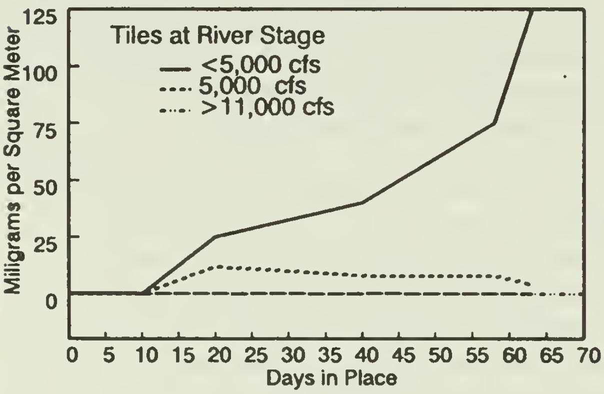
Larger aquatic invertebrate organisms (macroinvertebrates) are extremely important members of the aquatic community (and aquatic food base) of the Colorado River and may even bridge the gap into the terrestrial community. *Gammarus lacustris* has become an important member of the macroinvertebrate community. *Gammarus* was first introduced into Bright Angel Creek during the 1930's by the NPS and began colonizing the river shortly thereafter (Carothers and Minckley, 1981). *Gammarus* and a species of snail (*Physa* sp.) were also introduced to the river below Glen Canyon Dam by the Arizona Game and Fish Department (AGFD) during 1967-68 as a food source for the developing trout fishery (Arizona Game and Fish Department, 1968). Other important species probably already resided in the Colorado River, including aquatic worms (*oligochaetes*), chironomid midges, and buffalo gnats (Carothers and Minckley, 1981).

Researchers have found that wide canyon reaches (Blinn et al., 1992), eddies, and backwater areas are very important to the production of aquatic invertebrates (Carothers and Minckley, 1981). These areas of slower current tend to accumulate organic material from the drift (detritus) that forms the basis for their food source. The reduced temperature (or lack of seasonality), through direct and indirect means, influences the diversity and density of these invertebrates.

In total, the aquatic food base of the Colorado River below Glen Canyon Dam is a community of algae and invertebrate animals that forms the powerhouse for the aquatic ecosystem and, in some cases, an energy transfer route between the aquatic and terrestrial ecosystems. Solar energy, captured by *Cladophora* and the diatoms that encrust it, is transmitted through the food chain to many invertebrate and vertebrate species. The amount of energy that can be captured and made available to the food chain appears to be determined by the area of cobble bars inundated by water on a reliable basis (Blinn et al., 1992). Reliable minimum stage (the river stage that can be relied upon over extended periods of time) and reliable wetted perimeter become an important index of algal productivity that can be expected and a reflection of the strength of the aquatic food base.

Algal colonization experiments by Angradi (Angradi et al., 1992) illustrated the concept of reliable minimum flow by anchoring sandstone tiles in the river to measure the accumulation of growing *Cladophora* at different river stages. Figure III-26 shows the accumulation of algae at different river stage levels (-10.5-mile bar above Lees Ferry) during the spring of 1991. The figure illustrates the ability of the aquatic food base to develop in response to minimum flow. Even relatively reliably inundated areas (5,000 cfs) that were dewatered only 20 to 30 percent of the time showed less accumulation of attached algae than tiles that were always inundated.

(a) Chlorophyll a



(b) Biomass

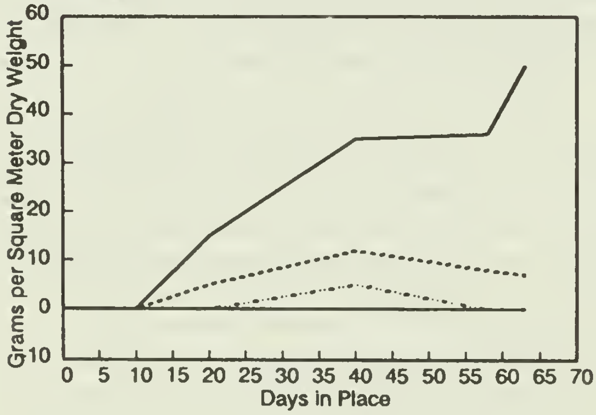


Figure III-26.—Accumulation of Cladophora measured as (a) Chlorophyll a, and (b) in biomass. Tiles placed below 5,000 cfs were always inundated (modified from Angradi et al., 1992).

Because of its sensitivity to flow, reliable minimum stage and reliable wetted perimeter in the Glen Canyon are used as indicators of effects to the aquatic food base.

Native Fish

The native fish of the Colorado River system make up one of the most unusual assemblages of fish specially adapted to their environment found anywhere in the world. These warmwater fish have adapted to the challenge of living in a highly variable environment subject to seasonal extremes of flow and water temperature and highly turbid conditions. Recent history has introduced new challenges by modifying the fish's evolutionary environment. Construction of major dams has modified flow extremes, cleared and cooled the waters, converted rivers to lakes, and cut off natural movement corridors. In addition to these physical modifications, fish not native to the Colorado River drainage have been introduced and may compete with or prey upon the natives. The cold, clear, fluctuating releases from the dam have caused declines in the number of kinds of warmwater fish, both native and non-native, that reside in Glen and Grand Canyons.

Of the eight species of native fish, three have been extirpated from the canyon, two are listed as endangered and one as a candidate species under the Endangered Species Act, and the remaining two species are relatively common (see table III-9). The Colorado River squawfish, the roundtail chub, and the bonytail chub are considered extirpated from Grand Canyon, and until recently, it was feared that the razorback sucker also was eliminated. Recent collections of razorbacks in Grand Canyon have changed that perspective somewhat. The population of humpback chub (a federally endangered species) in Grand Canyon is perhaps the largest of five remaining populations, and the only population of the species in the Lower Colorado River Basin.

Table III-9.—Native fish of Glen and Grand Canyons

Species	Status	Occurrence
Humpback chub	Federal endangered State endangered	One population in the Lower Colorado River in Grand Canyon
Razorback sucker	Federal endangered State endangered	Rare in Grand Canyon
Colorado squawfish	Federal endangered State endangered	Extirpated from Grand Canyon
Bonytail chub	Federal endangered State endangered	Extirpated from Grand Canyon
Roundtail chub	Being considered for listing	Extirpated from Grand Canyon
Flannelmouth sucker	Being considered for listing	Still common in Glen and Grand Canyons
Bluehead sucker	No special status	Still common in Grand Canyon
Speckled dace	No special status	Widely distributed in Arizona; common in Grand Canyon

Other native fishes of the Colorado River through Glen and Grand Canyons include the speckled dace, flannelmouth sucker, and bluehead sucker. Bluehead sucker and speckled dace are most common in the lower reaches of the river, while flannelmouth are most common in the upper reaches (Maddux et al., 1988). Flannelmouth suckers use the lower reaches of the river as important nursery and rearing areas, but as they grow, they apparently distribute themselves upstream. Further information on the razorback sucker and humpback chub can be found under ENDANGERED AND OTHER SPECIAL STATUS SPECIES later in this chapter.

The native fishes depend on the diversity of habitats available in the river system. Backwaters, tributaries, eddies, and the mouths of tributaries appear to be essential to their life cycles, particularly reproduction and recruitment.

Water temperature is an overriding constraint for native fishes in the Colorado River mainstem (figure III-27). Minckley (1991) indicated that "water temperature too low for reproduction or larval development clearly results in loss of populations and is the culprit excluding natives from Marble/Grand Canyons." He goes on, in discussing the larger causes of collapse of native fish populations throughout the basin, to indicate that "introduction and enhancement of non-native fishes as a result of river alterations forced the native species to extinction." At the same time, the "cold water of today is as large a deterrent for non-native warmwater species as for natives" (Minckley, 1991). Because the temperature of dam releases is not altered by any of the alternatives, other factors become important, including (1) access to tributaries for reproduction and (2) availability of warmer, low velocity environments in the main channel for rearing of young fish flushed from the tributaries (see ENDANGERED AND OTHER SPECIAL STATUS SPECIES).

Reproduction

Mainstem Reproduction. Water temperatures in the river are too low to allow development of eggs spawned there, which directly limits successful reproduction to tributaries (Hamman, 1982; Marsh, 1985; Valdez, 1991; and Maddux et al., 1987). Therefore, access to tributaries and tributary mouths for spawning is of primary importance to these species. Major warmwater tributaries (primarily the Paria and Little Colorado Rivers and Kanab Creek, but also

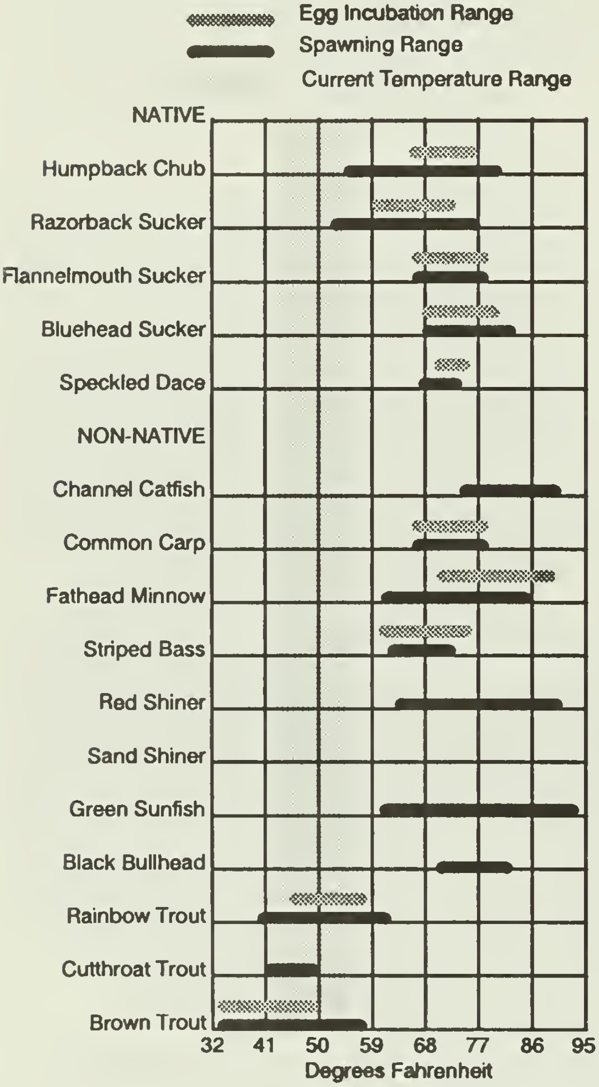


Figure III-27.—Spawning and egg incubation temperatures for native and non-native fishes. Shaded area denotes current temperature range.

Shinumo, Tapeats, Bright Angel, Diamond, Havasu, and Spencer Creeks) appear to contribute to native fish productivity.

Tributary Reproduction. Low flows of 1,000 cfs (Labor Day until Easter) or 3,000 cfs (Easter until Labor Day) may limit access to tributaries (except perhaps the LCR), especially at night, when adult spawners likely would be moving. Indirectly, this fluctuation pattern may further limit reproduction of native fishes. It is speculated that reliable minimum flows of 5,000 cfs are sufficient to allow access to tributaries for spawning. Reliable minimum flow is the indicator for accessibility to tributaries for reproduction.

Eggs and larval fish can be flushed into the mainstem by periodic floodflows in the tributaries. It is suspected that temperature shock to these flushed eggs and larval fish may be lethal (Hamman, 1982; Maddux et al., 1987). Thus, there is some dependence on tributaries to accommodate the earliest life stages of native fish. Very young native fish are found in specialized habitats in the mainstem, suggesting that refuge areas (nearshore, shallow water areas, and backwaters) play a role in recruitment of native fish.

Recruitment and Growth

Return-current channel backwaters (slackwater areas partially isolated from the main channel) and shallow nearshore areas along the main channel are important refuges for young native fish exiting tributaries and serve as nursery areas in the mainstem. Native fishes require the shallow, productive, warm refuges provided in these slackwater areas during their first 2 years of life. Maddux et al. (1987) found that young-of-year flannelmouth suckers, bluehead suckers, and speckled dace used backwaters extensively. They found these areas to be very important on a seasonal basis, when the sun can warm the backwater above ambient river temperature.

Angradi et al. (1992) illustrated the morphology of return-current channel backwaters (see figure III-16), emphasizing that during lower, steadier flow, return-current channel backwaters showed potential for warming. Maddux et al. (1987) found that in summer months during periods of steady flow, some backwaters reached nearly 77 °F, while main channel waters remained near 50 °F. Arizona Game and Fish Department (1993) reported similar summertime warming trends. They also suggested that rather shallow, return-current channel backwaters would cool to near ambient river temperature at night even if the backwater remained relatively stable. The combination of increased temperature and concentration of organic material in these areas makes return-current channel backwaters relatively productive zones capable of providing forage for young native fish during summer months.

Return-current channel backwater areas are most abundant at lower flows. Pucherelli (written communication, 1987) found that the number and area of backwaters between RM 52 and RM 72 increased as flow decreased. As river stage increases, return-current channel backwaters become eddies. Recent examination of aerial videotape suggests similar trends, with a nearly threefold increase in the numbers of backwaters as flows decline from 15,000 cfs to 5,000 cfs (Wegner, written communication, 1992). It is speculated that most return-current channel backwater habitats are functionally eddies at flows above 10,000 cfs.

Return-current channel backwaters have a tendency to fill with sediment through time. Excavation (maintenance) of return-current channel backwaters takes place in eddies during periods of high flow (Pucherelli, written communication, 1987). The exact magnitude of flows necessary to maintain or restore filled backwaters is not precisely known. Comparisons of backwater counts at near 5,000-cfs flows made during postflooding events in 1985 with backwater counts made during 5,000-cfs releases in 1991 suggest a near 80-percent decline in the number of backwaters (Weiss, written communication, 1993). This decline is attributed to filling with sediment and vegetative growth.

Daily fluctuations may destabilize these areas (Valdez, 1991) by alternately draining and refilling them with cold mainstem water. Forcing juvenile native fish into the mainstem as a result of these processes may result in direct mortality from several causes: temperature shock; high energy expenditures from movements in high velocity, cold waters and thus reduced growth; and exposure to non-native predators.

The indicator for mainstem recruitment and growth of young native fish is a combination of minimum reliable stage during the summer rearing period (principally July through September) and daily range of fluctuation. High daily minimum flows (above 10,000 cfs) reduce the numbers of return-current backwater habitats, and daily fluctuations in river stage have the potential to destabilize them by alternately flooding and drying them.

Adult native fishes are more tolerant of low temperature and variable flow than are larvae and juveniles. Nonetheless, temperature, availability of food items, and energy expenditures can constrain growth. Because the number of eggs produced by a female depends on the size and condition of an individual, reduced growth can have an influence on the reproductive potential of an individual fish and the population as a whole. The indicator for growth among the adult native fishes is the aquatic food base.

Non-Native Warmwater and Coolwater Fish

While cold water trout species make up the majority of non-native fishes in the Colorado River through Glen and Grand Canyons, other species have been introduced through the years (see table III-10). Closure of Glen Canyon Dam left a mixture of warmwater fishes that had previously resided in the river and trout that were being introduced to the fishery.

Currently, Lake Powell is managed as a warm/coolwater fishery featuring largemouth bass, smallmouth bass, bluegill, walleye, crappie, channel catfish, and striped bass. The primary forage for this multilayered sport fish community is the threadfin shad.

The non-native warmwater fish present near the damsite at the time of closure included common carp, channel catfish, fathead minnow, green sunfish, killifish, largemouth bass, mosquito fish, and red shiner (Stone, 1965).

The presence of these warmwater and coolwater species is an issue of considerable importance. Competition from and predation by non-native fish have been cited along with habitat modification as causes of the decrease of native fish in the Colorado River system (Minckley, 1991). The cold waters released from Glen Canyon Dam not only

Table III-10.—Introduced fish present in the Colorado River through Glen and Grand Canyons

Species	Temperature preference	Occurrence
Rainbow trout	Cold	Abundant–upper; common–middle
Brown trout	Cold	Common in Middle Gorge
Brook trout	Cold	Rare
Cutthroat trout	Cold	Rare
Channel catfish	Warm	Common–middle and lower (Present Lakes Powell and Mead)
Carp	Warm	Common–middle and lower
Fathead minnow	Warm	Common–lower
Striped bass	Cool	Seasonal–lower (Common–Lakes Powell and Mead)
Red shiner	Warm	Absent (Present Lake Mead)
Green sunfish	Warm	Rare–lower (Present–Lakes Powell and Mead)
Largemouth bass	Warm	Rare–lower (Present–Lakes Powell and Mead)
Smallmouth bass	Cool	Absent (Present Lake Powell)
Walleye	Cool	Rare (Present Lake Powell)
Plains killifish	Warm	Rare–lower
Black bullhead	Warm	Rare

put some of the warmwater native fish at risk by limiting natural reproduction but also may benefit them by limiting the numbers and activities of non-native predators and competitors.

Striped Bass and Other Predators. One way that non-native fish directly influence native fishes is through predation upon one or more of their life stages. Because of its position in the large lakes above and below Glen and Grand Canyons and its reputation as a voracious predator, the striped bass could become an important influence on native fish populations. Generally, striped bass are found in the lower reaches of Grand Canyon below Lava Falls, but in recent years isolated individuals have been captured near the mouth of the LCR.

Striped bass in the Southwest are far from their native range on the Atlantic coast, where they typically reside at sea but ascend rivers along the coastal plain to spawn. After spawning, they exit the riverine spawning areas (Crance, 1984), but some individuals remain resident in cool tailwater areas (Coutant, 1985). Striped bass appear to display this ascent and retreat spawning behavior in the Southwest, and recent research by BIO/WEST, Inc. (unpublished) has suggested that the seasonal occurrences of striped bass in Grand Canyon coincide with their spawning (April through July). Primary concerns of this research include whether operational changes would encourage greater movement of striped bass upstream into Grand Canyon, whether bass might become resident in the river, and whether they might feed on native fish.

The striped bass is not the only predator of native fish. Other non-native warmwater fish are already established in the river. Perhaps prime among those established is the channel catfish. The channel catfish is an omnivore by nature and can compete with native fishes for food as well as prey upon them. Channel catfish are established in and around the LCR and are potential predators of native fish, including the endangered humpback chub. Their numbers appear to increase with distance from the dam, reaching peak abundance below Lava Falls at the western end of Grand Canyon (Haden, 1991). Largemouth bass and green sunfish, currently restricted to the lower river reaches, also are potential predators of native fish.

Trout, among the most numerous fish in Glen and Grand Canyons, also have the potential to act as predators of native fishes. Brown trout, usually concentrated between Clear and Bright Angel Creeks (Valdez, 1991), typically feed on fish (piscivorous) at larger sizes. Rainbow trout, though generally not considered piscivores, also have been implicated as possible predators on young native fish and fish eggs (Maddux et al., 1987; Haden, 1991; Angradi et al., 1992; Valdez, 1991). Populations of trout use some of the same tributaries for spawning as do native fish. It was suggested by Maddux et al. (1987) that trout and native fish use tributaries in different seasons. Native fish rely on the tributaries for spawning during spring months and for rearing during summer months, while trout rely on tributaries during winter months for spawning and spring months for rearing.

Other coolwater fish also could be introduced accidentally from Lake Powell. The walleye and smallmouth bass, currently expanding their distribution in Lake Powell, could reside in reaches in Glen and Grand Canyons.

Establishment and Expansion of Other Competitors. While predation has a very direct effect on the abundance of native fish, competition has an indirect—but no less important—effect on the abundance and well-being of native fish. Fish life requirements include both the physical characteristics of where they live and reproduce as well as the food resources they depend on for energy and growth. When access to food resources and shelter is limited through competition, the abundance of the disadvantaged competitor is often reduced. While competition is difficult to document, its results usually are striking. Native fish living in altered habitats and competing with non-native fish for limited resources most often have been restricted, or even excluded, in their native range.

Potential competitors with native fish include carp, fathead minnow, killifish, rainbow trout, and red shiner and may include some of the omnivorous species that also prey on native fish. These competitors may share rearing habitats in backwater areas and eddies, upon which native fish appear to be dependent.

Cold water releases from Glen Canyon Dam, and possibly daily fluctuations and flood events, have considerably reduced the numbers of individuals and numbers of species (Minckley, 1991). Main channel habitat conditions for all warmwater non-natives are marginal. Channel catfish, carp, and fathead minnow persist and probably rely upon tributary spawning (and backwater spawning in the case of fathead minnow) to maintain their populations.

Reproduction, Recruitment, and Growth. Spawning and rearing habitat for warmwater non-natives is limited in the main channel due to perennially cold releases. Minimum reliable discharge is used as the indicator of tributary accessibility for reproduction, as it is for native warmwater fish. Growth of warmwater non-natives is limited, as is growth of native fish. The aquatic food base is used as the indicator for growth potential of non-native warmwater and coolwater fish.

Trout

The issues defined for detailed analysis under this topic include trout spawning and recruitment and trout food resources. Trout fishing, another important issue, is discussed under RECREATION later in this chapter.

As early as the turn of the century, fish not native to the Colorado River were introduced for sport. For the most part, these were warmwater fish from the Eastern United States, but they also included European transplants (carp, brown trout) considered at the time to be valuable introductions for sport fishing (Arizona Game and Fish Department, 1990b). Plans for the construction of Glen Canyon Dam and the anticipated transition of the Colorado River through Glen and Grand Canyons to a regulated cold water stream provided the opportunity to develop a multifaceted reservoir fishery above the dam and a trout fishery below the dam.

Trout can be found throughout the Glen and Grand Canyon reaches of the river. The "trout" of the study area actually are represented by a number of species. Rainbow trout make up the major part of the sport fishery in the 15-mile reach below Glen Canyon Dam and the trout fishery in Grand Canyon. Brook trout, brown trout, and cutthroat trout also have been stocked in the Glen and Grand Canyon reaches of the river. Brown trout, never stocked in the Lees Ferry area, increase in abundance below Clear Creek; brook trout have nearly disappeared from the system. Trout are not native to this stretch of the river and were introduced for sport purposes by NPS and the U.S. Forest Service in the 1920's. NPS discontinued stocking in 1964. The AGFD began stocking rainbow trout at Lees Ferry in 1964 (Reger et al., 1989), a practice that continues today.

Stocking practices have changed through time, shifting from stocking catchable-sized trout (1964-76) to stocking "fingerling" fish (1976-91). The shift from stocking catchable trout was prompted by the establishment of a reliable food source for trout, *Gammarus lacustris* (Reger et al., 1989). Following 1977, the reputation and importance of the trout fishery at Lees Ferry grew appreciably and established it as a premier fishery.

Since the early 1980's, the size of fish harvested from the sport fishery has consistently declined. In 1990 and 1991, the condition (relative plumpness) of rainbow trout showed a marked decline (Arizona Game and Fish Department, 1993), and a large number of trout apparently died. The abrupt decline was attributed to several factors:

- Extended low flow periods (5,000 cfs) during GCES research releases that may have restricted food resources
- Regulation changes that increased the number of individuals maintained in the population
- Eruption of a parasitic infestation in the trout

It is likely that a combination of these factors resulted in the population decline. It has been suggested that the eruption of the parasitic infestation may have been a result of crowded and limited forage (Arizona Game and Fish Department, 1993). The condition of individual trout recovered somewhat during 1992, likely as a result of interim operations implemented in August 1991.

Adult Stranding Mortality. Daily fluctuations have resulted in the stranding of adult rainbow trout, primarily during spawning. Spawning trout display a strong fidelity to a spawning site and may not abandon it even as the water recedes around them (Angradi et al., 1992), thus making them particularly susceptible to stranding.

The causes of death for stranded adults included dewatering, high water temperature, high pH and low dissolved oxygen in stranding pools, and exposure to predation by birds and land animals. All of the evaluated potential stranding pools are isolated at minimum flows of 1,000 cfs or 3,000 cfs. Stranding is less common in river reaches below the confluence with the Paria River, where trout spawning is tributary-oriented. As with native fish, trout reproduction and recruitment below the confluence with the Paria relies on accessibility to tributaries (Angradi et al., 1992).

Investigation of 11 major stranding pools from February 1990 through March 1991 (Angradi et al., 1992) located 1,924 adult trout stranded by fluctuations. Fifty-one percent of those were dead or dying when investigators arrived at the stranding pools. This incomplete sample of stranded fish—based on up to four visits per month per stranding pool—is equal to about 4 percent of the trout harvested in 1988 at Lees Ferry and nearly

20 percent of the trout harvested in 1991 (under very restrictive regulations). Because these typically are spawning fish, the effects are twofold:

- Relatively large individuals, the result of several years accumulated growth and of value to sport fishermen, are removed from the population.
- Potential reproductive contribution to the population is lost.

The presence of major stranding pools is a function of river stage. As stage increases, the number of pools capable of stranding adults decreases. The number of stranding pools (expressed as a percentage of the 11 pools studied) at the reliable minimum flow is used as an index of stranding mortality for evaluation of the alternatives.

Mainstem Reproduction and Recruitment. The contribution of naturally reproduced trout to the Glen Canyon reach was estimated at approximately 27 percent during steady, high flow conditions by Maddux et al. (1988). Evidence suggests that interim operations have increased naturally reproduced trout in the Lees Ferry population. Arizona Game and Fish Department (1993) estimated that 78 percent of juvenile trout (smaller than about 8 inches) sampled in August 1992 were naturally reproduced.

The act of spawning is only one variable in determining how many naturally spawned fish are in the population. Attempts to reproduce are not limited by daily fluctuations, as evidenced by the stranding of adult spawning fish. Angradi et al. (1992) illustrated that redd sites were selected based upon location of acceptable spawning gravels, regardless of whether they would be exposed by receding river stage. Direct mortality of eggs (Maddux et al., 1988), fry, and young trout (Persons et al., 1985) caused by redd exposure, stranding of young fish, or forcing young fish into less acceptable rearing habitats can prevent successfully spawned young from surviving to a size large enough to be less susceptible to changing flow conditions. Maddux et al. (1988) showed that exposure of spawning redds for more than 10 hours resulted in near total mortality of eggs. Spawning sites are selected based upon acceptability of the gravels in which the redd will be excavated. Maddux et al. (1988) reported that spawning conditions in the Glen Canyon reach varied from year to year. They suggested that available habitat for spawning (gravels) may be changing in quality as well as quantity. They speculated that, since the high flows of 1983-84, erosion of gravel bars may be decreasing the quality and quantity of available spawning habitat. Angradi et al. (1992) found that the density of redds on gravel bars was related to the size distribution of gravels. They also speculated that loss of finer gravels may be resulting in reduced area available for suitable spawning sites in the uppermost reaches of Glen Canyon, particularly since there are no sources to replenish those gravels.

Angradi et al. (1992) reported that fewer than 10 percent of the redd sites they mapped from the Glen Canyon reach (on four spawning bars) were unaffected by minimum flows as low as 3,000 cfs. These data suggest that at least 90 percent of the utilized spawning habitat was within the zone of potential daily fluctuation under no action and, if used by trout, the spawn would likely fail. Actual minimums during peak trout spawning seasons could be as low as 1,000 cfs.

These redd sites mapped by Angradi et al. (1992) are used as the indicators of effects on natural reproduction and recruitment in the reach between Glen Canyon Dam and the Paria River (the Lees Ferry fishery). The proportion of redds that would not be exposed (expressed as a percentage) is used as the indicator. Ultimately, this proportion may determine whether the fishery must be maintained by stocking or could become self-sustaining (a condition desired by the angling public).

Downstream Reproduction and Recruitment. While the trout in Glen Canyon spawn in the main channel, it is assumed that downstream populations (in Grand Canyon) are largely maintained by tributary spawning. It is unknown whether main channel spawning significantly contributes to the population.

Tributary populations may have persisted for many years with limited use of the main channel. NPS and the U.S. Forest Service began stocking those tributaries in the 1920's (Carothers and Minckley, 1981), and use of the mainstem was likely limited in summer months when water temperatures were unsuitable for trout. Tributary populations have persisted without augmentation since the cessation of stocking in 1964. Accessibility to tributaries is the prime issue for maintaining these populations. It is assumed that trout access has been sufficient under pre-1989 operational criteria, since trout dominate in these upper river reaches. Only extremely low flow in the mainstem, especially when coupled with low discharge from the tributary, would preclude its use.

Growth and Condition. Trout tend to be opportunistic feeders and often change the foods consumed based on their size. In Glen and Grand Canyons, trout fry appear to be rather dependent on zooplankton in the mainstem (Haury, 1988; Maddux et al., 1988). Adults, on the other hand, fed on chironomid midge larvae, *Cladophora*, *Gammarus*, and decaying organic material. Fish material appeared in less than 1 percent of stomach samples (Maddux et al., 1988).

Rainbow trout usually are not considered herbivores, but some researchers have indicated that the occurrence of *Cladophora* in their stomachs is no accident, or at least that they have benefited considerably from consuming it. It can be argued that *Cladophora* is consumed coincidentally when trout forage for bottom dwelling invertebrates like *Gammarus*. It also has been argued that trout benefit directly from feeding on *Cladophora* as well as indirectly by consuming the invertebrates that depend upon it (Pinney, 1991). Montgomery et al. (1986) and Leibfried (1988) proposed that the high fat content of the diatoms encrusting *Cladophora* provide a ready energy source and may be partially responsible for the enhanced growth of trout in the tailwater area. The amount of *Cladophora* in the diet of adult rainbow trout generally declines from upstream populations at Lees Ferry to downstream populations in the lower Grand Canyon, which probably reflects availability (Maddux et al., 1988). The aquatic food base is used as the indicator for growth and condition of trout.

Trout species may be potential predators of native fish. Brown trout in Grand Canyon, concentrated mainly between Clear and Bright Angel Creeks, typically become predaceous at larger sizes (Maddux et al., 1987; Carothers and Minckley, 1981). Rainbow trout in Grand Canyon generally are not considered fish eaters but have been implicated as possible predators of native young fish and eggs in some tributaries (Haden, 1991).

VEGETATION

Plant communities found in northcentral Arizona reflect the influences of climate, topography, soil, and elevations that characterize the area. For example, the uplands surrounding Grand Canyon support a unique blend of plants influenced by three adjacent deserts: the Mohave to the west, the Sonoran to the south, and the Great Basin to the east and north (Carothers and Brown, 1991). However, the Colorado River and operation of Glen Canyon Dam have little effect on the majority of plant life surrounding Grand Canyon. The river, as influenced by dam operations, affects a narrow band of vegetation along the river corridor known as the riparian zone. The riparian zone will be the focus of this discussion and chapter IV analyses.

Riparian Vegetation

Plant communities affected by releases from Glen Canyon Dam exist in a restricted zone at the juncture between the river's aquatic communities and upland plants adapted to desert conditions. Riparian zones are supported by inflowing water—either perennial, intermittent, or ephemeral—and occur in a continuous area inhabited by aquatic through semiaquatic, riparian, semiriparian, to upland vegetation (Johnson and Lowe, 1985). There is a dynamic interaction between water and plants in the riparian zone: the availability of water supports plants that could not otherwise survive in a desert climate, and the type of vegetation that survives reflects the water regime that supports it.

Thick growth and the variety of plant species present in the riparian zone provide a structural diversity that makes these areas some of the most important wildlife habitat in the region. Riparian vegetation supplies food and cover for abundant insects emerging from the river, as well as its own resident invertebrate populations. These resources, in turn, support numerous mammals, birds, reptiles and amphibians, and other invertebrates (Carothers and Brown, 1991). Vegetation may trap sediment during high flows, and nutrients within the sediment become available for plant growth. Various plants in the riparian zone and many of the animals supported by it are important to Native Americans.

Because of the dynamic interaction between riparian vegetation and water availability, changes in dam operations that change specific water-release patterns would be expected to affect the abundance and distribution of plants. These linkages—and anticipated changes—form the basis of analyses in the remainder of this document. However, because of the variety of plants growing in the riparian zone and their differing water requirements, a comprehensive evaluation of the effects of all alternatives on all plants is beyond the scope of the report. Therefore, two plant groups were selected to serve as indicators of riparian vegetation for detailed evaluation: woody plants (trees and shrubs) and emergent marsh plants (cattails and others). The following discussion explores existing conditions and how they reflect the predam environment and current dam operations.

Woody Plants

Plants in this group occur throughout the riparian zone from the dam to Separation Canyon (although data are available only to Diamond Creek). However, predam flows and postdam discharges have created conditions that define two subzones of vegetation: the OHWZ and the NHWZ (figure III-28). Each zone has its own water-dependent characteristics. Woody riparian plants also are associated with Lakes Powell and Mead and, because dam operations can affect this vegetation, are discussed below.

Old High Water Zone. Vegetation found within the OHWZ reflects historic and current regional climates and the influences of the high water stage of unregulated flows. Before Glen Canyon Dam, floodflows regularly scoured most vegetation from the river's banks up to an elevation about equivalent to the 100,000-cfs stage (Brian, 1987). The OHWZ developed above the scour zone from a stage equivalent to about 123,000 cfs and in some places extended up the bank to about 300,000 cfs (Stevens and Ayers, 1993). Thus, plants that can withstand conditions created by periodic flooding characterize the OHWZ. Dominant plants include netleaf hackberry in the upper reaches of Marble Canyon and other sites and honey mesquite and catclaw acacia in the lower reaches of the river.

There are an estimated 1,870 acres of vegetation in the OHWZ (Stevens, unpublished data, 1992). The exact relationships between the postdam river and the OHWZ are not clear. Some believe that without periodic inundation, plant germination in the OHWZ is limited, and growth of established plants is affected (Anderson and Ruffner, 1987). However, mesquite and acacia (including young plants) can be found growing at sites well-removed from the influences of river flooding. Age of plants may also play a role; plants in the OHWZ are long-lived, with some trees aged at several hundred years old (Hereford, verbal communication, 1992).

The OHWZ may be declining in some areas. Dying trees are evident along some river reaches. Mesquite appears to be less drought resistant than acacia, and the latter may become the dominant tree in the OHWZ (Anderson and Ruffner, 1987). Reduced flood frequency (a change in water regime) has permitted upland plants to move into some OHWZ areas. Common upland plants adjacent to or moving into the OHWZ include barrel cactus below RM 26, brittle bush below Marble Canyon, creosote bush and ocotillo below Havasu Creek, and cholla cactus below Lava Falls (Carothers and Brown, 1991).

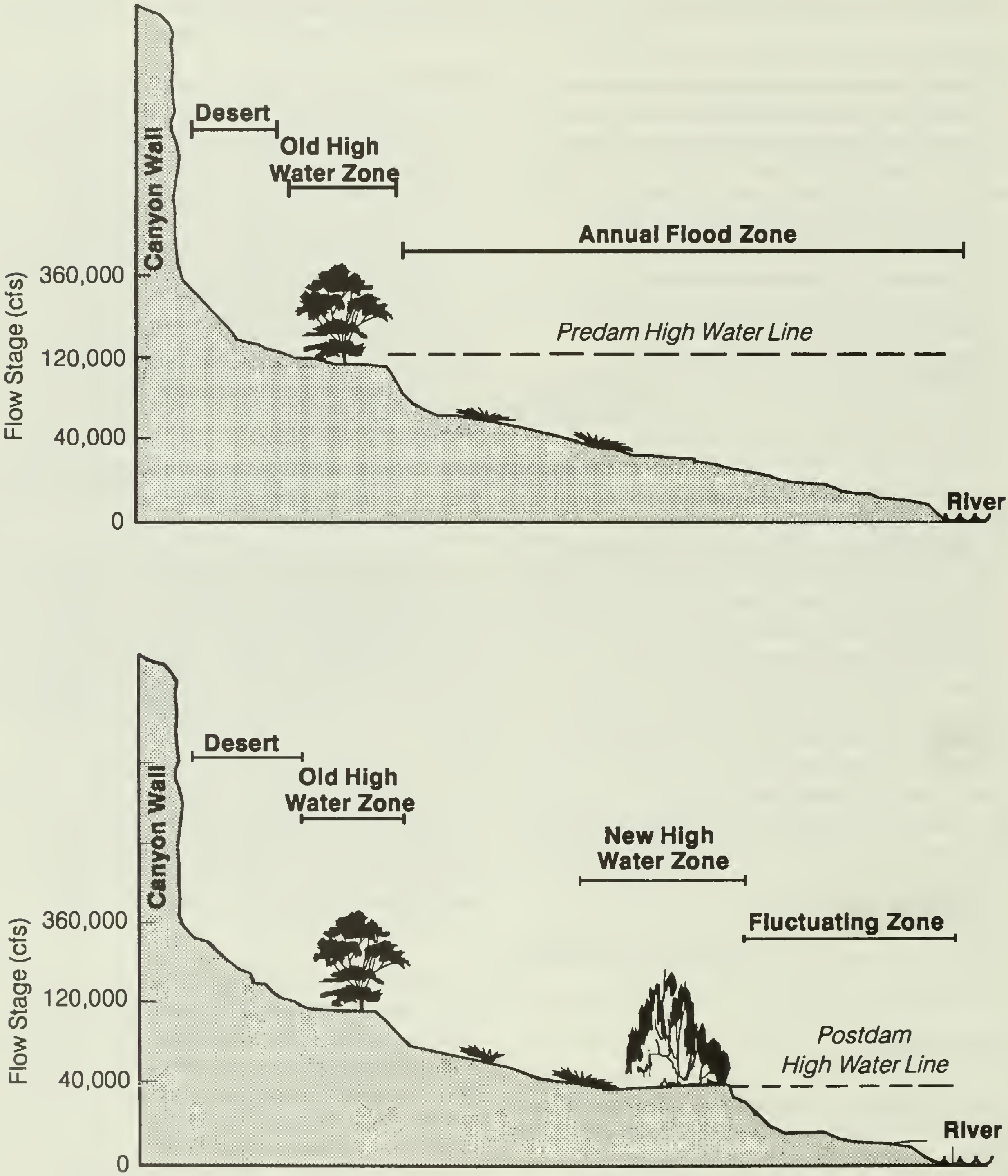


Figure III-28.—Grand Canyon riparian zone, predam (before 1963) and postdam (after 1963).

New High Water Zone. Before construction and operation of Glen Canyon Dam, little vegetation grew in the scour zone below the OHWZ. After the dam controlled annual spring flooding, additional vegetation began to develop near the river below the OHWZ. From 1963 to 1980, as the dam filled, a zone of vegetation developed that was characterized by high densities near the high water stage of the dam-regulated river (Carothers et al., 1979). This vegetation developed rapidly and has become known as the new high water zone. Between 1965 and 1973, vegetation at selected sites increased at a rate of one-half acre per river mile per year (Pucherelli, 1986). Between 1973 and 1980, the rate of increase slowed to one-fourth acre per mile per year.

The NHWZ exists in the predam scour zone (figure III-28), between the discharge stages of about 22,000 to 40,500 cfs (Stevens and Ayers, 1991). Common woody plants in this zone include both native and non-native species: seep-willow, arrowweed, desert broom, coyote willow, and tamarisk. Tamarisk, a non-native tree common throughout the Southwest, is the dominant woody plant in the NHWZ. Mesquite and other plants have moved into the NHWZ from the OHWZ.

Vegetation occupies approximately 1,320 acres in the NHWZ (Stevens, unpublished data, 1992). Woody riparian vegetation is not continuous along the river's banks throughout the canyon. Rather, stands of dense vegetation are found on sediment deposits associated with debris flows from tributaries or on lateral margin deposits between rapids. Between sediment deposits, scattered plants grow between rocks and boulders. In many locations, vertical rock walls confine the river and support no vegetation. Between Lees Ferry and Diamond Creek, less than half the riverbank miles support dense riparian vegetation.

Floodflows.–Riparian systems change as the water conditions that bound them change. The development of riparian vegetation in the NHWZ that began with the construction of Glen Canyon Dam was interrupted by high floodflows in 1983-86. In 1983, flows in excess of 90,000 cfs removed more than 50 percent of the plants at sample sites below the 60,000-cfs stage by either scouring, drowning, or burial beneath newly deposited sediments (Stevens and Waring, 1986).

Different plants are affected differently by high discharges. Species with deep taproots, such as acacia, mesquite, and tamarisk, are resistant to scouring, and losses ranged from 0 to 20 percent (Stevens and Waring, 1986). In contrast, high scouring losses (68 to 100 percent) were experienced by shallow-rooted clonal species such as coyote willow, arrowweed, giant reed, cattail, and bulrush. Willow, acacia, tamarisk, and arrowweed were resistant to drowning, while mesquite (50-percent loss), *Brickellia* spp. (62-percent loss), *Baccharis* spp. (64- to 79-percent loss), *Aplopappus* spp. (83-percent loss), and desert-adapted species drowned from inundation. Species tolerant of burial included tamarisk and clonal forms such as horsetail, giant reed, willows, camelthorn, aster, and arrowweed. Burial-intolerant species included mesquite, acacia, *Baccharis* spp., *Brickellia* spp., or desert plants. The riparian zone is a dynamic system, and Stevens and Ayers (1991) estimate that levels of riparian vegetation before interim flows were at 75 percent of 1982 levels.

Daily Flows.–While major flood events cause a temporary rearrangement of plant communities, daily release patterns dictate stability of sediment deposits and ultimately the area that will be occupied by riparian vegetation. Thus, daily fluctuating releases from Glen Canyon Dam influence expansion of vegetation from the NHWZ to sites at lower elevations. Fluctuating releases wet a large area that encourages seed germination, but recurring changes in river stage uproot seedlings before they can become established in sandy substrates. Tamarisk has been successful in expanding into some cobble bars disturbed by the flood releases of 1983-86 (Stevens and Waring, 1986).

Daily fluctuations not only affect area coverage of vegetation, but also species composition to some degree. At many sites, tamarisk marks the 30,000-cfs stage—unable to expand to high elevations without the disturbances of higher flows and unable to expand to lower elevation because of daily fluctuations. Sediment deposited by the high flows of 1983 is no longer wetted and is being colonized by coyote willow and arrowweed via rhizomes or underground running shoots from adjacent stands.

Plant species composition also depends on location in Grand Canyon. River elevation decreases almost 2,000 feet from Lees Ferry to Lake Mead, and the accompanying climatic changes affect plant community composition. For example, coyote willow is more common in the upper canyon, while arrowweed and horsetail are more common in the lower canyon. While various herbaceous plants form a ground cover near the high water stage below woody plants in the upper canyon, bermuda grass becomes the dominant ground cover at many sites below Havasu Creek.

Lakes Powell and Mead. Woody riparian vegetation also is associated with Lakes Powell and Mead. Lake levels have declined since the high floodflows of 1983-86 because of a regional drought. Riparian vegetation has increased on sediment exposed by declining water levels. Woody riparian vegetation has become particularly abundant below Separation Canyon into Lake Mead.

Emergent Marsh Plants

Common emergent marsh plants found in the study area include cattails, bulrushes, and giant reed. Another plant—horsetail—is not generally considered emergent marsh vegetation but is included in this discussion because it develops and grows under conditions similar to the other species listed. These conditions include a reliable water source and sediment properties found only at certain sites.

Deposits containing clay/silt sediments are necessary for development of emergent marsh vegetation (Stevens and Ayers, 1993). Low water velocity sites, such as eddies and return-current channels along the river (see figure III-16) and the deltas of Lakes Powell and Mead, permit clay/silt particles to settle from suspension. These deposits provide a higher quality substrate for seed germination and seedling establishment than underlying sand because of their greater nutrient levels and moisture-holding capacity. With an appropriate water regime, these are the sites that support emergent marsh vegetation.

Marsh plants were selected as one of the indicators of riparian vegetation because their requirements place them between the aquatic and terrestrial systems. Together with woody plants (which require drier conditions), these indicators are assumed to represent the range of riparian system responses to dam operations.

Marsh Plants Along the Colorado River. Patches of marsh vegetation can be found in backwaters, channel margins, seeps and the mouths of tributary streams, and in other isolated sites within the fluctuating zone located between the NHWZ and the minimum-discharge stage. Prior to closure of Glen Canyon Dam, annual floodflows prevented the establishment of marsh plants along the Colorado River in Grand Canyon (Stevens and Ayers, 1993). By 1976, 65 distinct sites supported about 12 acres of marsh vegetation. Further expansion occurred until 1983-86, when floodflows eliminated cattails and bulrushes from all but 17 sites.

Stevens and Ayers (1991) identify two types of marsh plant associations. Wet marsh plants include cattails, bulrushes, and some less common emergent plants. These associations develop on sediment deposits containing about half clay/silt and half sand, at sites between 10,000- and 20,000-cfs stages that are inundated once every 1.1 to 2.5 days (figure III-29). Patches of dry marsh plants (horsetail, giant reed) occur between discharge stages of about 20,000 to over 31,500 cfs that are inundated once every 3 days.

Emergent marsh plants commonly occur in small patches along the river between the dam and Lees Ferry (Stevens and Ayers, 1991). The average size ranges from 0.05 (dry) to 0.1 (wet) acre, with the largest (Cardenas Marsh), just over 1 acre in size. The aggregate acreage of emergent marsh plants along the Colorado River between the dam and Diamond Creek is 62 acres (19 acres of wet and 43 acres of dry marsh plants).

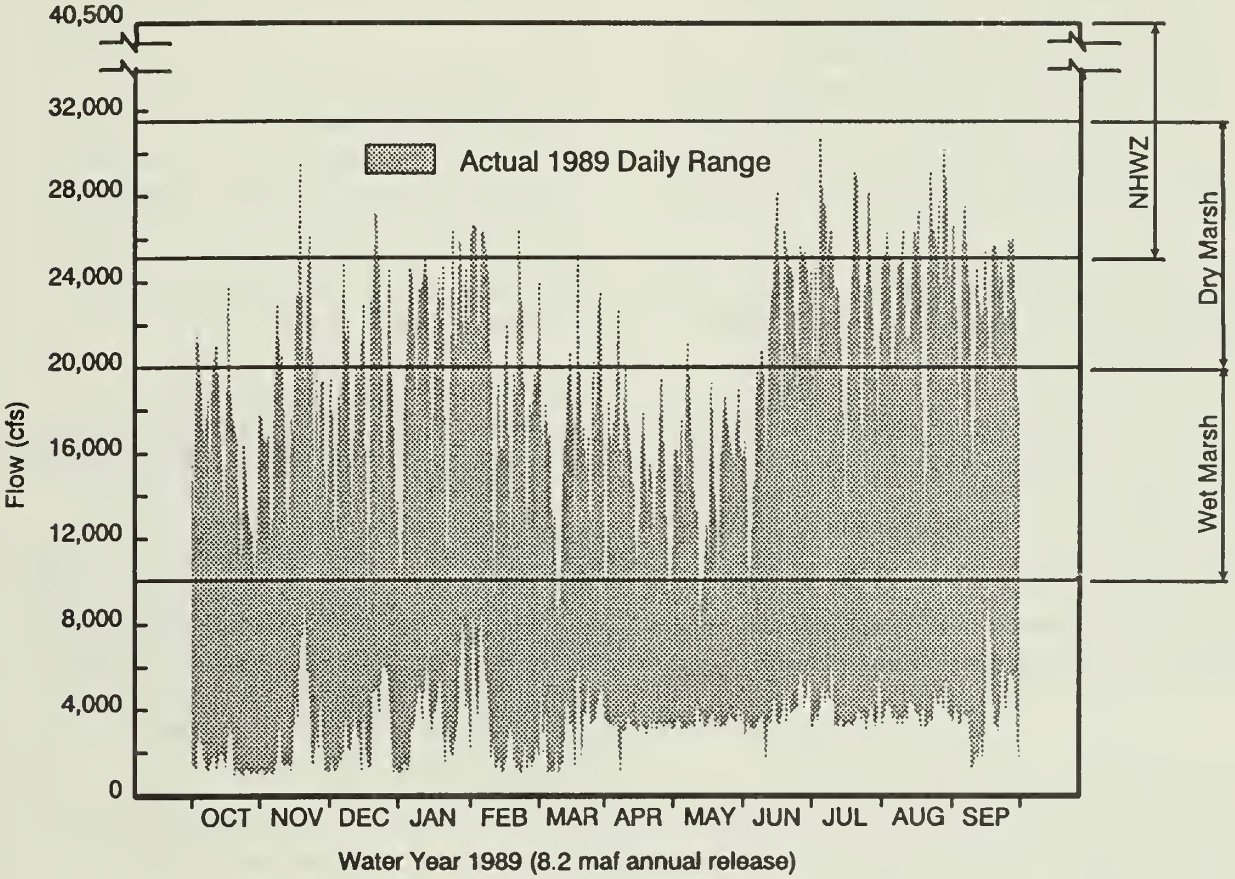


Figure III-29.—Wet marsh, dry marsh, and new high water zone plants occupy flow-stage bands defined by frequency and duration of inundation.

Marsh Plants Associated with Lakes Powell and Mead. As with woody plants, emergent marsh vegetation is associated with Lakes Powell and Mead and has increased in coverage since the high flows of 1983-86. Again, this is particularly true for Lake Mead, which supports hundreds of acres of cattails and bulrushes. Although no data are available, it is assumed that these stands of vegetation have the size, continuity, productivity, and other properties necessary to function as true marshes.

WILDLIFE AND HABITAT

Wildlife is both diverse and abundant along the river corridor through Glen and Grand Canyon. Riparian vegetation, which developed along the river after construction of Glen Canyon Dam, plays an important role as habitat to support this diversity and abundance. No detailed survey data prior to dam construction are available, but it is assumed that wildlife inhabiting the river corridor were species characteristic of the adjacent upland desert, tributaries, and OHWZ communities. The densities of some species in the riparian zone today are among the highest recorded anywhere. It is reasonable to assume that, as riparian vegetation increased, habitat and wildlife also increased to the levels observed today.

Riparian vegetation, and particularly that in the NHWZ, is among the most important wildlife habitat in the region. The structural diversity of the plant species and thick growth found in the riparian zone provides many habitat resources in a relatively small area. Riparian plants provide food and cover for insects emerging from the river, as well as providing habitat for its own resident invertebrate populations. The plants, insects, and other resources found in the riparian zone, in turn, support numerous mammals, birds, reptiles and amphibians, and other invertebrates.

Wintering waterfowl found along the river corridor cannot be directly linked to riparian vegetation, but they are attracted to and use the clear open water of the Colorado River within Glen and Grand Canyons. Although no predam survey data are available, the turbid river water was probably not very attractive to waterfowl. Dam construction resulted in clear, cold water that now supports an abundant green alga, *Cladophora glomerata,* and the aquatic food chain associated with it. Increased waterfowl numbers are probably a response to this increased aquatic productivity (Stevens and Kline, written communication, 1991).

The variety of animals present in the river corridor, their habitats, and how they use their habitats result in 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 Glen Canyon Dam operations. These linkages and anticipated changes form the basis for analyses in the remainder of this document. Two resources were selected for detailed evaluation to serve as indicators of wildlife: riparian habitat (woody and emergent marsh plants), to represent terrestrial wildlife, and the aquatic food base, to represent wintering waterfowl requirements. The following discussion explores existing wildlife and habitat and how they reflect predam conditions and dam operations.

Riparian Habitat (Woody and Emergent Marsh Plants)

Mammals

Some 26 species of mammals are considered uncommon to abundant along the Colorado River corridor in Grand Canyon (Carothers and Brown, 1991). Of these species, only the deer mouse depends directly on the riparian zone for its existence. Deer mice were not found along the river prior to construction of Glen Canyon Dam. Riparian vegetation may have provided a competitive edge for deer mice over cactus mice along the river's banks. Both the brush mouse and pinyon mouse have increased in numbers since closure of the dam and subsequent development of the NHWZ. Small mammals use all types of vegetation, from dense patches of marsh plants to scattered desert shrubs.

The beaver is a large aquatic rodent that lives in dens in stable deposits above the fluctuating zone and feeds on riparian vegetation. Although the river corridor through Grand Canyon may not appear to be beaver habitat, Larry Stevens (unpublished data, 1992) developed a conservative 1991 estimate of 200 beavers between Lees Ferry and Diamond Creek (225 miles). Beavers can affect plant species composition and coverage by their feeding activities. Cuttings and drag marks from these animals are common on beaches supporting stands of coyote willow.

Six bat species are uncommon to abundant along the river corridor (Carothers and Brown, 1991). While these species also inhabit desert habitats, they may be attracted to the river corridor by the insects associated with the river and riparian vegetation. Bats are important prey for peregrine falcons (Brown, B.T., 1991b).

There is one record of the spotted bat in the river corridor. This species is mentioned here because it is a candidate species under the Endangered Species Act. Very little is known about the spotted bat or its habitat requirements. The single record indicates that it is rare, and this species will not be treated in detail in this document.

Ringtail and the western spotted skunk are among the most common small mammals in the study area. These species may have become more abundant since construction of the dam. Whether riparian vegetation has contributed to this increase or human use at beach campsites has increased their food supply is unknown (Carothers and Brown, 1991).

Desert bighorn sheep and mule deer are the largest mammals that use sections of the river corridor. Bighorn sheep come to the river to drink and feed during the heat of summer (Carothers and Brown, 1991). Although rapidly increasing discharges may occasionally strand individual animals, the size, strength, and mobility of these two species make it unlikely that river discharge causes direct effects.

Birds

The importance of riparian vegetation as wildlife habitat, specifically in the NHWZ, is exemplified by bird use. Some 303 species of birds have been recorded in the Grand Canyon region, with 250 (83 percent) of these in the river corridor (Johnson, 1991). Most birds use the corridor as a travel lane through the desert and are not affected by dam operations. However, birds that nest in the riparian zone along the river corridor are directly and indirectly affected by flows.

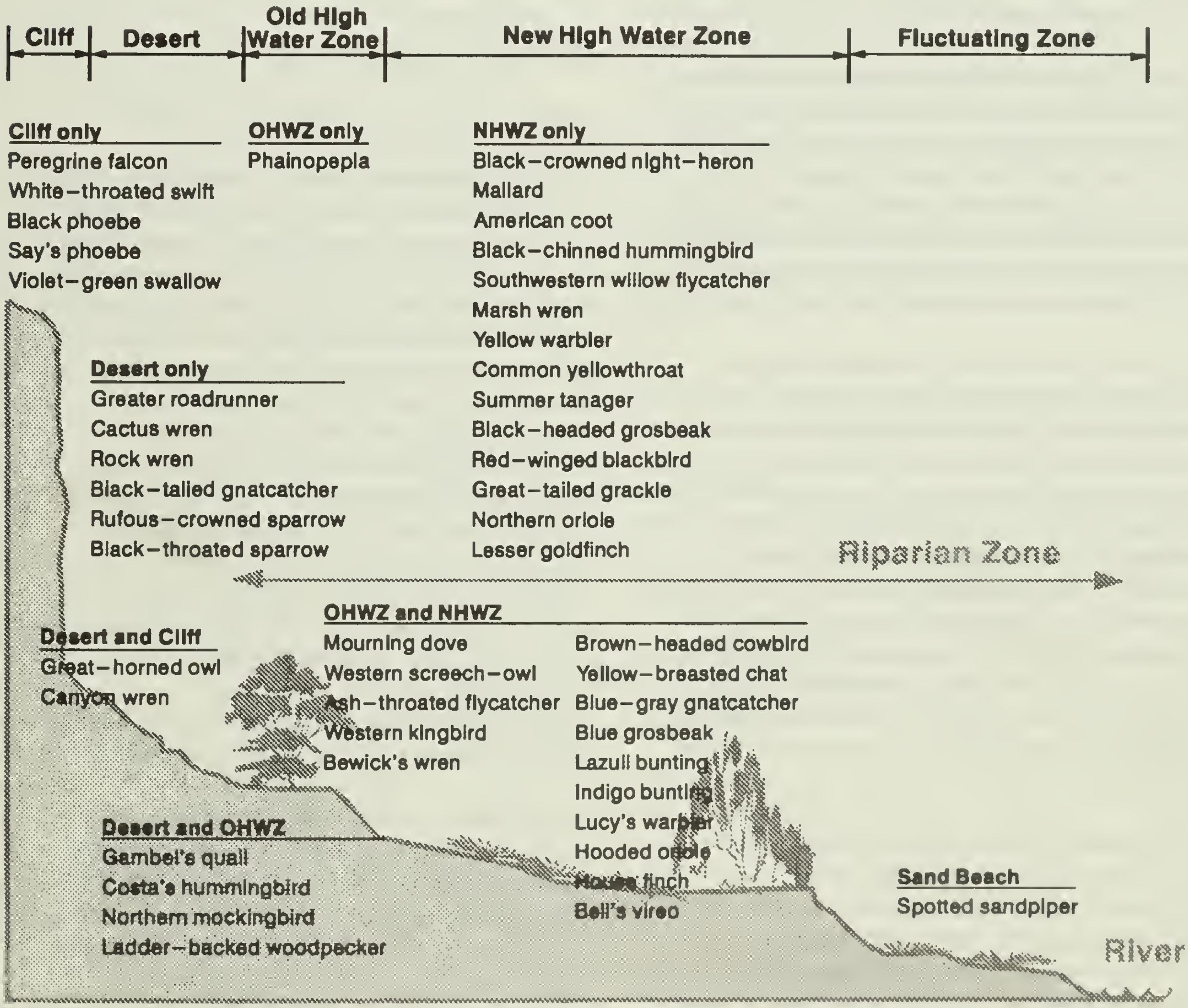


Figure III-30.—The importance of riparian vegetation as wildlife habitat is exemplified by nesting birds. The majority of birds nesting along the river corridor (30 to 48 species) nest in riparian vegetation.

Some 48 species of birds nest along the river (modified from Carothers and Brown, 1991). Fifteen species nest in both the OHWZ and NHWZ, with an additional 14 species nesting exclusively in the NHWZ (figure III-30). Only one species nests exclusively in the OHWZ. The number of nests at some sample sites in the riparian zone exceeded densities comparable to 800 pairs per 100 acres, among the highest ever recorded in North America (Brown and Johnson, 1988). Bell's vireo, summer tanager, hooded oriole, and great-tailed grackle have expanded their nesting ranges into Grand Canyon in response to riparian vegetation development (Carothers and Brown, 1991).

Riparian vegetation supplies both cover and food to birds and to a principal prey: insects. Of the 30 bird species that nest exclusively in the OHWZ, NHWZ, or both, 13 are insectivors; and at least 10 more bird species feed insects to their young. Other species that may not nest in riparian vegetation—such as phoebes, swifts, and swallows—feed on the insects associated with this zone.

Little direct effect has been recorded on birds nesting along the river corridor under historic dam operations. Bird populations were studied during the flood years of the 1980's when segments of riparian vegetation were inundated for long periods. Brown and Johnson (1988) recorded only one nest lost at flows up to 31,000 cfs. At higher discharges, bird nests located near water or on the ground risk inundation. Discharges of 40,000 cfs inundated 90 percent of common yellowthroat nests. Above 40,000 cfs, nests of Bell's vireo, yellow-breasted chat, black and Say's phoebe, and violet-green swallow were affected.

Mallards nest in dense vegetation—such as patches of emergent marsh plants—above the high water stage. Dense vegetation provides cover and abundant insects for foraging young. Mallard pairs were observed in almost every large eddy in Marble Canyon and upper Grand Canyon reaches in the summer of 1991 (Stevens, unpublished data, 1992).

Vegetation within the riparian zone is not continuous but rather occurs in disconnected blocks or patches. Factors that affect the patch sizes of vegetation—such as disease, fire, beach erosion, or colonization of barren sites—can indirectly affect habitat use by breeding birds. For example, patches of vegetation in the NHWZ must be at least 1.2 acres in size before black-chinned hummingbirds will use them for nesting (Brown, B.T., 1991c). Habitat patch size also is important to other species. Factors that decrease patch size would limit subsequent habitat use, while factors that permit increases in area would promote increased use by some nesting birds.

Amphibians and Reptiles

Some 27 species of amphibians and reptiles (herpetofauna) inhabit the river corridor (Carothers and Brown, 1991). In contrast to birds, only three species—Woodhouse's toad, leopard frog, and the desert banded gecko—are restricted to riparian vegetation. Although survey data are limited, the leopard frog is considered very rare in Grand Canyon. Recent sightings are limited to Cardenas Marsh (Miller et al., 1982) and Glen Canyon above Lees Ferry (Pinnock, verbal communication, 1993). Woodhouse's and red-spotted toads are common campsite visitors. The desert banded gecko is also considered rare (Carothers and Brown, 1991), but little is known about this nocturnal lizard in Grand Canyon (Miller et al., 1982). Most of the remaining species use both upland desert and riparian sites, and 10 of these species are considered common to abundant (Carothers and Brown, 1991). The densities of some species indicate the importance of the riparian zone to this group of wildlife.

Specific sites within the NHWZ, including the interface between the water and exposed sediment and open tamarisk sites, support lizard densities equal to or higher than any other sites reported in the Southwest (Warren and Schwalbe, 1988). The river is the source of abundant invertebrate food, while riparian vegetation—together with various other substrates including cliff faces—provides structural diversity. Together, these features create habitat conditions for some species of herpetofauna that may be unique in southwestern riparian zones.

While mammals and birds use riparian vegetation primarily for cover and secondarily for insect food, amphibians and reptiles focus their feeding activities on the many insects associated with riparian vegetation (Carothers and Brown, 1991). The importance of insects to herpetofauna is illustrated by the distribution of four common species: the side-blotched, the western whiptail, the desert spiny, and the tree lizard. Individuals of these species are most abundant within 16 feet of the water's edge, moderately abundant in the NHWZ and OHWZ, and least abundant at upland sites adjacent to the riparian zone (Warren and Schwalbe, 1988).

The NHWZ fluctuating zone is a particularly important source of food. The western whiptail commonly feeds in the fluctuating zone on harvester ants, stranded *Gammarus*, and black flies (Carothers and Brown, 1991). Warren and Schwalbe (1988) observed eight western whiptails and five desert spiny lizards feeding along a section of shoreline at Cardenas Marsh. Some species select specific substrate within the riparian zone. For example, side-blotched lizards are most commonly observed in open areas with rocks or bare soil, western whiptails on bare soil or litter, desert spiny lizards on large boulders or large tree trunks, and tree lizards on vertical cliff faces along eddies and quiet shorelines just above the splash zone (Warren and Schwalbe, 1988).

Numbers of lizards observed in the NHWZ were lowest in dense tamarisk sites (Warren and Schwalbe, 1988). Along the Gila River—a similar desert habitat with dense tamarisk—only desert spiny and tree lizards were captured in dense tamarisk (Jakle and Gatz, 1985). Jakle and Gatz speculated that dense stands of tamarisk do not provide suitable habitat for lizards.

Terrestrial Invertebrates

Invertebrates play a major role in both aquatic and terrestrial food chains in Grand Canyon. Some insects hatching and emerging from the river may swarm into the NHWZ and land on riparian vegetation, rocks, and other substrates, supplying abundant food for various forms of mammals, birds, and herpetofauna. Vegetation within the riparian zone also supports resident insect populations that are independent of the river. To date, several thousand species of insects, representing 260 families, have been identified along the river corridor (Stevens and Waring, 1986). Spiders, scorpions, and other invertebrates also are present in the varied substrates of the riparian zone.

Aquatic/Aerial Forms. The Colorado River mainstem supports a relatively low diversity of invertebrates, but these few species have high populations and produce a high biomass (see discussion of macroinvertebrates under FISH in this chapter). In contrast, the tributaries support high species diversity, with each tributary and spring supporting a different assemblage of species. Chironomid midges, simuliid black flies, and amphipod crustaceans dominate the aquatic food chain in the river (Carothers and Brown, 1991).

Species that develop in the clear, cold river water and then emerge to live in the air above are often important in terrestrial food chains. For example, black flies develop as larvae attached to underwater rocks. Instead of emerging directly from the water as adults like chironomid midges, black flies must first reach land and dry their wings (Carothers and Brown, 1991). These vulnerable emerging flies are an important source of food for numerous species that forage in the zone of fluctuating discharge.

Adult chironomid midges are a significant food resource available to predacious insects, amphibians, reptiles, and birds in this system (Stevens and Waring, 1986). Following emergence, chironomids prefer to alight on willows rather than on tamarisk. Adult chironomid populations were lowest during years of high flood discharges and large fluctuations.

Leibfried and Blinn (1987) noted a lack of invertebrates at sample sites exposed to fluctuating flows. More recently, Blinn et al.

(1992) found a total of only 33 invertebrates in 900 samples from 10 sites in the fluctuating zone between Lees Ferry and Diamond Creek.

Ground-Dwelling Forms. Another group of insects important in terrestrial food chains are species that live just below or on the ground. One of these species best known to campers is the harvester ant. Before Glen Canyon Dam, annual flooding removed colonizing harvester ants from the scour zone. Populations rose to 2.4 nests per 100 square yards after closure of Glen Canyon Dam but were reduced to predam levels by the 1983-86 floods (Carothers and Brown, 1991). Current population levels have stabilized at about 0.35 nest per 100 square yards. Harvester ants feed on vegetation or other insects, human food debris, and black flies. They are in turn fed upon by predacious insects, herpetofauna, birds, and mammals.

Vegetation-Using Forms. Although most terrestrial insects use plants to some extent, several forms exhibit important relationships with riparian vegetation. While tamarisk is the most abundant woody plant along the Colorado River in Grand Canyon, it supports only four or five species of insects. Among these are leafhoppers and armored scales restricted to tamarisk, a lady bug that preys on the armored scales, and Apache cicadas (Carothers and Brown, 1991). In contrast, coyote willow—second only to tamarisk in abundance—supports many different species of insects. Tamarisk produces a much greater amount of insect biomass primarily due to large outbreaks of leafhoppers (Carothers and Brown, 1991). Leafhopper outbreaks provide food that may be used by native predacious insects, amphibians and reptiles, birds, and mammals.

The insect community continues to develop as riparian vegetation becomes established. Tributaries support different insect species than the river corridor. Changes in discharge pattern will result in vegetation changes that affect these species.

Wintering Waterfowl (Aquatic Food Base)

The numbers of waterfowl using Grand Canyon increase in late November, peak in late December and early January, and then decrease in February, March, and April (Stevens and Kline, written communication, 1991). During peak winter concentrations in 1990-91, some 19 different species of waterfowl used the river between Lees Ferry and Soap Creek at a density of 136 ducks per mile. An average density of 18 ducks per mile occurred over the entire upper Grand Canyon (RM 0-77). It is assumed that the birds are attracted to and use the river because of the open water and abundant food resources available.

No specific information on feeding is available for wintering waterfowl in Grand Canyon. However, the diets of individual species are well known from other studies and indicate that foods taken from the river would range from plants through invertebrates to small fish. The variety and abundance of waterfowl using the river during winter indicate that a productive aquatic system exists below the dam. As described in the section on aquatic resources under FISH in this chapter, this system is supported by clear, cold releases from the dam and is based on the linkages between *Cladophora*, diatoms, *Gammarus*, and larval insects.

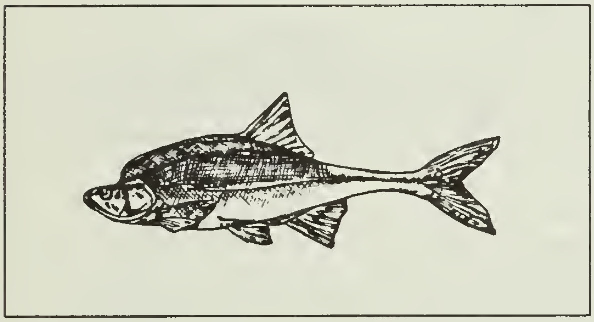
ENDANGERED AND OTHER SPECIAL STATUS SPECIES

The Federal endangered species considered in this report include the humpback chub, razorback sucker, bald eagle, peregrine falcon, and Kanab ambersnail. The southwestern willow flycatcher has been proposed for listing as endangered, and the flannelmouth sucker is a candidate species being considered for listing. Other Arizona species of concern in Grand Canyon are the southwestern river otter, osprey, and belted kingfisher.

An "endangered species" is defined as a species in danger of extinction throughout all or a significant portion of its range. Candidate species include category 1—a species for which there is substantial information to support listing as threatened or endangered—and category 2—a species for which some information indicates that listing is possibly appropriate, but biological data on vulnerability and threat are not currently available.

Endangered Species

Humpback Chub



The humpback chub evolved in the Colorado River system 3 to 5 million years ago but was not described as a species until 1946 (Miller, 1946). It was on the original 1967 Federal list of endangered species and remains endangered today. The Grand Canyon population of humpback chub is considered especially important to the recovery of the species (U.S. Fish and Wildlife Service, 1990b).

In 1978, a FWS biological opinion found that Glen Canyon Dam operations had an adverse affect on essential humpback chub habitat and were jeopardizing the continued existence of this species by limiting its distribution and population size. The opinion also stated that dam operations were modifying major portions of humpback chub and Colorado squawfish habitat and were limiting recovery of both species. A jeopardy biological opinion was not included for the Colorado squawfish since it was considered extirpated from Grand Canyon in 1978 and remains in that status today. The opinion suggested Reclamation fund long-term studies on:

- Impacts of warming the release water
- Ecological needs of the endangered species below Glen Canyon Dam
- Reducing the known factors constraining humpback chub populations, such as low water temperature and frequent flow fluctuations
- The relationship between mainstem and tributary habitats

Following GCES Phase I, Reclamation in 1987 requested formal consultation on the existing operation of Glen Canyon Dam. A draft biological opinion was prepared but not made final. Discussions between FWS and Reclamation resulted in an agreement for Reclamation to fund seven conservation measures that would identify actions to assist in removing jeopardy for the humpback chub. AGFD, FWS, Hualapai Tribe, NPS, Navajo Nation, and Reclamation have been working cooperatively to implement the conservation recommendations. With the announcement of the preparation of this EIS, FWS recommended that a biological opinion, including the seven conservation measures, be prepared only for the preferred alternative (see Chapter IV, ENDANGERED AND OTHER SPECIAL STATUS SPECIES).

The Grand Canyon population of humpback chub is found in Marble and Grand Canyons, including several tributaries to the mainstem river. Recent mainstem studies have found humpback chub more abundant in the reaches immediately upstream and downstream of the LCR (Kaeding and Zimmerman, 1983; Maddux et al.,1987; Valdez, Masslich, and Leibfried, 1992). The possibility exists that humpback chub in the Middle Gorge and lower Grand Canyon may represent a separate population. The genetic identity of the humpback chub throughout Grand Canyon is being investigated in a basinwide study of the genus *Gila* (U.S. Fish and Wildlife Service, 1991a).

While the humpback chub has evolved under large annual spring-summer floods and short-term rainfall flood events, only since closure of Glen Canyon Dam has the species experienced daily or more frequent fluctuations in river stage.

The cold water released from the dam prevents egg and larvae survival of most native fish in the mainstem, and successful reproduction and development of early life stages of humpback chub in Grand Canyon is known to occur only in the LCR. (Releases are warmer when Lake Powell is drawn down more than 100 feet—5 percent of the time). Besides water temperature, other environmental conditions important to spawning and egg development include streamflow and habitat (Valdez, Masslich, and Leibfried, 1992); however, quantities or measures of these conditions have not been verified. The lower 9 miles of the LCR are important habitat for the humpback chub (Kaeding and Zimmerman, 1983).

Humpback chub hatched in the LCR in the spring grow to sufficient size to be able to withstand the cold temperatures of the mainstem by October (Maddux et al., 1987). This life stage and 1-year-old humpback chubs have been found in the mainstem in backwater eddies, connected backwaters, and nearshore habitats (Angradi et al., 1992; Valdez, Masslich, and Leibfried, 1992). Backwaters, eddies, and nearshore areas are the habitats used by early life stages of humpback chub in the Upper Colorado River Basin (Holden and Stalnaker, 1975; Tyus et al., 1982). The AGFD (Maddux et al., 1987; Angradi et al., 1992) found similar habitats important to early life history stages of native fish, particularly backwaters connected to the mainstem during June through September. Compared to other mainstem habitats, backwaters offer higher zooplankton and benthic invertebrate densities, lower water velocities, and refuge from predatory fish (Angradi et al., 1992).

Habitats of adult and juvenile humpback chub in the Colorado River mainstem have not been satisfactorily determined, and response of adult humpback chub to daily fluctuations is the subject of an ongoing radio tracking research study in Grand Canyon (Valdez, Masslich, and Leibfried, 1992). Preliminary information from that study and from studies conducted in the Upper Colorado River (Valdez and Nilson, 1982; Kaeding et al., 1990) found humpback chub have an affinity for specific locations and use habitats such as eddies, return-current channels, and runs. In Grand Canyon, 48 humpback chub moved an average of 0.8 mile over a period of 5 to 149 days (Valdez, Masslich, and Leibfried, 1992). Daily habitat use and movement of adult humpback chub are influenced by time of day, riverflow and fluctuations, and turbidity. Movements of humpback chub in response to changes in flow (ramping) may be due to increased availability of food or to changes in the above habitats (Valdez, Masslich, and Leibfried, 1992). In February, adults were found to form aggregations in eddies and deep pools, while in March through May they move toward the mouth of the LCR.

Adult humpback chubs feed mostly on aquatic invertebrates, particularly immature chironomids and simuliids. The algae *Cladophora* is frequently found in humpback chub stomachs and may serve as a source of diatoms or other food items (Kaeding and Zimmerman, 1983; Kubly, 1990).

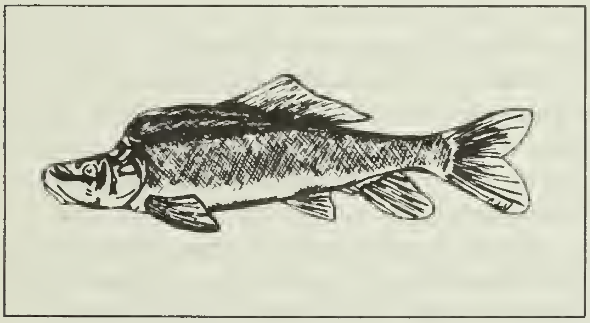
Non-native fish species are often competitors for food or space or are predators of native fish species, and this may be a major reason for the decline of native species (Holden and Stalnaker, 1975; U.S. Fish and Wildlife Service, 1990b). Cold water fish species such as brown trout, cutthroat trout, and brook trout usually prey on other fish, and the recovery plan for the humpback chub recommends against stocking predatory or competing non-native fish into waters occupied by threatened and endangered species. Rainbow trout have not been found detrimental to humpback chub (Maddux et al., 1987; Carothers and Minckley, 1981).

Native fish species dominate non-native species in tributaries to the mainstem. Of nine tributaries sampled by Angradi et al. (1992) in Marble and Grand Canyons, seven were found to be dominated by native species, and only two were found to be dominated by non-native species (the cold water rainbow trout).

General information on the biology and habitat requirements for the humpback chub, razorback sucker, and other native fish of Grand Canyon can be found in the individual species accounts by Minckley (1991), the *Humpback Chub Recovery Plan* (U.S. Fish and Wildlife, 1990b), a compendium of existing information on the four "big river" endangered fish (Miller and Hubert, 1990), and the chapter on management of the razorback sucker by Minckley et al. (1991). The last reference also includes information on native and endangered fish in the Western United States.

Information on designation of critical habitat for the humpback chub is included in the next section on the razorback sucker.

Razorback Sucker



The razorback sucker was listed as an endangered species throughout its range on October 23, 1991 (U.S. Fish and Wildlife Service, 1991b). Specific habitat requirements for the species are not well known and are the subject of several research programs. However, two major causes for its decline throughout its range were cited in the listing rule:

1. Modification of the natural riverine habitats (including impoundment of rivers), modification of historic hydrologic patterns, and cold water from bottom release dams

2. Predation by and competition with non-native fish introduced into the razorback's native range

FWS is in the process of determining critical habitat for all of the "big river" endangered fish species. Critical habitat is defined by the Endangered Species Act as habitat containing the physical and biological features essential to the conservation of a listed species and may include occupied or unoccupied habitat. A proposed rule, published January 29, 1993, includes the lower 8 miles of the LCR and the Colorado River from RM 34 to RM 208 as critical habitat for the humpback chub affected by this project. The proposed rule for the razorback sucker includes the Colorado River from the confluence with the Paria River (RM 0) to include Lake Mead. A final rule will be published after consideration of an economic analysis and biological support document.

The razorback sucker is rare in the Grand Canyon area of the Colorado River. A few were captured during recent surveys (1984-90), and it is uncertain whether they still reproduce in the area. While the historical status of the species is unknown, the canyons may have been refuges from high water temperatures or droughts that occasionally plagued the basin (Minckley et al., 1991). Historic habitat for the species may have included large backwaters and oxbows of the Colorado River and its larger tributaries.

While successful natural reproduction and recruitment in riverine habitats has not been recently documented, the species does reproduce and recruit in ponds and other similar habitats where there are no predators (Minckley et al., 1991).

Razorback suckers, like other "big river" endangered fish, are long-lived. Ages of individuals from Lake Mohave (downstream from Lake Mead), determined from polished and sectioned ear bones, range from 24 to 44 years (McCarthy and Minckley, 1987). Many of these fish would have hatched at or prior to reservoir impoundment.

Adult razorback suckers are still found in the Colorado River above Lake Powell and in the lower San Juan River. Recent collections of razorback sucker from the western portion of Lake Mead (Sjoberg, written communication, 1990) have renewed interest in increasing this limited population in Lake Mead. The species would then have access to over 250 miles of river in Grand and Marble Canyons.

Bald Eagle

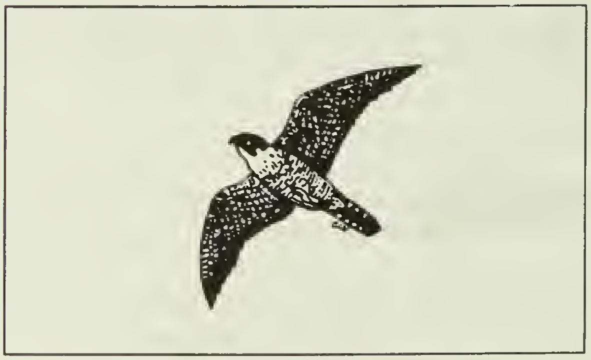
The Colorado River corridor through Grand Canyon is used by migrating bald eagles in the winter. While eagles are capable of taking fish from a river system with characteristics identical to the Colorado River before Glen Canyon Dam, they were not often observed in Grand Canyon until after the rainbow trout fishery was established. Eagles were first recorded in the winter of 1985-86 (four birds) and have increased to a high of 26 birds counted in a single day at Nankoweap Creek in the winter of 1989-90. Some 70 to 100 bald eagles moved through the area in February and March of 1990 (National Park Service, 1992). Bald eagle use of the river corridor is opportunistic and currently concentrated around Nankoweap Creek, where the birds exploit an abundant food source in the form of winter-spawning trout.

Use of the river by eagles may increase and eventually expand to other locations. For example, bald eagles are regularly located along the river corridor above the LCR and occur around Lake Powell (National Park Service, 1992). Bald eagles have been recorded wintering on Lake Powell in numbers ranging from 30 to 50 individuals since the early 1980's (Stevens, written communication, 1993). They are present from November through March, apparently using the recreation area both as a migration route and as a winter stopover.

Eagles eat trout stranded in isolated pools along the river near the creek mouth, but the main feeding activity is in Nankoweap Creek itself (National Park Service, 1992). Eagles appear to shift foraging strategies in response to food availability. At low riverflows, foraging is concentrated at the creek mouth and the lower 150 feet of stream. Bald eagle foraging locations appeared to be flow dependent. Increasing riverflows are directly related to an increase in bald eagle foraging attempts more than 150 feet above the creek mouth. However, the success rate for prey capture is the same at the creek mouth or 150 feet above it.

It appears that the number of eagles at Nankoweap Creek is related to the number of spawning trout. More than 500 trout have been recorded at Nankoweap Creek during recent years, with the spawning run peaking at 1,500 fish in 1990 (National Park Service, 1992). The number of trout attempting to ascend and spawn depends on the number of spawning trout in the river *and* conditions in Nankoweap Creek. Eagle numbers at Nankoweap Creek were down in 1990-91, as were the numbers of spawning trout. Low discharges in Nankoweap Creek, low water temperature, and ice may have limited the number of trout attempting to ascend and spawn in the creek.

Peregrine Falcon

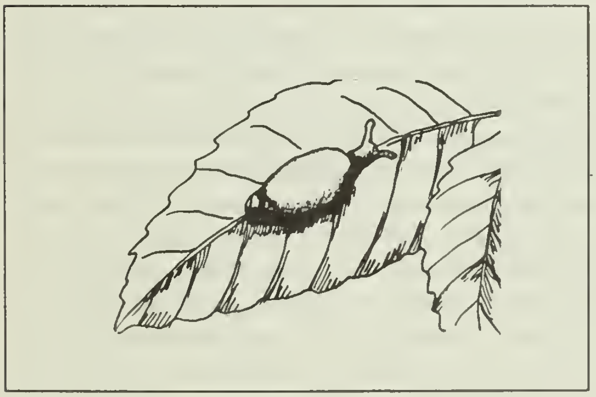


Grand Canyon and surrounding areas support the largest known breeding population of peregrine falcons in the contiguous United States (Carothers and Brown, 1991). Between 1988 and 1990, 71 different breeding areas were identified in Grand Canyon National Park. Extrapolation estimates indicate that 96 pairs of peregrine falcon may exist in the study area (Brown, B.T., 1991b). The birds using Grand Canyon appear to be part of an increasing Colorado Plateau peregrine falcon population. For example, more than 60 territories around Lake Powell have been geographically defined and confirmed to be occupied, within which about 50 peregrine breeding areas have been specifically located (Stevens, written communication, 1993).

Although relationships are still under investigation, it is assumed that the peregrine falcon's success in the area is at least partially due to the abundant prey: violet-green swallows, white-throated swifts, several species of bats, ducks, and other prey. Prey species are plentiful because of large insect populations produced in the clear river water.

The relationships between aquatic productivity, insects, prey species, and peregrine falcons are largely speculative. No specific data are available that could be used to refute or confirm the above relationships, and no data are available on peregrine falcons in Grand Canyon before Glen Canyon Dam. Swifts and swallows make up a significant part of the diets of peregrine falcons elsewhere in the Southwest where falcon densities are identical to those in Grand Canyon (Hays and Tibbitts, 1989; Tibbitts and Ward, 1990; Berner and Mannan; 1992). At those sites, surface water is often unregulated, limited (small perennial streams), or virtually absent (ephemeral streams).

Kanab Ambersnail



The Kanab ambersnail was designated an endangered species in 1992. Only three known populations exist—two near Kanab, Utah, and one in Grand Canyon on land around a perennial stream that plunges from the canyon wall to the Colorado River (Spamer and Bogan, 1993).

The Kanab ambersnail is a terrestrial snail in the family *Succineidae*. It has a mottled grayish to yellowish-amber shell and lives in marshes and seeps located at bases of sandstone cliffs. It is absolutely associated with a perennially wet soil surface or shallow standing water. The presence of cattail, or at least the permanently wet ground which indicates the potential for cattail, is believed to be a critical component of the species' habitat (Clarke, 1991). The population in Grand Canyon appears to be totally concentrated above the fluctuation zone of the No Action Alternative.

Other Special Status Species

Flannelmouth Sucker

The flannelmouth sucker is now listed as a category 2 species under the Endangered Species Act. The species is found in the Paria and Little Colorado Rivers; Shinumo, Kanab, and Havasu Creeks; as well as various locations in the main-stem (Arizona Game and Fish Department, 1993). During GCES Phase I, most juvenile and larval flannelmouth suckers were collected in the lower reaches of the Colorado River, while larger adults were found in the upper reaches—including the reach above Lees Ferry (Maddux et al., 1987). Recent collections in the Paria River have found flannelmouth suckers in reproductive condition, but survival of young-of-year fish has not been documented (Gorman et al., 1993). Larval through adult size flannelmouth suckers are found in the LCR (Arizona Game and Fish Department, 1993). More information on flannelmouth suckers can be found in the previous discussion on native fish.

Southwestern Willow Flycatcher

Nesting pairs of the southwestern willow flycatcher in Grand Canyon increased following closure of Glen Canyon Dam. In the 1980's, the population along the Colorado River in Grand Canyon was believed to be no more than a few dozen pair but represented the largest population of willow flycatchers in Arizona (Unitt, 1987). Carothers and Brown (1991) attribute this response to increases in riparian vegetation following reduced high flood discharges.

In a 1991 survey conducted in Glen Canyon and the upper portion of Grand Canyon to Cardenas Creek, only two pair of nesting birds were detected. It has been speculated that changes in the numbers of nesting pairs may be related to brown-headed cowbird parasitism and habitat fragmentation (Brown, B.T., 1991a). On July 23, 1993, this bird species was proposed to be listed as endangered (see discussion under "Consultation" in chapter V).

Arizona Species of Concern

The State of Arizona lists three species of concern that may use the river corridor and tributaries in Grand Canyon: the southwestern river otter, belted kingfisher, and osprey.

The southwestern river otter is considered an endangered species by the State of Arizona. River otters have always been considered rare in Grand Canyon, with the last sighting reported in 1983 (Bravo, verbal communication, 1991). The southwestern river otter is listed as a category 2 species under the Endangered Species Act but generally is believed to be extinct.

The osprey is a rare fall, spring, or accidental transient in the canyon listed by the State as a "State threatened" species (Arizona Game and Fish Department, 1988). The belted kingfisher is a "State candidate" species found in low numbers year-round in the canyon and its tributaries. Both birds are rare or uncommon in Grand Canyon.

CULTURAL RESOURCES

Cultural resources include prehistoric and historic archeological sites, traditional cultural properties, sacred sites, collection areas, and other resources that are important to Native Americans in maintaining their cultural heritage, lifeways, and practices. Both archeological sites and Native American traditional cultural properties exist in the corridor of the Colorado River between Glen Canyon Dam and Separation Canyon, a 255-mile section of the Colorado River within Grand Canyon and Glen Canyon. The affected area also includes lands adjacent to the Navajo Nation, the Havasupai and Hualapai Reservations, and Lake Mead National Recreation Area.

Both historic and prehistoric resources relate to cultural traditions beginning with the Archaic peoples (*ca.* 2500 B.C.), continuing through the Puebloan and Cohonina peoples (*ca.* A.D. 500–1200), the Cerbat tradition (*ca.* A.D. 1300–1700), and Paiute groups (possibly Archaic through historic times). Apachean occupation of the Grand Canyon region is documented by the late 17th century, and use by numerous groups continues to the present. Historic Anglo-American use of the area began in 1869 with the first attempt to explore the Colorado River and subsequent exploration and economic exploitation of the area.

The following Native American groups have ancestral claims to the canyon and continue to use the area today:

- Havasupai
- Hopi
- Hualapai
- Navajo
- Southern Paiute
- Zuni

Archeological Sites

Archeological research in Grand Canyon began in 1869 with the first report of "Moqui" ruins by John Wesley Powell, the first Anglo-American to travel the length of the Colorado River (Powell, 1875). Professional archeological work was begun in the Lees Ferry area by Julian Steward in the early 1930's (Steward, 1941) and by Walter Taylor along the Colorado River in Grand Canyon in 1953 (Taylor, 1958). Site reporting over the years and limited surveys of the rims and the inner canyon have recorded over 2,600 sites in Grand Canyon and 2,300 sites in Glen Canyon. A complete archeological inventory of the river corridor, encompassing all traversible terrain from the river up to and including predam river terraces, was completed for this EIS.

A total of 475 prehistoric and historic sites were located within the affected environment, many representing use by Puebloan people including the Hopi and Zuni (prehistoric and historic), Pai and Paiute (prehistoric and historic), and the Navajo and Anglo-Americans (historic). A total of 313 sites have been determined eligible for inclusion on the *National Register of Historic Places* (National Register) as contributing elements to the Grand Canyon River Corridor Historic District. Nine additional sites have been recommended for archeological testing before the determination of eligibility is made. The remaining sites either were ineligible or were not evaluated because they are outside the zone of impact.

Anglo-American historic resources within the affected area total 71 sites or components and represent use of the area between 1869 and 1940. One historic resource located in the Colorado River, the Charles H. Spencer Steamboat, was listed on the National Register in 1974 as part of the Lees Ferry Historic District. A separate nomination was prepared for the steamboat, and it was listed as an individual property in 1989. All other historic properties within the area are considered eligible for inclusion in the National Register.

Native American Traditional Cultural Properties

Six Native American tribes have ancestral and modern day ties to Grand Canyon and the Colorado River. While archeological data can provide some information concerning traditional uses of the area, each tribe has its own account of its history and relationships with other tribes. The Colorado River, the larger landscape in which it occurs, and the resources it supports are all considered sacred by Native Americans. Within this larger landscape are sites, locations, and natural resources that are of traditional significance to all tribes or to individual tribes. These Native American traditional cultural properties are tangible historic properties eligible for the National Register because of their association with cultural practices and beliefs rooted in history and their importance in maintaining the cultural identity of ongoing Native American communities. Many Native Americans believe that humans cannot own the land and its resources; rather, humans belong to the land. The following discussions summarize the importance of Grand Canyon and the Colorado River for all of the affected Native Americans of the region.

Havasupai Tribe

The Havasupai Tribe is one of two tribes still living within a segment of Grand Canyon. Their home within Cataract (Havasu) Canyon encompasses part of their 185,000-acre reservation, which includes land on the rims both east and west of Havasu Canyon proper. Traditionally, the Havasupai farmed the canyon areas during the summer months, moving to the plateaus during the winter to hunt and gather from the plentiful resources available. Their ancestral lands covered an area from the Colorado River on the north to the Bill Williams Mountains and the San Francisco Peaks on the south, and from the Aubrey Cliffs on the west to the LCR gorge on the east. Archeological evidence of their ancestral uses of the area dates to as early as A.D. 700, although the majority of remains found within Grand Canyon date to after A.D. 1100 (Dobyns and Euler, 1958; Euler, 1958).

Many of the native flora and fauna found in the canyon are important to the Havasupai, both economically and religiously. Native plants are used for medicinal purposes, as well as for everyday items such as basketry. Animal resources are very important for the basic subsistence of the tribe. Havasupai ancestral lands provided most of the resources needed to live successfully in and around Grand Canyon. The Havasupai were active trading partners with other tribes—most notably the Hopi, Hualapai, Navajo, and Mohave.

The Havasupai people are one of 14 bands of Pai Indians. Other local bands of Pai are known today as Hualapai and Yavapai. All share common ancestry and similar language, with Havasupai and Hualapai having nearly identical dialects. Formal divisions among the bands did not occur until white settlers moved into their homelands. While most bands were subdued and forcibly moved off their traditional lands, the Havasupai remained isolated in their canyon home. This isolation kept them from many of the direct military conflicts encountered by other neighboring tribes. They were, however, confined to a 500-acre reservation in 1882. Their reservation was expanded to its present site in 1975.

The Colorado River plays an important role in defining the Havasupai as a people. Many religious stories of origin exist for the bands of the Pai, with water a key element in most. One tells of the creation of the people from reeds cut down along the river. The Havasupai consider the Colorado River the spine of their lifeline and, as such, sacred in itself.

Hopi Tribe

Grand Canyon is significant in defining the cultural and religious life of the Hopi people. Archeological sites, religious shrines, springs, locations of medicinal herbs, and other sacred places in Grand Canyon are important because of their role in perpetuating Hopi life and culture. These places provide a vital spiritual and physical link between the past, the present, and the future.

Hopi culture begins with the emergence of the people into this present world from the *Sipapu*, a travertine cone in Grand Canyon. After their emergence, Hopi people migrated around the Southwest until all clans came back together at the center of their universe: the Hopi Mesas. For many clans, these migrations included residence in Grand Canyon. This is well documented in the archeological record (Balsom et al., 1991). Of the 475 cultural resource sites identified by the NPS during its survey of the canyon bottom, 180 consisted of the remains left by a prehistoric Puebloan people. Conventional archeological theory, as well as Hopi oral history, hold that these sites were produced by the ancestors (*Hisatsinom* in the Hopi language) of the present day Hopi people.

Evidence shows that use of Grand Canyon by the Hisatsinom began around A.D. 700–800. These people increased in number and began to use all portions of the northern and eastern canyon bottom, as well as both the north and south rims. By the 10th century, small pueblos dotted much of the arable land in the canyon bottom. Associated with some of these pueblos were *kivas*, ceremonial structures found in every modern Hopi village and centers of religious life. By A.D. 1200, the Hisatsinom had largely moved from Grand Canyon, migrating to areas nearer to the present day Hopi Mesas. Ties to the Grand Canyon region were not severed, however, as evidenced by Hopi ceramics dating to post-A.D. 1300 found throughout the canyon. Similarly, ritual pilgrimages to Grand Canyon for salt, minerals, and other resources—as well as to visit shrines—have continued into the 20th century.

Just as modern Hopi villages have shrines associated with them, so do their prehistoric counterparts. Any pueblo that contains a *kiva* can be assumed to have shrines. While people may no longer regularly deposit offerings at these shrines, they are still sacred areas.

Hopi people have a number of concerns about their ancestral homesites being damaged by erosion. The Hopis value these sites as markers on the landscape that serve to physically document their cultural claim to the land. Many of these sites contain the remains of Hopi ancestors. Proper respect for and treatment of the dead are extremely important values in Hopi culture. Hopi people feel that human graves should not be excavated solely to satisfy scientific curiosity. When graves are disturbed by erosion, however, most Hopis believe these graves should be reburied away from danger, not taken out of the canyon. Nondestructive study of human remains during the process of relocating graves is acceptable to most Hopi people.

Like ruins, rock art ties modern Hopi people to land inhabited by their ancestors. The Hopis have a rich interpretive scheme for assigning meaning to rock art. Their oral history records a number of clans residing in Grand Canyon. Hopi elders have observed the symbols of the Fire, Strap, Spider, Kachina, Lizard, Turkey, Bow, Water, Bear, Greasewood, and Badger Clans immortalized in petroglyphs in the canyon. The many hand prints at rock art sites are interpreted as the markings left by clan leaders during Hopi migrations.

All of the springs in Grand Canyon have spiritual importance to the Hopi people. One of these springs, Vasey's Paradise, was specified by Spanish priests as the location from which the Hopi people were to collect holy water and drinking water for the Catholic missions. It is important to the Hopi that these springs are not damaged in any way by the Glen Canyon Dam operations.

Hopi people continue to use Grand Canyon for important ceremonial and ritual purposes. The Hopi Salt Mines on the Colorado River are the focus of an arduous pilgrimage associated with initiation rites of Hopis. The Twin War Gods established the steep trail down the walls of Grand Canyon for this salt pilgrimage and identified many shrines where offerings and rituals are conducted along the way. Hopis continue to use these places for prayer and make offerings at them during winter ceremonies conducted on the Hopi Mesas. Circumstances relating to trail access and theft of ritual items have precluded the initiation rites which would allow Hopis to take part in the pilgrimages. Without initiation, Hopi visits to the mines are considered too dangerous. All of the Hopi ancestors have returned to Grand Canyon and now spiritually occupy it. The presence of their ancestors makes Grand Canyon an especially holy and spiritually dangerous place, and all use thus requires proper spiritual preparation and a respectful attitude.

The Hopis believe that humans are stewards of the earth and should nurture all living things. All living things play an important role in creation and therefore have a right to exist. The Hopi people think the loss of any fish, animal, or plant would impoverish the world and thus have a negative impact on Hopi life.

Given the sanctity of Grand Canyon, the Hopis are concerned about the attitudes of people who use the canyon for recreation or scientific research. With the proper attitude, use of the canyon for these purposes can be both enjoyable and educational. Using the canyon with a disrespectful attitude can cause serious spiritual problems.

While the Hopis no longer live in Grand Canyon, their concern for its physical and spiritual well-being is not diminished. In fact, their concern for the area is increased, because the Hopis are not there to take care of the sites. The Hopis feel that Glen Canyon Dam should be operated to limit sediment loss and minimize impacts to areas most important to the Hopi way of life.

Hualapai Tribe

The Hualapai Tribe has a long history in Grand Canyon. Their reservation borders 108 miles of the river corridor, although their ancestral interests are much broader. Natural features served as boundaries for their ancestral territory: the Colorado River on the north and west, the San Francisco Peaks on the east, the Bill Williams and Santa Maria Rivers on the south. Within the region, the Hualapai lived in groups composed of 14 bands. Each band consisted of nuclear and extended families who used this vast range for their livelihood. No single band owned the territory. The people lived in harmony as a group and also lived in harmony with nature.

The various bands descended from one people, a group known archeologically as the Cerbat. Culturally both the Hualapai and Havasupai—along with the Yavapai—are referred to as *Pai* (meaning "the people") and consider themselves as "one ethnic group, the only true human beings on earth." Physical remains of their presence in Grand Canyon date at least to A.D. 1300. Evidence of earlier use of the region has been documented near Hoover Dam at Willow Beach, where dates may extend back as far as A.D. 600 (Schroeder, 1961), and sites with associated ceramics date from A.D. 700-1890 (Dobyns and Euler, 1958).

The Colorado River is a significant landmark for the Hualapai both spiritually and physically. The Hualapai believe that the river is the backbone or spine known as *"Ha'yitad."* Historically, all of the

Yuman language family tribes were located on or near the river. There is a common bonding creation account which took place at "Spirit Mountain," or "*Wikahme*," along the Colorado River near Bullhead City, Arizona (Watahomigie et al., 1983).

Grand Canyon and surrounding plateaus offered the Hualapai the necessary resources to live successfully in the region. Wild game was the prime source for survival, most notably, the desert bighorn sheep. Other game animals including deer, elk, and antelope also provided shelter, clothing, tools, weapons, and ceremonial objects (Watahomigie et al., 1986). Plants were important, both for food and for medicinal purposes. The major wild foods were derived from cactus fruit and from seeds of grasses and plants native to the area (Watahomigie et al., 1982).

Hualapai historical accounts are recounted through oral traditions. The names of the landsites of sacred canyons are derived from important events in the areas. Trails and trade routes within Grand Canyon allowed the Hualapai to exist successfully within the region, not only with bands of the Pai but also with neighboring tribes such as the Hopi, Paiutes, Mohaves, and Navajos.

The Hualapai Indians have occupied and used the lands and waters lying within their ancestral territory, as well as within the present reservation, for more than 1,000 years—long before the records and history of white society in the area. Evidence of their occupancy, use, and ownership of the territory is contained in their family and tribal records, traditions, and legends—unwritten, but faithfully transmitted from parent and leader to offspring and follower, from a people that lived in the distant past to the present.

Navajo Nation

The Navajo Reservation borders part of the affected environment, from Glen Canyon Dam to the confluence of the LCR—a distance of 76.5 miles. Throughout the Colorado River corridor are places of historical, cultural, and religious importance to Navajo people.

Archeological and linguistic evidence suggest that the Apacheans (Athabaskan-speaking ancestors of the modern Navajos and Apaches) entered the North American Southwest sometime between A.D. 1000 and the 1400's (Brugge, 1983 and G.M. Brown, 1991). During this time, the Apacheans traded and intermarried with neighboring Puebloan and other groups. Traditional Navajo culture of today is the result of these interactions (Brugge, 1983; Kelley et al., 1991).

Historical accounts refer to ancestral Navajo interactions with Havasupais in the Grand Canyon region by the 1600's (Navajo Tribe of Indians, 1963). Evidence clearly establishes Navajo settlement on the plateaus surrounding Grand Canyon by the 1700's (Navajo Land Claims Archaeologists, 1952-60). By at least the mid-1800's, Navajos were fully using resources in and around Grand Canyon for farming, livestock grazing, plant gathering, hunting, and religious purposes, as well as seeking refuge from Mexican slave raiders and non-Navajo Indian Tribes. During the 1860's, when Navajos were conquered by the U.S. Army and incarcerated at Fort Sumner, New Mexico, many Navajo families escaped into the canyon and lived there for several years. The canyon continued to provide protection to Navajos and their herds of sheep, goats, and horses during the federally imposed livestock reduction program of the 1930's and 1940's.

The boundary of the traditional Navajo homeland is symbolized by the four sacred mountains (although the aboriginal use area extends beyond these mountains): *Sis Naajinii* on the east (Blanca Peak near Alamosa, Colorado), *Tsoo Dzil* on the south (Mount Taylor near Grants, New Mexico), *Dook'o'oosliid* on the west (San Francisco Peaks near Flagstaff, Arizona), and *Dibe Ntsaa* on the north (La Plata Mountains near Durango, Colorado).

Navajos believe they originated from three underworlds and emerged through a series of events into this, the fourth world. These worlds were given to the Navajo people by the Holy People. Water is the basis for the origins of many Navajo clans and is important in oral tradition and many ceremonies.

The Colorado River is a sacred female being and forms a protective boundary on the western border of Navajo land. It is inseparable from the larger sacred landscape of which it is an integral part. Oral traditions and physical places connect Grand Canyon to its tributaries and the landforms that surround it. Prayers are offered to all these places. The LCR is considered a sacred male being. These rivers provide protection to the Navajo people, not only in the water that is ceremonially used, but in the refuge the canyons have provided to Navajos throughout history. These are among the many sacred and secular resources these canyons, collectively called Grand Canyon, provide to the Navajo people.

In addition to ceremonial uses of water, the Colorado River and its tributaries have provided water for both people and livestock for many generations. The beaches provided arable land for corn fields, and the river terraces provided habitat for the deer, bighorn sheep, and other game that Navajos hunted. The beaches and terraces also support the vegetation that continues to be used for medicinal, ceremonial, and daily domestic purposes. The salt mines also provide salt that is still used ceremonially and was historically used for seasoning food. The many trails used to access the canyons also serve both sacred and secular purposes.

Any effects on Grand Canyon and its resources from the operation of Glen Canyon Dam ultimately affect the stories that are told about them. These stories are the most irreplaceable of Navajo cultural resources.

Southern Paiute Tribe

The traditional lands of the Southern Paiute people are bounded by more than 600 miles of Colorado River from Kaiparowits Plateau in the north to Blythe, California, in the south. According to traditional beliefs, Southern Paiute people were created in this traditional land. Through this creation, the Creator gave Paiute people a special supernatural responsibility to protect and manage this land, including its water and natural resources. *Puaxant Tuvip* (sacred land) is the term that refers to traditional ethnic territory.

Southern Paiute people express a preservation philosophy regarding *Puaxant Tuvip* and the water, minerals, animals, plants, artifacts, and burials existing there. Natural resources are perceived as having their own human-like life force. The Colorado River is one of the most powerful of all natural resources within traditional lands. Elders tell children about its power and the gifts it provides when talked to and treated with great respect. Traditionally, Southern Paiutes lived, farmed, collected plants, and hunted along the Colorado River where it passed through their land. For this reason, the riverbanks are full of culturally meaningful human artifacts and natural elements.

Historically, most Southern Paiute people died when Europeans encroached upon *Puaxant Tuvip*, bringing domestic animals and diseases. Paiute people soon lost control over most of the tributaries of the Colorado River, including the Santa Clara River, the Virgin River, and Kanab Creek. As Paiute people were forced out of these riverine oases, they retreated to Grand Canyon to live in regions of refuge. Thus, Grand Canyon became the final refuge for traditional Southern Paiute life and, as such, assumed additional cultural significance.

Modern Southern Paiute people continue to use Grand Canyon and the Colorado River in traditional ways because the Creator requires them to do so. If a land and its resources are not used in an appropriate manner, the Creator becomes disappointed or angry and withholds food, health, and power from humans. For this reason, Paiute people continue to visit the canyon and river to harvest plants and fish and to conduct ceremonies—even though access to these areas is now limited.

Zuni Tribe

The traditional territory of the Zuni Tribe is bounded by the San Francisco Peaks on the northwest corner and by portions of the LCR and the Pueblo Colorado Wash on the far northern boundary. Although they do not reside in the directly affected environment, Zunis have close ties to the Colorado River and Grand Canyon.

The area of Zuni traditional use extends considerably beyond their traditional territorial boundaries and includes Grand Canyon.

Archeological sites, traditional cultural properties, and other sacred locations along the Colorado River corridor and the LCR are important to Zuni traditional and cultural values, providing important spiritual linkages to the place of emergence for the Zuni Tribe. Areas where soil, water, plants, and rocks are collected for ceremonies, as well as a portion of the Zuni Grand Canyon Trail are located within the affected environment of the Colorado River.

From the moment that the Zunis arrived on the surface of the earth, Grand Canyon and the Colorado River have been sacred. Creation narratives describe the emergence of the Zuni people from Earth Mother's fourth womb, coming out into the sunlight at the bottom of Grand Canyon. The narratives also describe the Zunis' subsequent search for the center of the world, the Middle Place. The people moved up the Colorado River and then up the LCR, periodically stopping and settling in locations along the rivers. At the junction of the LCR and the Zuni River, many *Kokko*—or supernatural beings—came into being. After a long search, the Zunis located the Middle Place and settled there in the village of Zuni.

Trails used by the Zunis for religious purposes have special significance and are cared for by means of particular blessings and prayers. Once a trail is blessed, it remains blessed permanently. The Zuni people thus have important concerns about the ancient Zuni trail from their village to the bottom of Grand Canyon.

Zunis pray not only for their own lands but for all people and all lands. To successfully carry out the prayers, offerings, and ceremonies necessary to ensure rainfall for crops and a balanced universe, Zunis must collect samples of water, plants, soil, rocks, and other materials from various locations. While collecting these materials, Zunis also pray and leave offerings at the locations within the project area. Samples of water from the bottom of Grand Canyon carried in sacred gourds have special significance to Zuni ceremonies and very special meaning to the Zuni people.

The Zuni Tribe is in the process of identifying cultural resources of importance to the tribe within the EIS study area. When these studies are completed, the Zuni Tribe will be able to more fully assess impacts to the resources, as well as traditional and cultural values.

AIR QUALITY

Air quality was identified as an issue for this EIS during public scoping. The area of potential impacts includes not only the immediate Grand Canyon vicinity, but also the regional area served by Western's Salt Lake City Area Integrated Projects (SLCA/IP).

Grand Canyon Air Quality

Grand Canyon enjoys some of the cleanest air in the lower 48 States, resulting in a visual range that sometimes exceeds 240 miles (Bowman, 1991). Under the provisions of the Clean Air Act, Grand Canyon National Park falls under the designation of a class I area. Class I areas have special significance for their natural, cultural, recreational, or wilderness characteristics. The Clean Air Act includes standards or increments for maximum allowable increases in ambient pollutant concentrations over baseline conditions. The increments for sulfur dioxide (SO_2), nitrogen dioxide, and total suspended particulates are more stringent in class I areas than in other areas and are highly protective of class I area air quality.

Influences on the air quality of the Grand Canyon region include fog, rain, winter storms, and air pollution, most of which is not visible. During most of the year, a white veil of haze hangs in the canyon—air pollution carried by the wind. Navajo Generating Station near Page, Arizona, has been identified as a major source of canyon air pollution. A survey of park visitors (Bell et al., 1985) concluded that visitors are very aware of the haze and feel that it detracts from their visit.

Regional haze generally is at its worst during summer months. Average visibility is only 100 miles, and it drops below 68 miles 10 percent of the time (Bowman, 1991). Air is carried into the Grand Canyon area from the south and west, where it picks up heavy loads of pollutants from urban and industrial areas. By the time the air masses reach the canyon, they are well mixed, and the haze spreads evenly throughout the lower atmosphere. As a result, haze is more apparent when viewing distant landmarks than when viewing the canyon.

During the winter, strong cold fronts bring in clean air from sparsely populated areas. Average visibility is 158 miles, but it reaches more than 211 miles 10 percent of the time (Bowman, 1991). Between the passages of cold fronts, however, the air stagnates. Under these conditions, pollution from local sources sinks into the canyon, where it can be trapped by strong inversions until a front again brings in clean air.

Haze appears when light passes through tiny particles in the air and is scattered in many different directions (Malm, 1983). More particles mean more scatter. The observer sees this scattered light as a white haze. Some of the particles that scatter light are natural; the sky is blue because some gases in the atmosphere scatter blue light. Other natural particles also scatter or absorb light. Dust raised by the wind, smoke and soot from forest fires, and volcanic ash and gases scatter light and produce haze. Usually these particles are rather large (more than 2.5 microns in diameter). The large size means two things:

- They settle out of the air faster.
- They are only about one-tenth as efficient at scattering light as small particles.

Figure III-31 shows the relative proportions of various fine particles measured in Grand Canyon air in 1982-83.

Anthropogenic (human-created) haze is usually different, resulting from fine particles such as soot from fires and diesel engines, dust from farming and dirt roads, and other sources. However, not all particles can be easily categorized as natural or human created. For example, forest fire smoke may be from a natural wildfire or a prescribed fire. Other particles have few natural sources; sulfates almost always are the result of human activities (with the exception of volcanic eruptions).

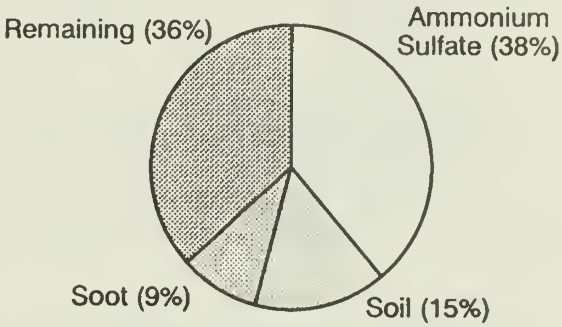


Figure III-31.—Various types of fine particles measured at Grand Canyon, 1982-83. (Percentages were rounded to the nearest whole number.)

Sulfates

Sulfates are the major contributors to haze at Grand Canyon and in the rest of the United States (Shaver and Morse, 1988; Malm, 1989). Their role in creating haze is shown in figure III-32 (Malm, 1989). Sulfates are produced from SO_2, a colorless gas released from many sources, especially burning fossil fuels and smelting metals. If SO_2 were to remain a colorless gas, it would not be a visibility problem (although it would continue to contribute to acid deposition). But SO_2 is not inert; it reacts in the air to form sulfate particles. This reaction depends on a number of factors but occurs fastest when the relative humidity is high. The sulfates then bind with water vapor to form tiny particles that very efficiently scatter light.

The major sources of sulfate at Grand Canyon are to the south and west of the park (Malm, 1989). During the summer, wind patterns bring air over distant SO_2 sources such as southern California. While this air travels to Grand Canyon, SO_2 converts to sulfate, thus creating the thick summer haze. During the winter, air from distant areas is clean, but during periods of stagnation, there is time for the SO_2/sulfate conversion to create haze

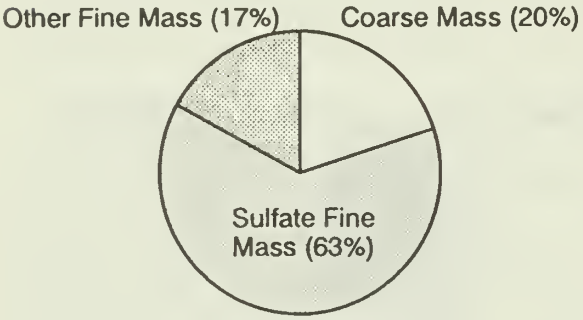


Figure III-32.—The amount of haze caused by various particles in Grand Canyon air.

from local SO_2 sources including areas to the north and east. Figure III-33 shows year-round averages for sulfate sources affecting Grand Canyon from 1981 to 1985. The relative importance of a source area may vary throughout the year and even with the passage of a specific air mass. The absolute amount of sulfate varies from year to year as well. For example, during 1980-85, there was a 50-percent increase in summer sulfate levels measured at the canyon.

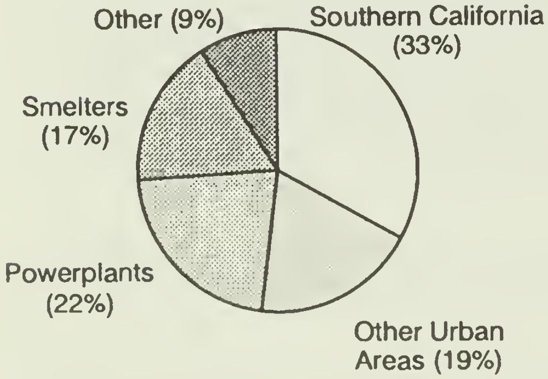


Figure III-33.—Sources of sulfates at Grand Canyon, 1981-85.

One source of sulfate in Grand Canyon is Navajo Generating Station, identified as a major SO_2 contributor by an NPS study. In response to the study, EPA mandated modifications to reduce emissions beginning in 1995. These modifications are scheduled to be in service for all three powerplant units by August 1999.

Regional Air Quality

Change in Glen Canyon Dam operations may affect regional air quality. Glen Canyon Powerplant is integrated into a regional power system (chapter III, HYDROPOWER). If power production at Glen Canyon Dam is reduced or altered, that power will have to be replaced elsewhere in the system. If the alternative power source uses fossil fuel, a net change in system emissions would result. This change could be apparent either in the region, or elsewhere in the marketing area served by the Salt Lake City Area (SLCA). SO_2 is now a regulated pollutant associated with adverse health effects. Nitrogen oxide (NO_x) emissions also are produced from burning fossil fuels and react in the atmosphere to form ozone and acid aerosols. Most utilities presently concentrate their efforts on reducing SO_2 and NO_x emissions, so changes in these emissions will be tracked under this analysis.

RECREATION

Dam operations affect the experience of recreationists using the Colorado River in Glen Canyon and Grand Canyon, as well as those using Lake Powell and Lake Mead. The recreationists most affected by different flows are anglers, day rafters, and white-water boaters.

The 15-mile segment of the Colorado River below Glen Canyon Dam, located within the Glen Canyon National Recreation Area, is the last remaining riverine section of the 189-mile river-carved channel that was once Glen Canyon. This segment, the Glen Canyon reach, is used by a variety of recreationists including fishermen, boaters, day rafters, campers, and hikers.

The Colorado River through Marble and Grand Canyons is the longest stretch of river (277 miles long, with over 160 recognized rapids) for recreational use entirely within a national park. The river is surrounded by more than 1 million acres of land with little human development. Some of the world's most challenging and exciting white water occurs here. The river's isolation in the mile-deep gorge of Grand Canyon gives it primitive recreational qualities and enhances off-river hiking, climbing, and sightseeing.

Hoover Dam impounds the water of the Colorado River, forming Lake Mead—the largest reservoir in the Western United States. About 100,000 boaters annually use the stretch of Lake Mead and Grand Canyon from South Cove to Separation Canyon for scenic boating, camping, fishing, water-skiing, and other recreational pursuits.

Fishing

A discussion of trout as a biotic resource can be found under FISH in this chapter.

Fishing in Glen Canyon

The Glen Canyon trout fishery is a byproduct of Glen Canyon Dam. Discharge from the dam is colder, carries less silt, and is more stable on an annual basis than it was in this section of the Colorado River prior to construction of the dam. This altered environment is ideal for trout, allowing AGFD to begin a stocking program in 1964. As many as 100,000 rainbow trout have been stocked in some years; and in more recent years, brook and cutthroat trout have been stocked as well. *Gammarus*, shrimp-like amphipods, were introduced in 1968 to provide a forage base for trout and have flourished, providing ample support for the fishery.

The introduced trout have created an important fishery that is considered by many to be blue ribbon quality. Surveys of Arizona anglers conducted by AGFD in 1981 and 1989 found that, collectively, trout were the most desired sport fish in the State (this preference has been recognized since territorial days).

Each year, more than 19,000 anglers fish for trophy-sized rainbow trout in the 15-mile reach below the dam. Of these, about 11,000 anglers fish by boat while 8,000 wade or fish from the bank in the Lees Ferry area. Angler days decreased from a peak of 52,000 in 1983 to only 15,000 angler days in 1985, but now participation has returned to a level exceeded only by the 1982-84 peaks (Reger et al., 1989).

NPS places higher priority on maintaining native fish species than on maintaining recreational resources. However, NPS recognizes that this stretch of the Colorado River is now a cold water fishery and thus designates trout as a recreational resource.

Fishing Trip Attributes. The angling day for boat fishermen averages about 7 hours, while shore anglers fish for an average of 4-1/2 hours (Reger et al., 1989). Use levels peak in early spring and fall, corresponding to times when air temperatures are less extreme and flows fluctuate least. Catch rates are highest in midsummer and midwinter.

A study by Bishop et al. (1987) revealed that the attributes that contribute most—either positively or negatively—to the Glen Canyon fishing experience are the size and number of fish the respondent expects to catch. The two most important attributes of an excellent or perfect Glen Canyon fishing trip were "catching a trophy fish" and "good weather"; "camping along the river" was the least important attribute.

The respondents also were asked to rate the importance of a list of factors that might contribute to a poor fishing trip. The most important flow-related trip attributes to anglers on the Colorado River in Glen Canyon are catching fish, degree of crowding, ability to get upstream, and boat or motor trouble due to low water. Fishing success is believed to be flow-influenced in two ways: rising waters may improve fishing as fish begin to feed on the debris stirred up by the rising water; and flows of 10,000 cfs and less provide gravel and rock bars for fishing and some room for bank fishing between the water's edge and shore vegetation. Low flows influence boaters' ability to get upstream, especially at 3-Mile Bar, and are a potential cause of boat or motor trouble (these topics are covered under "Day Rafting" and will not be treated here).

Glen Canyon Blue Ribbon Trout Fishery.— The AGFD's management objective for the Colorado River below Glen Canyon Dam is to provide a blue ribbon fishery. To accomplish this, the State of Arizona uses special regulations to improve the natural productivity of the system. Under a blue ribbon fishery designation, the State hopes to provide the opportunity to catch large fish. Blue ribbon fishery management limits the harvest of fish through special regulations that encourage "catch and release" by implementing low daily bag limits, size limits, and gear restrictions.

The fishery in Glen Canyon is one of only two blue ribbon stream fisheries in Arizona, which increases its importance to anglers and AGFD. Blue ribbon fishery waters can be maintained through natural reproduction or by stocking. Under historic dam operations and current fishing regulations, supplemental stocking is necessary in order to maintain catch and harvest rates. Rainbow trout spawning occurs on gravel bars in Glen Canyon, and naturally-reproduced fish represent about 28 percent of the average trout harvest (U.S. Department of the Interior, 1988).

Janisch summarized the history of the Glen Canyon fishery in four stages (Bishop et al., 1987).

- Put-and-take era (1964-71)
- Trophy era (1972-78)
- Quality era (1978-84)
- Something less than quality but not put-and-take (1985-present)

From 1964 to 1971, the "put-and-take" era, catchable-sized trout were stocked and most were caught within a few months. The average weight of the rainbow trout taken was less than 0.75 pound during this period, and fishing pressure was relatively light.

Around 1971, *Gammarus* became a major part of the trout's diet, and the trout growth rate apparently increased. This resulted in the "trophy" fishery era from 1972 through 1978. Bag limits of 10 fish weighing a total of 40 pounds were not unusual during this period. In response, the number of angler days rapidly increased. Water temperature and habitat seemed conducive to natural reproduction, so the AGFD fish stocking strategy shifted from introducing catchable-sized trout (as practiced during the put-and-take era) to stocking fingerlings. Research subsequently showed that the fishery heavily depends on stocking and that only limited natural reproduction is taking place (Persons et al., 1985).

In 1978, the bag limit was reduced from 10 to 4 trout in an attempt to protect the resource from ever-increasing fishing pressure. In 1980, a rule was enforced requiring that trout either be released or killed immediately after being caught. This rule was an attempt to discourage people from keeping fish alive for extended periods and then releasing them if a larger fish was taken, a practice resulting in high mortality rates for the released fish. Even though the fishery has declined in productivity since 1978, fishing pressure continued to escalate until 1984. Janisch termed the period 1978-84 the "quality" fishery era. Creel census reports still showed a very respectable average weight of 2.79 pounds for fish caught and kept through this period. However, the days of the trophy fishery were ending, and the average weight of fish taken steadily declined.

Janisch characterized the current era (beginning in 1985) as "something less than quality but not put-and-take." Catch rates are still relatively high and some large fish are taken, but most fish are small in comparison to the trophy era (Bishop et al., 1987). Management strategy is to reduce fishing pressure and stock trout so the fishery can be restored to the quality, if not trophy, level.

Fish over 20 inches long made up about 25 percent of the harvest in the period 1979-83 and less than 10 percent during 1985-88. In 1984-85, fish less than 15 inches long accounted for about 50 percent of the harvest; this decreased to about 20 percent in 1986. However, the harvest percentage of fish less than 15 inches long has been increasing ever since (Reger et al., 1989).

Angler Safety. This flat water section of river is fished predominately from boats launched at Lees Ferry. Bank fishing, including fly fishing by wading fishermen, occurs in the area around Lees

Ferry. They wade out into the channel to the depth their wading gear permits. The rate of increase in flow directly affects the safety of fishermen, in terms of their ability to respond and move toward shore once they notice changing water levels. Lee and Grover (1992) found that anglers believe high flows (30,000 cfs or more) decrease the potential for safely wading in the river. At least three drownings in the past 12 years possibly are related to river stage or stage change.

Camping and Day Use Sites. Within the Glen Canyon reach are six designated camping areas above the high water zone, generally on terraces. There are up to three campsites per camping area, designated by pit toilets and fire grates. Beaches in this reach are used mainly by anglers and day rafters, with over 50,000 visitors each year. Although the camping surfaces generally are located well above the river, discharge and its influence on sediment deposits and sedimentation processes ultimately will influence the size and distribution of these sites. Other flow-related problems include accessibility to sites and physical space for mooring boats at campsites.

Kearsley and Warren (1992) inventoried sites available in the Glen Canyon reach for camping and day use. Of the potential 18 camping and day-use sites in this reach, only 12 normally are available. The other 6 are low water sites available only when flows are 15,000 cfs or less.

Fishing in Grand Canyon

Fishing in Grand Canyon is largely an activity incidental to white-water boating or backpacking. The exceptions are found mostly in the vicinity of Jackass Canyon and in other side canyons around Marble Canyon.

NPS controls most access to these wild trout fisheries by issuing backcountry and river permits. Commercial river companies are not allowed to offer trips that are primarily for fishing within Grand Canyon; however, fishing is allowed as an incidental activity on river trips. The only restrictions on anglers are localized closures to protect endangered species and a required fishing license from the State of Arizona.

Wild Trout Fishery. The Arizona Coldwater Sportfisheries Plan uses a wildfish concept to "provide anglers the opportunity to catch fish that are naturally reproduced in the wild." The tributary and mainstem fisheries (table III-11) for rainbow and brown trout in Grand Canyon are managed under the wildfish concept.

Table III-11.—Wild trout fishery designations in Grand Canyon (AGFD, 1990)

Bright Angel Creek (12.9 miles)
Clear Creek (4.1 miles)
Colorado River (229.0 miles)
Crystal Creek (5.2 miles)
Deer Creek (0.1 mile)
Havasu Creek (3.5 miles)
Nankoweap Creek (0.1 mile)
Phantom Creek (3.9 miles)
Pipe Creek (0.5 miles)
Royal Arch Creek (0.7 mile)
Shinumo Creek (0.1 mile)
Stone Creek (5.0 miles)
Tapeats Creek (4.5 miles)
Thunder River (0.4 mile)
Vishnu Creek (1.8 mile)

Wild fisheries are sustained entirely by natural reproduction. Since most of the waters within Grand Canyon are accessed by trail or raft, angler density is limited, thus protecting the fishery from over-harvest. The daily limit is four fish for the Colorado River from the Marble Canyon Bridge through Grand Canyon to Separation Canyon, including all tributaries. Trout taken from these areas must be either immediately released or killed and retained as part of the bag limit.

Angler Safety. Most Grand Canyon fishing is conducted from either a raft or the riverbank; few anglers wade into the river to fish. As a result, angler safety is not considered a major issue.

Day Rafting

A Glen Canyon raft trip is a leisurely 15-mile, 1-day float trip. In 1991, more than 33,000 visitors took half-day raft tours of the Glen Canyon reach. All Glen Canyon raft trips have professional guides to run the rafts and explain the river attractions. Wilderness River Adventures is the only concessionaire authorized to provide commercial Glen Canyon raft trips. Several tour companies support these trips by busing raft passengers from Grand Canyon south rim and other areas to Glen Canyon.

Trip Attributes

Bishop et al. (1987) found that the only flow-sensitive attribute of a Glen Canyon day-raft trip may be its origin. At low to moderate flow levels (generally less than 29,500 cfs), the 20-person tours depart from a dock near Glen Canyon Dam and float or motor downstream to Lees Ferry. When releases are above 29,500 cfs and outlet works are in use, departure from the base of the dam is unsafe due to the volume and turbulence of the water. In these cases, rafts normally depart from Lees Ferry carrying fewer people (10) and motor part way upstream before floating back downstream. The decreased raft capacity occurs because the pontoons are removed to reduce water resistance while motoring upstream, which reduces stability. Most trips departing from Lees Ferry do not go all the way up the river, and passengers do not get a view of Glen Canyon Dam from the river.

Lee and Grover (1992) found that—at low flows—day rafters were more likely to feel that the water was too low and slow, more likely to wait longer to launch, or more likely to experience minor motor or raft damage. At high flows, rafters were more likely to notice beach erosion at shore stops. Overall trip satisfaction remained high and not significantly different at all flow levels.

Raft trips stop at channel margin sediment deposits for day-use and lunch stops. These sites are beach-like in character and likely to be influenced by discharge from the dam.

Navigability, Access, and Boating Safety

Individuals who boat in the Glen Canyon reach must launch at Lees Ferry and motor upstream. The narrow constrictions and riffles within the reach cause the greatest difficulties during periods of low flow. Certain types of equipment, such as jet boats, can better negotiate the river during periods of low discharge.

During flows of 3,000 cfs and less, few boaters are able to go up-river past 3-Mile Bar (RM -3), a shallow riffle (Welsh, verbal communication, 1991). Damage to boats and motors is more frequent than at higher water levels. In addition, fishing activities at flows less than 3,000 cfs are concentrated within the 3 miles above Lees Ferry, especially on weekends and other high-density days; some boats are stranded upstream of 3-Mile Bar following lowering of flows. If tied too tightly to banks, boats are left "high and dry" above water stage, only to become swamped when discharge increases. During 5,000-cfs flows, about 75 percent of boaters are able to negotiate 3-Mile Bar, while nearly all boaters can do so during 8,000-cfs or greater flows.

Up to 23 rafts are launched daily by the rafting concession. Discharge from the dam becomes an influence on these rafts at constrictions in the channel, causing the most problems during periods of flows less than 5,000 cfs (O'Mary, verbal communication, 1993).

White-Water Boating

The history of running the Colorado River in Grand Canyon can be traced back to 1869, when John Wesley Powell led the first expedition down the Colorado River through Grand Canyon. Commercial river trips began in 1938. Today, white-water boating in Grand Canyon is a major industry, with 21 companies having permits to conduct commercial raft trips in the park. Also, the Hualapai Tribe conducts river trips from Diamond Creek to Lake Mead.

Prior to the early 1960's, there was little concern about resource impacts along the river. Glen Canyon Dam was yet to be completed, and few visitors entered the canyon or ran the river. From 1960 to 1972, the number of boaters annually running the river grew from 205 to 16,432 persons, paralleling a dramatic increase in white-water boating nationwide. In 1972, increasing problems with management of campfires, human waste, and trash along the river; damage to fragile soils and vegetation; unofficial trails; and destruction of prehistoric sites prompted NPS to regulate river use more closely.

Approximately 15,000 to 20,000 commercial and private boaters annually run the river. This range reflects the changing trends in the length of commercial trips—presently, short duration trips. The number of user days is restricted to 115,500 for commercial trips and 54,450 for private parties. Motorized trips are allowed to launch from mid-December through mid-September. Oar-powered craft can be used throughout the year and exclusively during the "oar-only" period from September 15 to December 15. Noncommercial group size averages below the limit of 16, while commercial group size usually is 36 people. The Lower Gorge, beginning at Diamond Creek, is used for the Hualapai Tribe concession as well as by other commercial and private rafters.

The number of visitors on the river is not solely a reflection of increased popularity of white-water sporting nationwide. Before the dam, riverflows were highly variable and ranged from low flows frequently less than 3,000 cfs to peak flows occasionally in excess of 100,000 cfs in spring and early summer. Now, riverflows are within a much narrower range—from 3,000 to 31,500 cfs—and show less seasonal variation, making it possible to raft during all months of the year. However, most commercial and private raft trips take place during May through October.

Commercial trip passengers contract with an outfitter to provide a boat, other rafting equipment, food, and a guide. Commercial trips use both oar- and motor-powered rafts and typically run from 3 to 4 days for a motor trip (only the upper stretch of the river from Lees Ferry to Phantom Ranch) to 20 days for an oar-powered trip (the full 255 river miles through the park). One- to 2-day trips launch from Diamond Creek.

Private parties furnish their own boats, rafting equipment, food, and guides or boat operators. Individuals must apply for private permits, which are awarded in the order that applications are received. Currently, the waiting list for private permits is about 6 years, although 40 percent of the individuals on the list are able to take trips sooner due to cancellations.

River Trip Attributes

Bishop et al. (1987) asked white-water boaters, including commercial passengers, to report the attributes that contribute most to an excellent Grand Canyon trip. Good weather, good social interaction, good guides, an unrushed pace (time for layovers and stops at attraction sites), and a wilderness experience were the attributes mentioned most often by respondents. Of the attributes listed by at least 15 percent of all respondents, four are potentially affected by discharges:

- Time for layovers and stops at attraction sites
- Good/exciting rapids
- A wilderness experience
- Not feeling crowded

Bishop et al. (1987) asked white-water boaters and commercial white-water guides to provide self reports on the quality of Grand Canyon white-water trips. Both the guides and the passengers reported that the quality of trips was highest during periods of constant flows in the range of 25,000 cfs to 30,000 cfs.

Rapids are important attributes of white-water boating trips (Bishop et al., 1987). Rapids are flow-related since a number of small to medium rapids become "washed out" at relatively high flows, while other larger rapids become more exciting to run. Constant daily flows affect trip procedures at major rapids differently for commercial motor, commercial oar, and private trips. Most commercial oar guides stop to scout major rapids no matter what the flow level. In contrast, commercial motor guides are more likely to stop when flows are below 10,000 cfs and above 50,000 cfs. (Releases higher than 31,500 cfs are rare and unscheduled.) Private trip leaders are most likely to scout rapids at moderately high levels of 25,000 to 35,000 cfs. Guides and trip leaders also are more likely to have passengers walk around major rapids at flows above 35,000 cfs. At low flows (5,000 cfs or less), it often becomes necessary to either walk passengers around some rapids or wait for higher water.

Flow levels also can affect trip schedules. Commercial guides are more likely than private trip leaders to attempt to compensate for the speed of the current at high or low constant flows. Nearly all commercial guides will row or motor more at flows of 10,000 cfs or lower, while most will row or motor less at flows higher than 35,000 cfs.

Numerous attractions are found along the tributaries and side canyons of the Colorado River. River trips make planned stops at many of these and schedule short or extended dayhikes. These stops are important attributes of white-water trips. During low flows, both commercial and private trip passengers may have to miss one or more attraction sites because of the additional time needed on the river to maintain a trip schedule.

Finally, white-water boaters may feel more crowded at high flows because the number and size of beaches for camping are significantly reduced. In addition, during daily fluctuations in flows, boaters may congregate above rapids as they wait for the water level to rise. Jalbert (1992) found no relationship between flows and the incidence of on-river contacts between river rafters, probably because other factors—such as launch dates and itineraries—have a greater influence.

Wilderness Values

Studies of wilderness values in Grand Canyon were begun in the early 1970's but postponed due to the controversy over motorized raft use on the Colorado River. An amendment (Public Law 94-31) to the Grand Canyon Enlargement Act of 1975 called for completion of a wilderness study within 2 years. NPS released for public comment a draft environmental impact statement (DES 76-28) and a preliminary wilderness recommendation in 1976. The preliminary recommendation was for designating 82 percent of the park area as wilderness and an additional 10 percent as potential wilderness. Following incorporation of comments, a final EIS was completed in August of 1980 and forwarded to the Department of the Interior. No further action has been taken.

NPS is mandated by the Wilderness Act to protect wilderness values in the park, including those along the river, and to take no action that would potentially compromise future wilderness suitability. Motorized rafts are still in use on the river, and it is anticipated that the Congress, if it enacts a wilderness designation for the park, will stipulate the conditions under which motor use will or will not continue (under the direction of the Secretary of the Interior) on the Colorado River within Grand Canyon.

Wilderness is both a legal and philosophical concept—an area that appears to be influenced primarily by the forces of nature. The presence of Glen Canyon Dam does not preclude wilderness designation for the Colorado River through Grand Canyon, but dam operations can have an influence on the wilderness setting. The feeling of being in a wilderness area can be affected by fluctuations in daily flows since changes in releases from the dam would continually remind boaters of human control over riverflow and thus the recreational environment.

One of the attributes of an excellent or perfect river trip most often identified by river-runners is a wilderness experience. Enjoying a "wilderness experience" is more important to private (noncommercial) rafters and oar trip passengers and least important to motor passengers. Most river-runners are aware of wide daily fluctuations, and most feel that the fluctuations make the trip seem less like a natural setting (Bishop et al., 1987)

Safety

Riverflow levels affect accident rates; floodflows and low flows are believed to be the most hazardous. Fluctuating flows are not considered a significant factor in river safety. At low flows, major rapids (such as Hance) become difficult to navigate. Depending on the craft being used and the skill of the boatman, it often is necessary to camp above a rapid to wait for the river to rise. As the average daily flow increases, boaters become more tolerant of wider fluctuation ranges (Bishop et al., 1987).

Commercial guides believe that minimum constant flows must be over 8,000 cfs to safely run river trips with passengers. Commercial motor guides prefer flows around 20,000 cfs, while commercial oar guides and private trip leaders prefer higher mean discharges of 25,000 to 26,000 cfs. The preferred mean maximum flow for commercial guides is over 50,000 cfs, while a great number of private trip leaders prefer 40,000 cfs or less (Bishop et al., 1987).

Accident Occurrence. Although the actual boating accident rate is not high, the very nature of the Colorado River in Grand Canyon presents an unusually severe hazard for white-water boaters since rapids are difficult to navigate and people might fall into the water. In addition to the high water velocities and turbulence, the cold water is life threatening.

Flows in the range of 10,000 to 17,000 cfs appear to be the safest (Brown and Hahn, 1987). The chance of hitting rocks generally decreases as flow increases. The chance of going overboard, flipping boats, and sustaining injuries increases with higher flows. Actions taken to avoid rapids—such as walking passengers around a rapid and portaging—increase at extremely high (above 31,000 cfs) and low (below 5,000 cfs) flows.

Taking into account a boatman's judgment of risk and the actions taken to avoid accidents, high flows (16,000 to 31,500 cfs) are safest for both private and commercial trips, with medium and low flows presenting increased hazard for both. During flows less than 5,000 cfs, commercial motor trips have the highest rate of all types of accidents, but private oar-powered trips sustain more equipment damage and more frequently have their passengers walk around rapids (Jalbert, 1992). During floodflows, accident risk is much greater for private than for commercial trips. The risk of accidents varies by the type of boat employed. At extremely low flows (less than 5,000 cfs), motor rigs have the highest incidence of accidents, followed by small (typically private group) rafts (Jalbert, 1992). At flows higher than powerplant capacity, smaller craft—such as small rafts, dories, kayaks, and canoes/inflatables—have more accidents (Brown and Hahn, 1987). It appears the large, oar-powered rafts had the lowest incidence of accidents over the range of flows (Brown and Hahn, 1987; Jalbert, 1992).

Handicapped Accessibility

White-water boating in Grand Canyon—though a rigorous activity—is in demand by many, including handicapped individuals. Federal law ensures that special populations with mobility difficulties can take white-water trips. In 1991, two such trips were conducted specifically for special populations.

It is likely that many commercial and private rafters could accommodate handicapped individuals for a raft trip down the Colorado River. Potential inconveniences might include steep-pitched beachfaces and poor mooring sites (for example, a highly armored beachface). Where a party might otherwise be required to carry gear around a rapid, it might be necessary to alter an itinerary, set up camp, and wait for more suitable flows.

The greatest risk to disabled populations occurs during flows that have the highest incidence of accidents resulting in persons going overboard. This risk is compounded by the probability that another person will go into the water to help rescue the disabled individual. Dam operations have the greatest influence on handicapped accessibility during low flows, especially those below 5,000 cfs, when passengers (possibly handicapped) need to walk around a potentially unsafe rapid.

Camping Beaches

Sandbars form the camping beaches used by river runners (see chapter III, SEDIMENT). Camping is possible in only a limited number of locations along the river between Glen Canyon Dam and Lake Mead because most of the shoreline is unsuitable. An inventory of these camping beaches in 1975 listed about 400 campsites within the river corridor, but these were unevenly distributed in size and location. These beaches were resurveyed to assess how high flows influence individual beaches (Brian and Thomas, 1984). At least 277 were verified as being inventoried in both surveys. A survey of the Lower Gorge (Ross, written communication, 1992) inventoried 14 camping beaches.

The 1983-84 flood releases caused numerous changes in camping beaches. Of inventoried beaches, 30 percent increased in size, 28 percent decreased in size, and 42 percent remained the same. Beach degradation occurred in narrow, upstream reaches, while aggradation occurred mostly in wide, downstream reaches. The result was 24 beaches removed or nearly eliminated and 50 new campsites deposited. Brian and Thomas (1984) hypothesized that the system was not in equilibrium after the 1983 floods and that the number, size, and distribution of beaches would change depending on the stability of the sediment deposited at the new beaches.

A survey by Kearsley and Warren (1992) revealed that the total number of suitable camping beaches above the new high water zone had declined to 219 sites, a 50-percent decline in the number of sites considered usable. This reduced number of usable camping beaches can be attributed to erosion and vegetation growth. In narrow (critical) reaches of the river, erosion was the primary cause of campsite degradation. Vegetation encroachment accounted for nearly 50 percent of the campsite degradation in wider (noncritical) reaches (figure III-34).

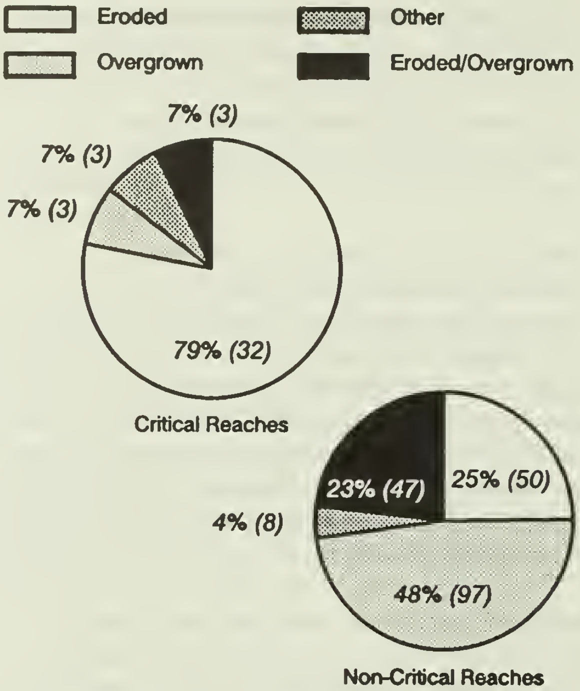


Figure III-34.—Number of camps degraded by reach type and type of degradation.

Campable Beach Area. Flows affect the usable area of a camping beach. The rise and fall of water levels, as a result of fluctuating discharges, inundates portions of the beaches, strands boats, and influences the wild character of the setting. Daily fluctuations influence campsite selection; many river runners will not choose a campsite that does not offer protection against water level changes (Bishop et al., 1987).

Kearsley and Warren (1992) evaluated the average area for small, medium, and large campsites (based on size of group accommodated) at several discharges. They concluded that campable areas differed significantly under the discharges evaluated. Table III-12 shows the average area of camping beaches by size class and discharge, while figure III-35 shows the percent of beach area change between evaluated discharges. Although large campsites lose more area at higher levels of discharge, this loss is not important in terms of carrying capacity for many camps. The campable area of most large camps far exceeds that needed for the maximum trip size of 36 people. The percent change in area of campsites between discharges for critical reaches was not significantly different than that for noncritical reaches at any discharge level.

An average of 35 percent of potential campsite area is inundated when releases increase from 5,000 to 25,000 cfs. About 36 percent of the small and medium sites available at 25,000 cfs become

Table III-12.—Average area in square feet of campsites by size class and discharge for 1991

Size class	25,000 cfs	15,000 cfs	8,000 cfs	5,000 cfs
Small	2,390	2,660	3,560	3,960
Medium	4,950	4,940	6,490	7,210
Large	11,720	13,980	17,660	19,340
All	7,720	9,200	11,740	12,910

Note: Low water campsites not included.

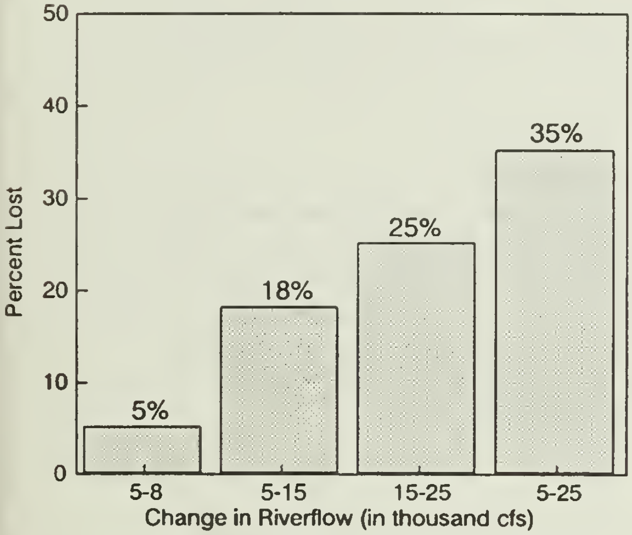


Figure III-35.—Percentage of beach area inundated between discharges.

large enough to change size class when dam releases are reduced to 15,000 cfs or less (Kearsley and Warren, 1992).

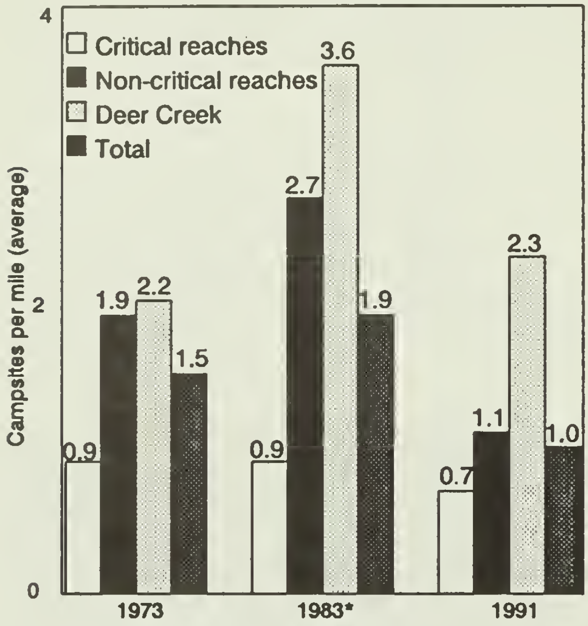
Beach Availability and Distribution. The location and distribution of beaches, by reach, set the absolute limits on visitor carrying capacity; i.e., the numbers of groups in a critical reach must be equal to or less than the number of campsites available in that reach. The distribution of camping beaches by reach is shown in table III-13.

The number of campsites averages 1.0 per mile, with campsites in critical reaches averaging 0.7 per mile and campsites in noncritical reaches averaging 1.1 per mile (Kearsley and Warren, 1992) (figure III-36). Campsite availability is

Table III-13.—Distribution of camping beaches by reach (Kearsley and Warren, 1992)

Reach	Small (1-12 people)	Medium (13-24 people)	Large (25-36 people)	Total
1	2 (1)	0 (0)	2 (0)	4 (1)
2	5 (6)	3 (1)	3 (0)	11 (7)
3	3 (0)	3 (2)	5 (0)	11 (2)
4	3 (3)	8 (0)	15 (0)	26 (3)
5	3 (0)	3 (0)	13 (0)	19 (0)
6	9 (3)	7 (1)	9 (0)	25 (4)
7	5 (2)	6 (1)	6 (0)	17 (3)
8	1 (1)	13 (0)	7 (0)	21 (1)
9	3 (5)	7 (2)	1 (0)	11 (7)
10	22 (9)	21 (3)	20 (0)	63 (12)
11	2 (1)	5 (2)	4 (0)	11 (3)
12	3 (*)	8 (*)	2 (*)	13 (*)
Totals	58 (31)	76 (12)	85 (0)	232 (43)

Note: Numbers in parentheses indicate additional campsites available at low water (15,000 cfs or less) only.



*1983 does not include "small" camps

Figure III-36.—Number of campsites per mile by type of reach, 1973, 1983, and 1991 (modified from Kearsley and Warren, 1992).

critically limited in four narrow sections of the river:

- Supai and Redwall Gorge
- Upper Granite Gorge above and below Phantom Ranch (RM 76–117)
- Muav Gorge above and below Havasu (RM 140–165)
- Lower Granite Gorge and Lake Mead (RM 226–270)

Critical reaches have disproportionately fewer large campsites per mile at 0.22 per mile compared to 0.46 large site per mile in noncritical reaches. Deer Creek reach (RM 131-139) has more sites per mile than any other river reach at 2.3 sites per mile. However, because of the popularity of attractions in the area, it is not uncommon for most of these sites to be occupied during the high use season. As a result of launch limits, usually no more than 60 groups are on the river within Grand Canyon at any one time during the peak season. However, it is not uncommon for all campsites in a critical reach to be in use and for some groups to have to share a camping beach. Lower Granite Gorge to Lake Mead is considered critically limited for camping and affects Hualapai and other commercial and private river recreation by limiting the number of 2-day river trips through the Lower Gorge.

Forty-two favorable sites that become available at discharges of 15,000 cfs or less were identified by Kearsley and Warren (1992). Nineteen (45 percent) of these are in critical reaches of the river, while 23 (55 percent) occur in noncritical reaches. Including these low water sites, the total distribution is 0.9 site per mile in critical reaches and 1.28 sites per mile in noncritical reaches; the low water sites make a more significant contribution to the critical reaches.

Mooring Quality. Kearsley and Warren (1992) analyzed mooring conditions at 129 campsites. Mooring conditions were influenced by large fluctuating flows at all sites. This study indicated that better mooring quality exists under constant flows than under fluctuating flows primarily because overnight boat management problems are eliminated (figure III-37).

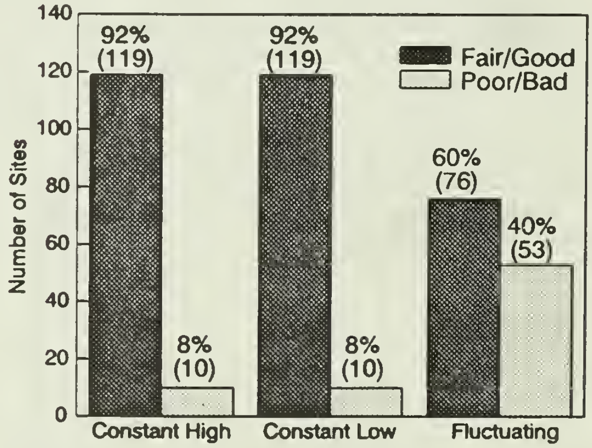


Figure III-37.—Mooring quality on the Colorado River under steady high, steady low, and fluctuating releases.

Lake Activities and Facilities

Recreation at Lake Powell

Lake Powell is the second largest reservoir in the Western United States. Glen Canyon Dam and Powerplant were constructed to operate between the elevations of 3490 and 3700 feet above sea level. Within this range, the lake has a water surface area of 52,000 to 163,000 acres and a shoreline of 990 to 1,960 miles. Lake Powell provides public recreation in several major categories of activities: lakeshore and backcountry camping, campground use, fishing, boating, beach use, and picnicking.

Normal fluctuations are a part of the nature and role of Lake Powell, with highest water levels generally occurring during the April to June spring runoff and lowest levels during February and March, when the reservoir is drawn down to provide flood storage capacity.

Facilities. Lake Powell currently has five developed marinas, with some expansions and additions planned. Existing facilities (marinas, boat docks, launch ramps, etc.) were constructed when Lake Powell was near its maximum surface elevation of 3700 feet. Normal lake fluctuations influence recreational boating because changing water levels affect access to the water via developed facilities. Change in reservoir levels requires adjusting facilities including marinas, docks, buoys and buoy lines, breakwater barriers, channel markers, and possibly ramps.

Boating. The amount of water storage in Lake Powell directly influences surface area, which in turn dictates boating capacity. At the 3700-foot level, the lake has 163,000 water surface acres. Using the safety standard developed in 1977 by the Bureau of Outdoor Recreation for open lake boating at unlimited power, a 1987 Lake Powell carrying capacity study applied a 9-acre-per-boat density limit, resulting in a safe boating density of approximately 17,932 boats. As shown in table III-14, less water surface results in increased boating density.

Table III-14.—Density as a function of lake surface area (Combrink and Collins, 1992)

Elevation (feet)	Lake surface area (acres)	Safe boating density (No. of boats)
3660	134,280	14,920
3680	147,490	16,387
3700	161,390	17,932

Recreational boating is the largest type of boating activity on the lake surface, with an estimated 1.5 million boater nights per year. While use of the major marinas at Wahweap, Hall's Crossing, and Bull Frog decreased during the low water period of 1989, the total number of boats reported on Lake Powell as of July 31 had increased 14.5 percent compared to the same period in 1988.

Camping. Ninety-five percent of Lake Powell boaters spend at least 1 night on the lakeshore (Combrink and Collins, 1992). As lake level decreases, so does the amount of shoreline and thus the number of suitable campsites. Competition for prime camping areas may result in unavoidable crowding, which in turn may influence the recreational experience.

Lake Level and River Rafting. Lake levels have an influence on commercial raft trips taken on the San Juan River and on the Colorado River through Cataract Canyon. The lake is considered a take-out point for raft trips, and most operators are more concerned about lack of water volume in the San Juan and through Cataract Canyon than they are about low lake levels. Lake levels do have an influence on operating costs (in the form of wear and tear on equipment and increased labor costs) and on trip duration.

Navigability of Upper Lake Mead

Boats usually are launched at Pierce basin, South Cove, or Temple Bar for excursions into Grand Canyon. Rental houseboats also travel to the Grand Wash Cliffs area on their week-long trips. Because there are no gas facilities on the lake upstream from Temple Bar, boaters must carry enough fuel to complete a round trip to their destination. Popular points of interest on these trips are Columbine Falls, Bat Cave, and Separation Canyon. Overnight beach camping is often a part of the itinerary for people enjoying the lower Grand Canyon by powerboat.

Before construction of Glen Canyon Dam, spring runoff carried heavy loads of sediment down the Colorado River to Lake Mead, where the sediment dropped out and settled at the lake bottom in the vicinity of Grand Wash to Pierce basin. After the dam was completed, sediment continued to be transported down the river, but in smaller quantities from side canyons and the beaches below the dam. Over the years, these sediment deposits have built up and are now exposed as broad mud flats in the vicinity of Pierce basin when lake levels fall below 1180 feet. Because no well-defined river channel has been established through these flats, the river is too shallow at low flows for boaters to navigate up to the Grand Wash Cliffs and into the lower reaches of Grand Canyon. Also, the channel changes with fluctuating flows, making it hard for even small boats to stay in the channel.

Economics of Recreational Use

This section describes the existing quantity, distribution, and economic impact of recreation in the study area. Two economic measures—the net economic value of recreation and the regional economic impact of recreation—are introduced. These measures are used to illustrate the national and regional economic impacts of the proposed alternatives.

The net economic value of an activity is the net addition to the nation's output of goods and services measured in dollar terms. The term "net economic value" is used to emphasize that it is a measure of the value over and above the costs of participating in a recreation activity. The costs of participation in a recreational activity are simply the expenditures made by recreators.

Regional economic impact is a measure of the importance to the local economy of the expenditures made by recreators. Since such expenditures reflect the costs of participation, they are not considered benefits from the national point of view and are excluded from the calculation of net economic value.

Recreation Use in the Study Area

The amount and distribution of recreational use in the study area have important implications both for estimating regional economic impact and for estimating the net economic value of recreation. The distribution of visitation during calendar year 1991 by recreational activity is shown in figure III-38. As shown, much of the white-water boating use occurs during the summer months when most Americans take their vacations. Most of the angling use occurs during the spring and fall. This pattern of use has an important effect on the generation of net economic benefits. To the extent that net economic benefits are directly determined by flow, changes in flow during periods of high recreational use produce larger changes in net economic value than similar changes in flow occurring at other times of the year.

NPS limits commercial and private white-water boating in Grand Canyon to 115,500 and 54,450 visitor days per year, respectively. White-water boating use is limited to 166 visitors per day during the primary season, May 1 through September 30. These use limitations were designed to increase boating safety, reduce crowding on the river, and minimize resource damage. These regulations are important since they preclude any increase in white-water boating use.

Presently, there are no constraints on the number of anglers permitted to fish in Glen Canyon. The number of fishing trips to the area in any given year is expected to vary with general economic conditions, fishing regulations, and the quality of the fishery.

Net Economic Value of Recreation

River-based recreation activities in Glen and Grand Canyons are nationally and internationally renowned for their quality and scope. Because of this significance, it was hypothesized that the net economic value of these activities was substantial.

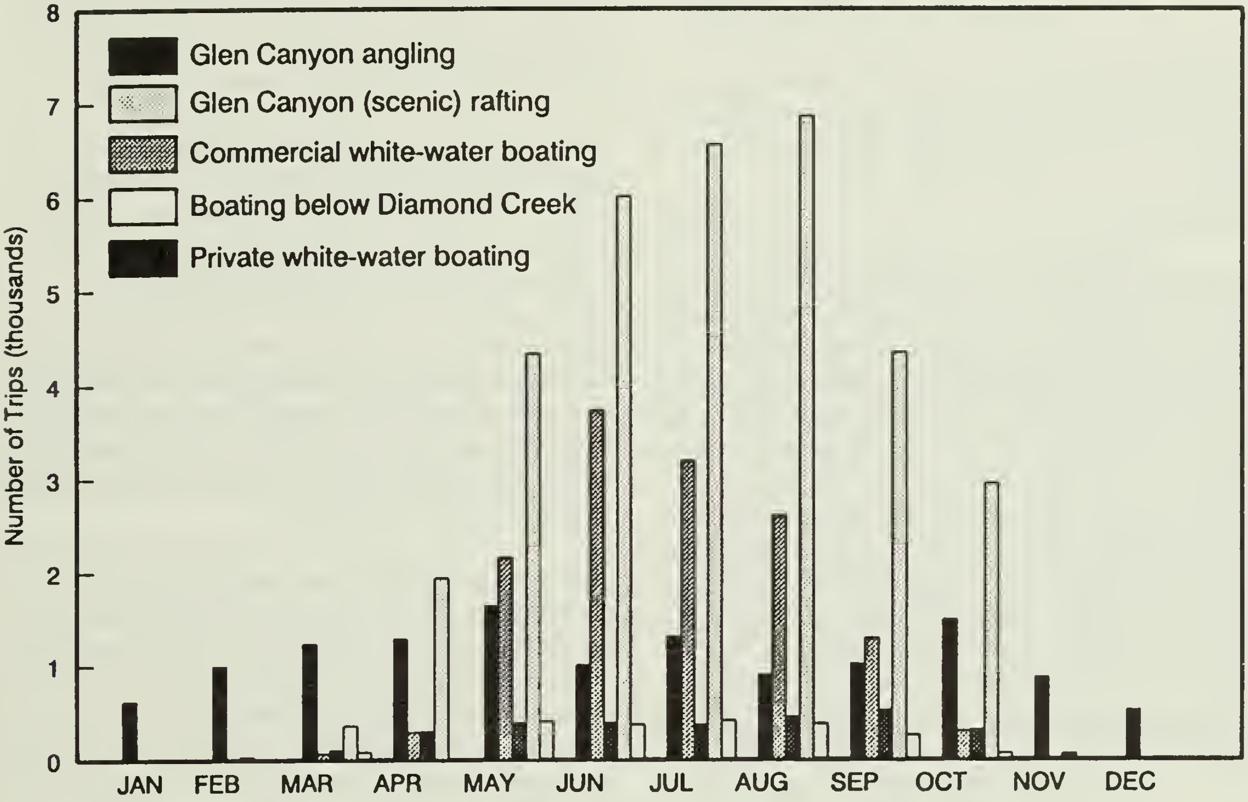


Figure III-38.—Recreational use in Glen and Grand Canyons, 1991.

However, the magnitude of this value and the degree to which it depends on flow were not investigated until relatively recently.

In 1987, a study of river-based recreation in the study area was completed by Bishop et al. The goals of this intensive study were:

- To document quantity and pattern of river-based recreational use
- To identify factors having a significant impact on the net economic value of recreational use
- To estimate net economic value of river-based recreation in the study area

The authors identified four major categories of river-based recreational use:

1. Day (scenic) rafting in Glen Canyon
2. Angling in Glen Canyon
3. Commercial white-water boating in Grand Canyon
4. Private white-water boating in Grand Canyon

The study by Bishop et al. (1987) was based on the contingent valuation technique, a survey method for estimating the net economic value of recreation use. The study found that the value of angling and white-water boating was related to flow and that there were significant differences between the effects of flow on commercial white-water boaters and private white-water boaters. In contrast, the authors reported that they were unable to identify a correlation between the value of day use rafting and flow. For this reason, no estimates of the net economic benefits of day rafting are presented.

White-water boating below Diamond Creek was not investigated by Bishop et al. (1987), and the potential influence of flow on the net economic value of white-water boating in this reach has not been empirically determined. For this reason, estimates of net economic benefit in this reach were made by prorating the net economic benefits from Bishop et al. (1987) on a per day basis. Table III-15 presents the estimated net economic value of recreation use based on 1991 use and price levels and on flow patterns for representative years.

It should be noted that the estimates of net economic benefit presented here and in chapter IV represent a "snapshot" in time. These estimates are based on the statistical relationship between flow and recreation with all other factors held constant at the time of the study. Therefore, these benefit estimates do not account for any long-term flow impacts on the environment. If, for example, camping beaches eroded over time, the estimated net economic benefit presented here would not reflect any negative impact that this might have on the value of the recreation experience. Conversely, if the number and size of camping beaches were to increase under some alternative, this too would not be reflected in the estimates of net economic benefit presented here.

Regional Economic Activity

River-based recreational users, such as anglers and white-water boaters, spend large sums of money in the Glen/Grand Canyon region. These recreators purchase gas, food and drink, lodging, guide services, and outdoor equipment while visiting the region. Expenditures represent participation costs and thus **do not** represent a benefit measure from the national viewpoint.

Direct expenditures are nonetheless important since they support local businesses and provide employment for local residents. In this sense, such expenditures provide some measure of the local impacts of recreational users.

However, direct expenditures alone do not fully measure the impacts of spending by visitors to the region. Local businesses and residents spend part of the money they receive from anglers and white-water boaters to purchase goods and services from other individuals and local businesses. These individuals and businesses, in turn, spend a portion of their revenue in the region, and so on. A portion of each dollar spent by nonresident recreators is re-spent over and over in the region, and the impact of each dollar of direct expenditure by visitors is greater than $1.

An example can be used to demonstrate this concept more clearly. Suppose that all of the businesses, government agencies, and households in a hypothetical county spent 40 percent of the money they receive from nonresident expenditures on goods and services in the local area. They spend the other 60 percent of the money to buy goods and services outside of the region. Each dollar spent by nonresident visitors will stimulate an initial $1 worth of local economic activity. That $1 is re-spent by businesses, government agencies, and households. Of that $1, $0.60 is spent outside the county and $0.40 is spent inside the county. Of that $0.40, $0.40 x 40 percent = $0.16 is re-spent in the region and $0.40 x 60 percent = $0.24 is spent outside of the county. After six successive re-spendings, the money that circulates inside the

Table III-15.—Net economic value of recreation
(Annual benefits in 1991 $ millions)

Type of release year	Anglers	Commercial white-water boating	Commercial white-water boating below Diamond Creek	Private white-water boating	Total
Low (1989)	1.3	5.4	0.1	1.1	7.9
Moderate (1987)	1.2	6.4	0.1	1.2	8.9
High 1 (1984)	1.1	12.4	0.2	2.0	15.7

hypothetical county is less than $0.01. In this example, the effect of each $1 of direct expenditures by nonresident visitors is:

Initial expenditure = $1.00
$1.00 x 40% = $0.40
$0.40 x 40% = $0.16
$0.16 x 40% = $0.06
$0.06 x 40% = $0.03
$0.03 x 40% = $0.01
Total impact = $1.66

This simple example illustrates that each additional dollar of direct expenditure by a nonresident visitor produces $1.66 in local economic activity. A simple multiplier is calculated from this result: ($1.66/$1.00) = $1.66.

A multiplier relates the amount of direct nonresident expenditure to the total amount of local economic activity produced by the visitor's spending. The size of a multiplier differs depending on the economic structure of the region. In general, the more complex the economy, the larger the multiplier and the more the impact on the local economy from each dollar of nonresident expenditure. Multipliers allow the impact of nonresident expenditures to be more fully assessed. For instance, suppose that a nonresident visitor spent a total of $101.00 in the hypothetical county discussed previously. Using the multiplier of 1.66, this direct expenditure would create $101.00 x 1.66 = $167.77 in local economic activity.

The U.S. Forest Service's Impact Analysis for Planning (IMPLAN) model (Taylor et al., 1992), a sophisticated framework for assessing regional impacts, was used to estimate multipliers for this analysis. These multipliers are based on the concept described above. However, unlike the example discussed, IMPLAN multipliers are disaggregated into business sectors.

Two Arizona counties, Coconino and Mohave, were assumed to capture the bulk of the local economic impacts generated by river-based recreation in Glen and Grand Canyons. River-based recreators who reside outside of these two counties are described as nonresidents for the purposes of this analysis. River-based recreators who reside in either Coconino or Mohave Counties were classified as residents.

Using IMPLAN, multipliers were developed for the local impact region and were used to develop the results reported in table III-16.

Estimates of average expenditures by anglers and white-water boaters were obtained by Bishop et al. (1987). Expenditures by white-water boaters below Diamond Creek are unknown. Estimates of their expenditures were derived by apportioning the trip costs found in Bishop et al. (1987) on a daily basis and by substituting their commercial trip fees as appropriate.

As shown, commercial white-water boaters generate most of the economic activity in the region. In total, river-based recreational users generated approximately $23 million in local economic activity in 1991.

Recreation, Economics, and Indian Tribes

Hualapai Tribe. Recreation access fees and commercial recreation enterprises generate a significant percentage of the total revenue earned by the Hualapai Tribe. This revenue supports the reservation's economy and creates employment for tribal members.

Recreational use of Hualapai resources in Grand Canyon has increased in the past decade and is anticipated to increase over time. Figure III-39 illustrates this trend. As shown, recreational use has increased substantially over the period that data is available.

The revenues generated by recreational activities on the Hualapai Reservation are earned by tribally-owned enterprises. The Hualapai Tribe's recreational enterprises can be classified into two types:

- River-based recreational activities
- River-related recreational activities

River-based recreational enterprises are those that are directly flow dependent, including such activities as fishing and white-water boating.

Table III-16.–Number of nonresident trips, direct expenditures by nonresident river-based recreators, and estimated local economic activity generated in the region

	Number of 1991 trips by nonresidents	Estimated regional expenditures per trip (1991 $)	Total direct expenditures by nonresidents (1991 $)	Local economic activity generated (1991 $)
Glen Canyon (scenic) rafting	32,816	72	2,374,000	3,928,000
Glen Canyon anglers	10,270	122	1,252,000	1,833,000
Private white-water boaters in Grand Canyon	2,926	255	747,000	1,124,000
Commercial white-water boaters in Grand Canyon	13,478	711	9,581,000	15,420,000
Commercial white-water boating below Diamond Creek	1,504	299	450,000	735,000
Private white-water boating below Diamond Creek	467	103	48,000	75,000
Total	61,461		14,452,000	23,115,000

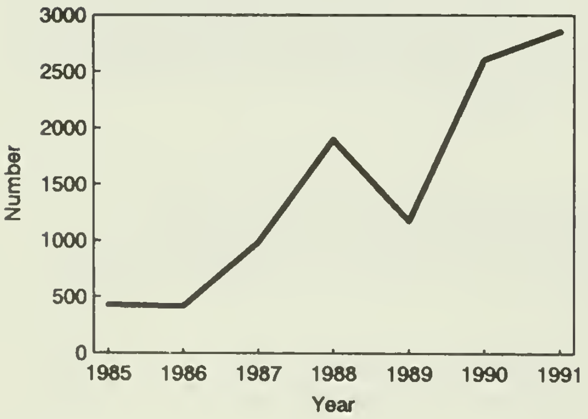


Figure III-39.—Total recreation permits sold by Hualapai Tribe, 1985-91.

Conversely, river-related activities such as sightseeing and camping take place in the river corridor but are not directly influenced by flow.

Commercial white-water boating below Diamond Creek may have net economic value and regional economic impact. However, Bishop et al. (1987) did not investigate the net economic value of white-water boating in this reach.

Based on use data provided by the Hualapai Tribe and several assumptions about boater expenditure patterns, estimates of the regional economic impact of boating below Diamond Creek were developed. These estimated impacts are shown in table III-16.

River-Based Recreation.–A substantial portion of the Hualapai Tribe's gross revenue is derived from river-based recreational activities. The largest of these activities is white-water boating. The Hualapai Tribe owns and operates Hualapai River Runners, a commercial white-water boating company. Hualapai River Runners is one of four tribal enterprises and was the major source of tribal income in the 1980's. In addition to offering white-water boating trips, Hualapai River Runners provides shuttle services, tows across Lake Mead, and access for river takeouts at Diamond Creek. In 1987, Hualapai River Runners earned 49 percent or approximately half of the Hualapai's total gross income.

The tribe has diversified its business interests and now depends less on river-based recreation activities than it did in the past. Nevertheless, the tribe earned about 33 percent of its total 1991 income from such activities.

River-Related Recreation.–The Hualapai Tribe also owns and operates Grand Canyon West, an enterprise based on the natural beauty of Grand Canyon and the Colorado River. This enterprise offers guided tours of the Hualapai Reservation at the west end of the canyon. Currently, Grand Canyon West provides only river-related activities that are not directly flow dependent.

The Hualapais sell permits for sightseeing and camping on the reservation. Much of this river-related use is concentrated along the river corridor. In addition, the Hualapai Tribe derives approximately one-quarter of its gross revenue from the sale of permits to hunt desert bighorn sheep. Some of these sheep are known to use riparian zones in Grand Canyon.

Navajo Nation. The Navajo Reservation borders portions of Glen Canyon National Recreation Area and Grand Canyon National Park. There has been little development of business enterprises in this region due largely to the "Bennett Freeze." Imposed by the Federal Government in 1966, this statutory freeze precluded construction or development on this portion of the reservation pending resolution of a territorial dispute. The Bennett Freeze has recently been lifted, and river-based enterprises may develop in the near future. At the present time, however, no river-based enterprises owned or operated by the Navajo Nation have been documented.

At various times, the Navajo Nation has planned to construct a marina at Antelope Point on Lake Powell. Should such a marina be constructed, it would be subject to the same impacts as existing NPS facilities on the lake. These impacts are described under "Lake Activities and Facilities."

A number of tribally owned or operated businesses in Cameron, Tuba City, Grey Mountain, and elsewhere on the reservation are dependent on Grand Canyon visitors. The many jewelry stands along Arizona Highway 89 and other approaches to the park are especially prominent examples. Owned and operated by individual Navajo families, these small enterprises are frequented by visitors to the region.

Other Tribes. Portions of the Havasupai Reservation border Grand Canyon National Park. No river-based enterprises owned or operated by the Havasupai Tribe have been documented. The Hopi Tribe, Pueblo of Zuni, and Southern Paiute Tribe have both current and historical ties to Grand Canyon and the surrounding region. No river-based enterprises owned or operated by these tribes have been documented.

HYDROPOWER

This section describes hydropower resources as they affect, or are affected by, Glen Canyon Dam operations. The discussion is presented under two major headings:

- Power operations
- Power marketing

Power generated at Glen Canyon Dam is marketed mostly in six Western States by the Department of Energy's (DOE) Western Area Power Administration (Western). Western's primary mission is to sell power from Federal water project powerplants under statutory criteria in the Reclamation Project Act of 1939, the Flood Control Act of 1944, and the Colorado River Storage Project Act of 1956. These criteria include:

- Preference in the sale of power must go to municipalities, public corporations, cooperatives, and other nonprofit organizations.

- Power must be marketed at the lowest possible rates consistent with sound business practices.
- Revenues generated from power sales must pay for power generation and all allocated investment costs under the original Colorado River Storage Project (CRSP) Act.
- Projects should generate the greatest amount of power and energy that can be sold at firm power and energy rates, consistent with other project purposes.

Western's other statutory responsibilities include construction, operation, and maintenance of transmission lines and attendant facilities.

In this document, power refers to both capacity and energy.[1] Capacity refers to the total powerplant generation capability. Energy is electric capacity generated and/or used over time. Capacity and energy both can be sold on a firm (guaranteed by contract) or nonfirm (provided as available, not guaranteed) basis.

Glen Canyon Dam and Powerplant are part of the CRSP, one of the Federal projects from which Western's SLCA markets capacity. SLCA is part of an interconnected generation and transmission system that includes Federal, public, and private power generating facilities. Other Federal projects and facilities from which SLCA markets power are presented in Appendix E, Hydropower.

To ensure timely repayment of Federal project construction debt and coordinate electric power rate-setting and marketing efforts, the Colorado River Storage, Collbran, and Rio Grande Projects were administratively integrated into the Salt Lake City Area Integrated Projects in 1987 (figure III-40).

Actual operating capacity for each powerplant depends on generating unit capabilities and efficiencies, reservoir elevation, and maximum water releases through the powerplant.
CRSP powerplants, together with Fontenelle Powerplant, provide approximately 98 percent of SLCA/IP's total capacity and 97.5 percent of the energy.

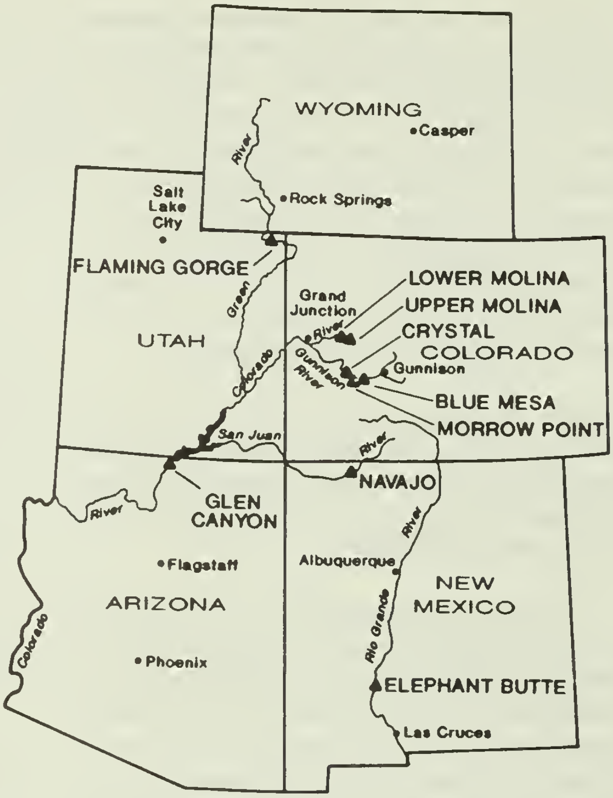


Figure III-40.—Location of Salt Lake City Area Integrated Projects

Power Operations

Power operations refer to the physical operations of a large electrical power system, including power generation, control, and transmission. Power operations form the basis of all power sales and services, referred to as marketable resources.

To ensure system reliability, Western is required to meet operational and reliability guidelines of the North American Electric Reliability Council (NERC), the Western System Coordinating Council (WSCC), and the Inland Power Pool (IPP).

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[1] Capacity vs. energy: megawatts and kilowatts represent power, while megawatthours and kilowatthours represent energy. Reclamation and Western can deliver kilowatts (power) from Glen Canyon Dam as a function of generator size and the capability of the hydroelectric network. Kilowatthours (energy) are delivered by employing capacity over time.

Each WSCC utility must be within a load control area, and one utility serves as load control area operator. Western is a load control area operator, responsible for ensuring that each utility within the area:

- Serves its own internal load (demand) and meets its power obligations
- Maintains enough generating reserve to respond to its internal load changes and disturbances (such as loss of a generator or a transmission line) on the interconnected system

Within the Western Area Upper Colorado (WAUC) load control area, the flexibility and quick response of CRSP hydroelectric powerplants—particularly Glen Canyon—are important in meeting reliability criteria.

The WAUC load control area was combined with the Western Area Lower Missouri load control area in April 1993; however, since management and procedures for the larger load control area are still being refined, discussion of Glen Canyon Dam operations will be limited to the WAUC.

Operational Flexibility

One of the major benefits of a hydroelectric powerplant is flexibility—it can quickly and efficiently increase or decrease generation as needed. The following events typically require powerplant responses:

- Changes in customer demand
- Generating unit or transmission line outage
- Special requests for assistance
- Unscheduled customer deviation from power schedules

The previous factors are made more complex by the following variables:

- How often an event occurs
- Season and time of day the event occurs
- Restrictions at other CRSP generating facilities
- Availability and price of alternative power resources

Individual components of operational flexibility are described in the rest of this section.

Scheduling. Scheduling is the process of matching each day's system energy and capacity needs with available generation. Many factors affect the daily scheduling of energy and capacity from Glen Canyon Dam:

- Monthly water volumes and how water allocations are distributed over the month
- Water release patterns (maximum and minimum flows, allowable daily change in flows, up and down ramp rates)
- Availability of Glen Canyon units and other generation units in the system
- Customer allocations and special requests
- On-peak and off-peak periods
- Weather forecasts
- Market prices

Generally, scheduling to meet power requirements means making higher water releases in peak load months (December, January, July, and August) and lower water releases when electric power demand is less. This allows Western to take advantage of market conditions for cost-effective sales and purchases.

Interchange occurs when one utility delivers energy or capacity to another utility, which the second utility agrees to return at a later time in agreed upon quantities. Western uses interchange, when financially feasible, to ensure system reliability and acquire additional power when available water releases can't generate enough to meet loads. Flexibility to change water releases—between seasons and days and during each day—determines how effectively interchange can be used.

Load Following. Power generation rises and falls instantaneously with the load (or demand)—a pattern called load following. The amount of load on the system is determined by how many electrical devices are using power.

Glen Canyon Dam can immediately increase or decrease water releases, thus changing power generation instantaneously. As load control area operator, Western provides immediate response to changes in control area load up to a maximum of plus or minus 2-½ percent of its total load, or about 56 megawatts (MW). (A release of 1,000 cfs through the powerplant turbines generally equates to generation of approximately 35 MW, depending on the elevation of Lake Powell.) By comparison, coal- and nuclear-based resources are less efficient and have a relatively slow response time; consequently, they generally are not used for load following. Oil- and gas-based powerplants fall between hydro and coal/nuclear in efficiency and response time and can be used for load following.

Under normal conditions, the system load pattern throughout the region stays about the same Monday through Friday. On Saturday and Sunday, load drops considerably as companies with a heavy commercial or industrial load shut down. System load also varies with seasonal conditions.

Minimum and maximum water release levels determine the minimum and maximum power generation capability. Both scheduled and unscheduled ramping are crucial in load following, emergency situations, and variations in real-time (what actually happens compared to what was scheduled) operations.

Regulation and Control. Regulation and control maintain electrical system stability, frequency, and voltage. These actions can occur either automatically (through automated generation control as explained in chapter II) or manually by dispatcher actions. Regulation depends on being able to ramp up or down quickly in response to system conditions. SLCA/IP powerplants provide regulation services to the city of Farmington, Tri-State Generation and Transmission Association, and Deseret Generation and Transmission Cooperative. Glen Canyon Powerplant provides the majority of system regulation and control for the WAUC control area.

Reserves. Each utility is required to have sufficient generating capacity—in varying forms of readiness—to continue serving its customer load, even if the utility loses all or part of its own largest generating unit or largest capacity transmission line. This reserve capacity ensures electrical service reliability and uninterrupted power supply. Reserve requirements are based on total available capacity—which, in turn, is determined by the minimum and maximum allowable releases through the generators.

Due to its flexibility and rapid response, Glen Canyon Powerplant provides excellent reserves. Spinning reserves are used to quickly replace lost electrical generation resulting from a forced outage, such as the sudden loss of a major transmission line or generating unit. Operating reserves also are used to replace generation shortages but cannot be provided as quickly as spinning reserves.

Emergencies and Outage Assistance. Western's operating procedures meet North American Electric Reliability Council guidelines for emergency operating criteria. NERC guidelines state that under emergencies, generation must be available to quickly restore the transmission system and start the return to normal operating conditions within 10 minutes. Generally, emergency services are needed only for short periods (1 hour or less).

Glen Canyon Powerplant is important in responding to interconnected transmission system emergencies. Western has existing contractual agreements to use Glen Canyon capacity to restart thermal powerplants in the area in the unlikely event of a widespread power outage.

Emergency assistance is similar to emergency operations, but generally involves smaller outages that last longer. Under this service, each IPP member utility is obligated to provide up to its spinning reserve amount of capacity and energy for 72 hours if an unplanned outage occurs. Western's ability to supply IPP emergency assistance is limited by two factors: available transmission capacity and generation capability.

Western's ability to deliver emergency assistance varies on an hourly basis, depending on firm load obligations and available generation from project resources. Under historic operations, with a full reservoir and average loads, Glen Canyon Powerplant has provided emergency assistance beyond its required reserves.

When an unplanned outage extends beyond 72 hours, the affected utility may arrange to purchase or exchange firm capacity and/or energy with another utility. The SLCA often provides scheduled outage assistance due to its central location within IPP and the flexibility of its hydroelectric resources.

Transmission System. The CRSP/WAUC transmission system has approximately 2,300 miles of transmission lines. The following map shows the CRSP Interconnected Transmission System. The CRSP transmission system stretches from southern Wyoming through western Colorado and eastern Utah, down to northern New Mexico, across northern Arizona, and finally into the south-central Arizona area. The WAUC is interconnected with six other Federal and private load control areas:

- Public Service Company of Colorado
- PacifiCorp (including Utah Power and Light)
- Public Service Company of New Mexico
- Western Area Lower Missouri
- Arizona Public Service Company
- Western Area—Lower Colorado

Western's transmission lines transport electricity from Glen Canyon Dam and other generating sources to customer utilities that serve end-users, such as residential, irrigation district, and commercial and industrial consumers.

Both hydroelectric and thermal generation are affected by transmission limitations when lines do not have enough capacity to transport electricity from the point of generation to the point of demand. At times, Western can mitigate existing limitations on Glen Canyon's eastern transmission line by exchanging power with the Salt River Project (SRP), as explained later in this section.

The amount of power scheduled for transmission varies from season to season, day to day, and hour to hour. Scheduling limits are derived from physical limits and determine how many transactions may occur. Actual transmission refers to the actual measured flow of power on the line. NERC requires monitoring of the actual and schedule power flow for system operation.

Transmission Service.–Western, like many utilities, offers both firm and nonfirm transmission service. Firm transmission service is contractually guaranteed for the term of the agreement. Nonfirm transmission service is provided as available and is not guaranteed. Western participates in electricity transfers through "wheeling," which occurs when two indirectly connected utilities agree to purchase or sell power to each other. The purchaser or seller must make arrangements to use the transmission system that electrically connects them. Western offers wheeling service over particular CRSP transmission paths, including lines carrying power from Glen Canyon. Nonfirm transmission service, like nonfirm power sales, can be interrupted on short notice.

SRP Exchange Agreement.–Seventy-five percent of SLCA/IP generating resources are located at Glen Canyon, while many of SLCA/IP loads are located in Utah, Colorado, and New Mexico. All capacity needed to satisfy load in these areas cannot be sent directly from Glen Canyon because of the limited capacity of the Glen Canyon-Kayenta-Shiprock transmission line, which links the powerplant to these major load areas.

To compensate, Reclamation and the SRP Agricultural Improvement and Power District entered into a long-term contract in 1962 to exchange Glen Canyon generation for SRP generation at coal-fired powerplants in Craig and Hayden in Colorado, and at Four Corners, New Mexico. The SRP exchange, amended in 1974, also provides for limited transmission of SRP capacity during times when a full hydro-thermal exchange is not possible. The SRP exchange agreement has operated successfully for many years, with proven benefits to both parties. This arrangement maximizes efficiency and has reduced overall environmental impacts.

Power Marketing

Power marketing involves determining appropriate levels of long-term firm capacity and energy commitments based on the long-term firm capacity and energy available from SLCA/IP powerplants. It also involves establishing contractual arrangements to provide long-term, firm electrical service—on a wholesale basis—to electrical utility customers.

Several laws govern the marketing of capacity and energy. Section 9(c) of the Reclamation Project Act of 1939 discusses principles of power rates in terms of the minimum charges for power. The law also makes it clear that the United States markets power to serve the public interest, not to make a profit. Section 7 of the CRSP Act of 1956 instructs Western to generate the most power practicable without interfering with other authorized project purposes.

Ninety-five percent of CRSP costs must be repaid to the U.S. Treasury by power and water users. Reimbursable costs include:

- One hundred percent of the Federal investment in power facilities, plus interest
- One hundred percent of annual operation and maintenance costs for power facilities
- Federal investment in irrigation facilities beyond the irrigators' ability to repay

The remaining 5 percent of CRSP costs are nonreimbursable, paid by monies appropriated primarily through Federal taxes. Additional background on project cost repayment can be found in appendix E.

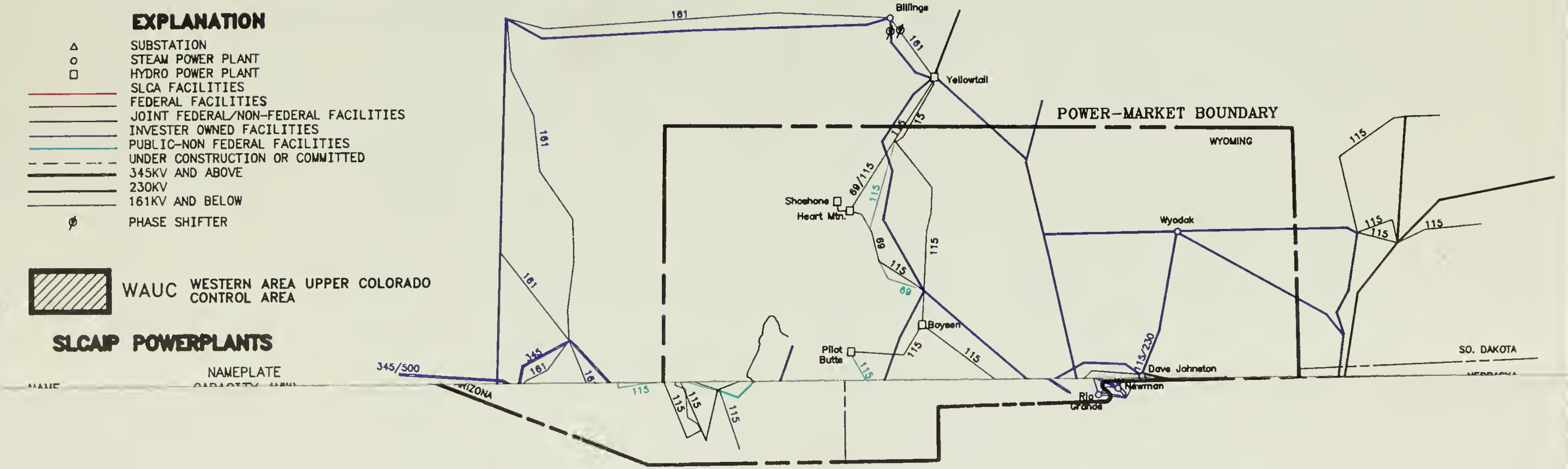
Western markets a number of electric power services such as long-term firm capacity and energy, short-term firm capacity and energy, and nonfirm energy. Loads are made up of firm load, nonfirm sales, and interchanges out of the control area. Firm load includes long- and short-term firm sales, Reclamation project use loads, system losses, control area regulation, firm load reserves, and scheduled outage assistance. By law, capacity must be reserved to operate CRSP, participating projects, and Reclamation's irrigation and drainage pumping plants before marketing long-term firm capacity. Western's ability to make nonfirm sales depends on SLCA/IP's flexibility to take advantage of the difference in the off- and on-peak spot energy markets.

Long-Term Firm Power

Generally, long-term firm contracts are for 10 years or more and are based on estimates of the long-term availability of capacity and energy. Determining the amount of resources that can be sold on a long-term basis requires a balance between the mandate to market the greatest practicable amount of firm resources and the risk of occasionally being unable to meet firm contract commitments due to periods of drought. Generally, Western must meet its firm contract commitments, either through generation alone or by generation combined with purchases. Long-term firm commitments vary seasonally according to project loads and customer requirements.

Seven of SLCA/IP's customers are considered to be "large" systems—utilities that buy capacity and energy to supplement their own generating resources. The rest of Western's customers are "small" systems, which means they have little or no generating capacity and rely on purchases for most or all of their capacity and energy needs. Almost all SLCA/IP customers have supplemental suppliers to meet additional capacity needs.

The SLCA/IP marketing area and some of the many customers are shown on customer service maps in appendix E, along with a detailed listing of their firm capacity and energy allocations.



UNITED STATES
DEPARTMENT OF ENERGY
WESTERN AREA POWER ADMINISTRATION
SALT LAKE CITY AREA OFFICE

COLORADO RIVER STORAGE PROJECT
INTERCONNECTED TRANSMISSION SYSTEM

APRIL 1993

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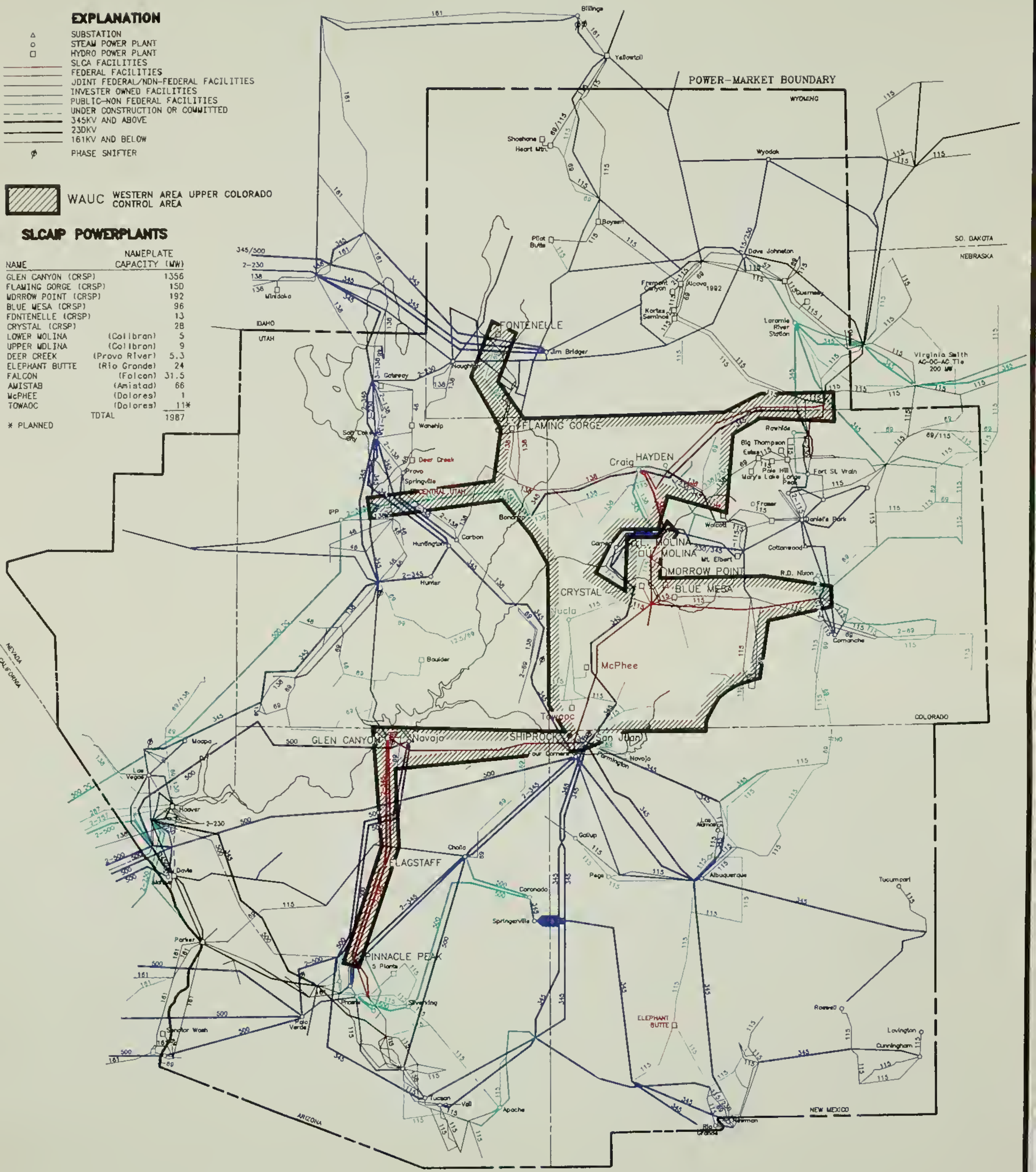

EXPLANATION

- △ SUBSTATION
- ○ STEAM POWER PLANT
- □ HYDRO POWER PLANT
- SLCA FACILITIES
- FEDERAL FACILITIES
- JOINT FEDERAL/NON-FEDERAL FACILITIES
- INVESTER OWNED FACILITIES
- PUBLIC-NON FEDERAL FACILITIES
- UNDER CONSTRUCTION OR COMMITTED
- 345KV AND ABOVE
- 230KV
- 161KV AND BELOW
- ϕ PHASE SHIFTER

▨ WAUC WESTERN AREA UPPER COLORADO CONTROL AREA

SLCAIP POWERPLANTS

NAME		NAMEPLATE CAPACITY (MW)
GLEN CANYON (CRSP)		1356
FLAMING GORGE (CRSP)		150
MORROW POINT (CRSP)		192
BLUE MESA (CRSP)		96
FONTENELLE (CRSP)		13
CRYSTAL (CRSP)		28
LOWER MOLINA	(Collbran)	5
UPPER MOLINA	(Collbran)	9
DEER CREEK	(Provo River)	5.3
ELEPHANT BUTTE	(Rio Grande)	24
FALCON	(Falcon)	31.5
AMISTAD	(Amistad)	66
McPHEE	(Dolores)	1
TOWAOC	(Dolores)	11*
	TOTAL	1987

* PLANNED

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Short-Term Firm Power

Short-term firm sales of capacity or energy can be made seasonally or monthly. Short-term firm sales are based on resource availability projections that exceed long-term firm commitments. Prior to each 6-month marketing season, Western determines whether excess capacity or energy will be available for a season or a month. This short-term firm resource is made available first to Reclamation for project needs, then to preference customers (municipalities, public corporations, cooperatives, and other nonprofit organizations). Any remaining resources are offered to nonpreference customers. Prices are based on long-term firm power rates.

Nonfirm Energy

Nonfirm sales are short duration energy transactions, always less than 1 year. Normally scheduled 1 day in advance, they can be determined up to the hour of transaction. The flexibility of hydropower operations allows actual deliveries to be modified hourly, as system conditions warrant. Western may market nonfirm energy and arrange for interchange transactions, depending on revised water release estimates. Nonfirm energy sales are not guaranteed and may be interrupted with advance notice. The price for this service is based on market conditions.

Nonfirm sales also are known as economy energy or fuel replacement sales, terms related to substitution of hydroelectric generation for oil- and gas-fueled generation. The fuel replacement program began in the early 1980's to encourage this substitution. Economy energy sales are scheduled as market and hydrologic conditions allow.

SLCA/IP Post-1989 Power Marketing Criteria

In 1980, Western began to review and modify its marketing and allocation criteria because existing power contracts were due to expire on September 30, 1989. The associated public process in 1986 resulted in the post-1989 marketing criteria. Western is preparing an EIS on the post-1989 marketing criteria.

Marketable Resources

The SLCA/IP hydropower resources supply the marketable energy and capacity under the post-1989 power marketing criteria. Capacity and energy are marketed on a seasonal basis—winter season (October through March) and summer season (April though September). Under the post-1989 marketing plan, SLCA/IP has contractual commitments for 1,407 MW of capacity and 3,105,848 megawatthours (MWh) of energy in the winter season and 1,315 MW of capacity and 2,904,403 MWh of energy in the summer season. These amounts are explained in greater detail in the following sections.

Capacity. The CRSP and Fontenelle Powerplant components of the SLCA/IP total long-term firm capacity values are based on the amount of capacity available 9 of every 10 years.[2] Critical seasonal loads occur in winter (December-January) and summer (July-August). Critical seasonal capacity values are based on the heaviest load month in each of those two seasons.

Energy. Marketable CRSP energy is based on projected annual seasonal averages, plus 400 gigawatthours (GWh). The rationale for selecting approximate average seasonal energy, plus 400 GWh, is similar to the rationale for selecting capacity levels.

Average generation, plus 400 GWh, corresponds to the level that would be equaled or exceeded about 4 of every 10 years on an average annual basis. Western must purchase any shortfalls

---

[2] Marketable firm capacity and energy are based on attempts to ensure a reliable level of capacity and energy, while maintaining an acceptable level of risk. This level of acceptable risk was approved by Western's customers following review of the September 1984 "Revised Proposed General Power Marketing and Allocation Criteria" (Department of Energy, 1985).

below the annual average, plus 400 GWh. Historically, SLCA has purchased up to 2,000 GWh annually to make up for generation shortfalls, as well as interchange and on- and off-peak economy transactions.

Net Marketable Capacity and Energy. Net marketable capacity is determined by subtracting project use loads, system losses, control area regulation needs, firm load reserves, and scheduled outage assistance loads from generation. The resulting winter and summer capacities are 1,407 MW and 1,315 MW, respectively. Net marketable energy is determined by adding purchases to the combined powerplant resources and subtracting losses and project use. The winter and summer marketable firm energy is 3,106 GWh and 2,904 GWh, respectively. These amounts vary seasonally due to differences in project use loads and exchanges. Approximately 12 percent of this energy and capacity is delivered to customers within the WAUC control area; the remainder is exported to six adjoining control areas (listed under "Transmission System") for delivery to SLCA/IP customers.

Wholesale and Retail Power Rates

Western's customers typically are municipal utilities, Federal or State public power projects, or rural electric cooperatives paying wholesale rates to purchase power for resale to their customers. Retail rates are those paid by end-users (residential, commercial, and industrial clients of Western's wholesale customers). Changes in Glen Canyon operations could impact both wholesale and retail power rates; therefore, wholesale and retail rates are used as indicators of power marketing impacts.

Wholesale Rates and Repayment. Power repayment studies are used to ensure project power revenues will be sufficient to pay all costs assigned to power within the prescribed time periods. Payment criteria are based on law and on policies established in DOE Order RA 6120.2.

Power revenues also pay annual power operation and maintenance, purchased power, transmission service, and interest expenses, as well as various miscellaneous costs. CRSP power revenues also must contribute toward salinity control costs under the Colorado River Basin Salinity Control Act and construction costs of CRSP participating projects.

By law, firm power rates are based on recovering costs—i.e., only what it takes to keep the system operating and pay its obligations. Therefore, Western's rate-setting procedures differ from those of profit-making utilities.

SLCA/IP revenues are used first to pay annual operation and maintenance, purchased power, transmission service, and other annual expenses, then to pay interest expense. Any remaining annual revenues are applied to the investment costs assigned to power, so that each investment can be paid within the time allowed. Normally, the highest interest-bearing investments are repaid first, because this usually results in a lower overall power rate.

Since the CRSP and the Rio Grande and Collbran Projects were integrated, parts of their power repayment studies also were combined. The resources of all three projects are summed to arrive at an estimate of the total available. The gross power-related revenue required for the smaller projects is added as another expense to the CRSP. The power repayment study then helps determine the combined rate needed to meet the total revenue requirements of each SLCA/IP project.

Retail Rates. Approximately 180 public power utilities, servicing more than 3 million retail customers, currently purchase electric power from the SLCA/IP. Most of these utilities are located in Arizona, Colorado, Nevada, New Mexico, Utah, and Wyoming (figure III-41), though some extend into California, Nebraska, and Texas.

The retail rates charged by these public power entities normally are set to cover system operation and capital costs. The largest portion of these obligations, in the case of Glen Canyon, is attributed to operating expenses. As costs of these individual components change, the retail rates are adjusted to ensure enough revenue is collected to meet the utility's financial obligations.

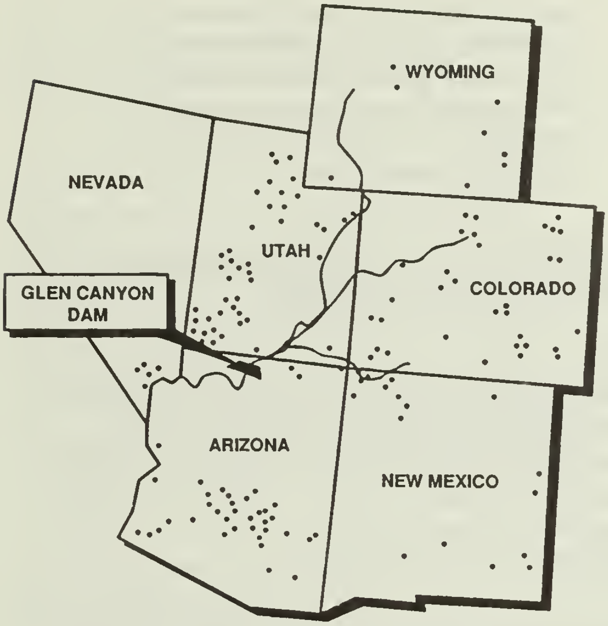


Figure III-41.—The SLCA/IP markets power to approximately 180 utilities, mostly in six States.

NON-USE VALUE

The previous sections on recreation and hydropower focused on the human uses for Colorado River flows in Grand Canyon. These uses include fishing, white-water boating, and the production of electric power. Analyses of the impact of riverflows on all of these uses are presented in chapter IV. Until recently, most descriptions of these uses of resources probably would have ended there.

However, social scientists have long acknowledged the possibility that humans could be affected by changes in the status of features of the natural environment even if they never visit or otherwise use these features. These individuals may be classified as non-users, and expression of their preferences regarding the status of the natural environment may be termed "non-use value." Non-use value is the term used in this EIS to describe the monetary value non-users place on the status of the natural environment.

This section details the concept of non-use economic value and describes the ongoing non-use value study for this EIS.

Market Value, Non-Market Value, and Non-Use Value

Use values for marketed goods are one traditional measure of impacts to the human environment. Theoretically similar measures of use values for nonmarketed goods also are routinely used to support decisionmaking (Water Resources Council, 1983). Non-use value is a special case in which the nonmarket good is the status of particular attributes of the physical environment.

Measures of non-use value rarely have been considered in evaluations of impacts to the human environment. However, applications of non-use value have become more numerous in recent years. Proposed Department of the Interior regulations allow estimates of non-use value to be used in natural resource damage assessment cases (U.S. Department of the Interior, 1991), and the Department of Commerce is now considering the use of non-use value for damage assessment in cases involving oil spills and toxic releases (U.S. Department of Commerce, 1990, 1991, 1992). As part of this consideration, the Department of Commerce commissioned a panel chaired by two Nobel laureates to study the concept, underlying theory, and related estimation techniques. The findings of this "blue ribbon committee" support the application of non-use value in these prescribed situations (U.S. Department of Commerce, 1993).

Conceptual Basis for Non-Use Value

Individual consumers use their incomes to purchase marketed goods and combine these marketed goods with time, human knowledge, and available nonmarketed goods to produce a particular quality of life. In these terms, it is clear that an individual's perception of well-being is determined by the interaction of the individual's preferences and the available marketed and nonmarketed goods. It is equally clear that consideration of only the value of marketed goods could overlook important impacts of various alternatives if the alternatives affect nonmarket goods about which individuals care.

The state of the natural environment affects people both in how they use the environment and how they would prefer the environment to be. Thus both use and non-use values need to be considered when assessing impacts to the human environment.

Given that non-use values are relevant in the decisionmaking process, it is worthwhile to review the factors that might give rise to non-use values. Frequently mentioned origins of non-use values are:

- Desire to preserve the functioning of specific ecosystems
- Desire to preserve the natural ecosystem to maintain the option for future use
- Feeling of environmental responsibility or altruism toward plants and animals

The most commonly accepted classification of these motives is the division of non-use value into bequest value and existence value, with option value sometimes considered as a third component. Bequest value is the value individuals place on preserving the resource for use by their heirs. Existence value is the benefit generated by knowing that a resource will continue to exist in the future even if no onsite use is contemplated. Option value is the value of preserving a resource so that the option to use the resource in the future is maintained.

The literature on non-use value emphasizes the uniqueness or specialness of the resource in question and the irreversibility of the loss or injury. Indicators of non-use value are described in the proposed Department of the Interior rules for damage assessment (U.S. Department of the Interior, 1991) which state:

> *. . . an injury to a common natural resource with many substitutes (e.g., a typical small stream), may not generate large non-use values, particularly for those residing outside the area where the injury occurred, even if the recovery takes a long time. However, a permanent injury to a unique resource (e.g., Grand Canyon) may generate significant non-use values, even for those residing in areas far removed geographically from the site where the injury occurred.*

Evidence of the Relative Magnitude of Use and Non-Use Value

Since the role that non-use value might play in a decision regarding dam operations at least partly depends on the magnitude of the value, it is worthwhile to review how non-use values were measured in other contexts. Particularly relevant are two studies that explored the non-use value associated with water resources.

Sanders et al. (1990) estimated the total value of preserving 15 wild and scenic rivers in Colorado. They reported that Colorado residents expressed a use value of $19.16 and a non-use value of $81.96 per household per year. The total (use and non-use) value of protecting 15 Colorado rivers aggregated over these 1.2 million households is approximately $120 million annually. As noted by the authors, non-use value was approximately four times the recreation use value.

Loomis (1987a, 1987b) estimated both use and non-use value for Mono Lake in California. Based on an analysis of open-ended responses, he reported that use value was approximately $40 per visit. Aggregated over 145,000 visits, total use value was approximately $5.8 million annually (Loomis, 1987a). For households, estimated non-use value was approximately $42.71 per year. Aggregated over 10 million households in California, total non-use value was approximately $422 million annually (Loomis, 1987a). In this case, too, estimates of non-use value greatly exceeded estimates of use value.

Non-use value estimates cited in the examples above are for "with and without" analyses. As described elsewhere in this document, this EIS focuses on how alternative Glen Canyon Dam operations will impact affected resources. Since these impacts are incremental in nature, non-use value estimates in this EIS will reflect only these incremental changes and may or may not approach the magnitude of the two examples.

As these examples demonstrate, if interest in the affected resources is widespread, then even a small per person or per household value can be very large when extrapolated across the population holding non-use value. It is possible that interest in the resources affected by Glen Canyon Dam operations could extend to all areas of the United States. If this is found to be the case, the non-use value of operational changes might be quite large.

Potential Non-Use Value for Hydroelectric Power

The discussion of non-use value presented thus far has focused exclusively on nonmarket goods. During this EIS process, the question arose whether there is some non-use value associated with hydroelectric power—a good sold in the market.

In the literature to date, there is only one example suggesting that non-use value might be associated with market goods (Lockwood et al., 1993). Nonetheless, the question of whether there is non-use value for hydropower generated at Glen Canyon Dam is one of more than purely academic interest. If non-use value for hydropower could be demonstrated, an unbiased approach would require estimating both the non-use value for the affected natural resources and the corresponding non-use value for hydropower.

Since the possibility of non-use value for market goods cannot be discounted, appropriate efforts will be devoted to investigating the existence and magnitude, if any, of non-use value for hydropower.

Implications of Non-Use Values

Estimating non-use value for the alternatives, if possible, may have important implications for the decisionmaking process. To the extent that non-use value is comparable with other estimates of economic impact presented in this EIS, including non-use value potentially could alter the outcome of the economic evaluation of alternatives.

If estimates of non-use value are not comparable to other economic impact estimates—perhaps because of concern about their precision—they nevertheless provide an invaluable quantitative gauge of public sentiment. It seems likely that decisionmakers would carefully assess such a quantitative measure of public preference.

Estimating Non-Use Value for This EIS

The Glen and Grand Canyon resources are known throughout the Nation and world. The Grand Canyon is, in fact, used as an example of a resource for which non-use value may be significant. The National Academy of Science Committee to Review the Glen Canyon Environmental Studies recognized this significance and noted that the GCES Phase I economic studies failed to consider non-use value (National Research Council, 1987).

Reclamation retained HBRS, Inc., an independent consulting company, to complete an analysis of the feasibility of estimating non-use value for the Glen Canyon Dam EIS. As part of this analysis, a panel of well-known economists was convened to review the HBRS, Inc. report, to provide written commentary on the technical adequacy of the work, and to provide their views on prospects for successfully completing a non-use value study for this EIS. While some technical and practical difficulties were noted, the findings of this panel were in favor of initiating a non-use value investigation (HBRS, 1991). As a result, the cooperating agencies decided to investigate the feasibility of estimating non-use value for this EIS.

In the initial stages of this investigation, a series of focus groups was held in 1992 at sites around the United States. Summary findings of these focus groups are described in HBRS (1992). These findings were presented to the cooperating agencies in Peach Springs, Arizona, in November 1992. Focus group results appear to indicate that non-use value for operational changes may be estimated, and the cooperating agencies jointly decided to continue the investigation in a stepwise manner.

The next step is a pilot testing research phase using a non-use value survey. A technically defensible non-use value survey depends on neutral depictions of the physical and biological impacts of the proposed alternatives. The research findings that would allow for these descriptions have only recently become available. A non-use value survey instrument is now being developed.

The Grand Canyon Protection Act of 1992 stipulates the completion of the final EIS by October 30, 1994. In order to meet this schedule, it was necessary to release the draft EIS prior to completing the non-use value study. Findings of the pilot testing research phase and of the full-scale non-use value study, if any, will be reported in the final EIS.

The nature and findings of the focus groups, references to the methodologies employed in the non-use value study, and a qualitative description of the likely outcome of this study are presented in chapter IV.

CHAPTER IV

Environmental Consequences

CHAPTER IV

Environmental Consequences

This chapter describes and analyzes the impacts of alternatives considered in detail on the affected resources. The analyses are organized by resource: water, sediment, fish, vegetation, wildlife and habitat, endangered and other special status species, cultural resources, air quality, recreation, hydropower, and non-use value.

The linkages among these Colorado River system resources are described in chapter III. Where possible, the impacts described for each resource take into account the impacts on other related resources. For example, each alternative affects streamflows, which in turn affect sediment. Sediment affects vegetation, which in turn affects wildlife and habitat—all of which affect recreation.

The conditions that existed in 1990, prior to the Glen Canyon Environmental Studies (GCES) research flows and the subsequent interim operations, establish the baseline for analyses of effects (see "Chapter III, Affected Environment"). Some anticipated impacts are a result of the existence of Glen Canyon Dam and will occur in the future regardless of which alternative is implemented.

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**

The area of potential impacts on water includes the Colorado River downstream from Glen Canyon Dam, Lakes Powell and Mead, and the Upper and Lower Basin States. Computer modeling studies projected operations for 50 years to determine long-term impacts and for 20 years to determine short-term impacts.

Analysis Methods

The Colorado River Simulation System (CRSS) was used in analyzing impacts on annual and monthly streamflows, floodflows and other spills, water storage, water allocation deliveries, and Upper Basin yield determinations for this environmental impact statement (EIS). CRSS is a package of computer programs and data bases designed to assist water resource managers in performing comprehensive long-range planning and operation studies. CRSS is used to address the many "what will happen if . . . " questions that arise from proposed changes in Colorado River operations, from proposed Colorado River Basin development, or from changes in present water use throughout the basin.

While earlier computer models for the Colorado River existed as early as the mid 1960's, CRSS stemmed from the need for a comprehensive model of the Colorado River Basin that would incorporate all areas of interest, including legislative requirements. Work on CRSS began in 1970, and—after 10 years of development, testing, and initial use—the model began to gain widespread use and support in the early 1980's. Today, CRSS is the most comprehensive and detailed simulation system of the Colorado River and serves as the Bureau of Reclamation's (Reclamation) primary tool in studying the river's operation.

The main CRSS module, which contains all of the operations logic, is the Colorado River Simulation Model (CRSM). Frequently the terms CRSM and

CRSS are used interchangeably; CRSS is used in this document to refer to the computer model. CRSS is described in relative detail in the publication, *Colorado River Simulation System, System Overview* (Schuster, 1985).

A computer model (peak-shaving model) developed by the Environmental Defense Fund was used for the hourly distribution of CRSS-projected monthly release volumes. These hourly distributions were produced for the No Action and Maximum Powerplant Capacity Alternatives and for each of the restricted fluctuating flow alternatives. Steady flow alternatives did not require this analysis because flows from hour to hour would be essentially steady. (The hourly distributions were done to supply information to the GCES). Those hourly projections are the basis for summaries of future flow patterns under the alternative dam operations. Peak shaving is the concept whereby hydroelectric powerplants are used to serve (shave) the highest electric load (peak) during a 24-hour period.

For the purposes of comparison, CRSS projections were made for annual and monthly values under each alternative. Where appropriate, the peak-shaving model was used to predict future hourly flows and daily fluctuations. In the discussion below, projected differences among alternatives are compared to the baseline (no action). An overview of model results is included; more detailed results of model studies are presented in Appendix B, Hydrology.

Summary of Impacts: Water

Table IV-1 summarizes the projected effects of the alternatives on annual and monthly **streamflows, floodflows and other spills** (as indicated by annual streamflows), **reservoir storage, water allocation deliveries**, and **Upper Basin yield determination**. Hourly streamflows are the means of change rather than an impacted parameter and are discussed under each alternative.

Impacts of the alternatives on water issues are essentially the same as under the No Action Alternative, except for monthly flows and floodflow frequencies. Streamflows, reservoir storage, water allocation deliveries, Upper Basin yield determination, and water quality are affected only negligibly by the alternatives.

Initially, endangered fish research flows would be included in the Modified Low Fluctuating Flow Alternative during minimum release years. The extent to which steady flows would be permanently incorporated would depend on evaluation of the research results. Because these 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 table of impacts. Endangered fish research flows (when they occur) would have impacts on water that fall within the range of impacts between the Modified Low Fluctuating and Seasonally Adjusted Steady Flow Alternatives.

The lack of data characterizing **water quality** in Lake Powell over seasons, years, and reservoir filling and drawdown cycles is discussed in chapter III. Potential impacts of each alternative were assessed based on analysis of existing limited data on chemical, physical, and biological processes influencing water quality in Lake Powell.

Two major influences on Lake Powell and downstream water quality are:

- Reservoir elevation (the amount of water in Lake Powell)
- The intake level where water is withdrawn

None of the alternatives involve changing the intake levels at Lake Powell. Reservoir elevation will vary with hydrologic conditions.

Under normal hydrologic conditions, changing release patterns under any alternative would not affect reservoir or release water quality. Under any alternative, greater amounts of certain constituents (salinity, nutrients, sediment, selenium, and mercury) enter Lake Powell than are discharged. Therefore, these constituents would tend to increase in concentration, primarily in sediment and deep reservoir waters that rarely circulate. Lead concentrations also would continue to increase, as a result of leaded fuels

Table IV-1.—Summary of anticipated impacts on WATER during the 50-year period of analysis by alternative[1] [2]

WATER	No Action	Maximum Powerplant Capacity	High Fluctuating Flow	Moderate Fluctuating Flow[3]	Modified Low Fluctuating Flow[3][4]	Interim Low Fluctuating Flow	Existing Monthly Volume Steady Flow	Seasonally Adjusted Steady Flow[3]	Year-Round Steady Flow
Streamflows (1,000 acre-feet)									
Annual median streamflows	8,573	8,573	8,559	8,559	8,559	8,559	8,559	8,554	8,578
Monthly median streamflows									
Fall (October)	568	568	568	568	568	568	568	492	699
Winter (January)	899	899	899	899	899	899	899	688	703
Spring (May)	587	587	592	592	592	592	592	1,106	699
Summer (July)	1,045	1,045	1,045	1,045	1,045	1,045	1,045	768	699
Floodflows (>40,000 cfs)									
Frequency (years)	1 in 40	1 in 40	<1 in 100	<1 in 100	<1 in 100	<1 in 100	<1 in 100	<1 in 100	<1 in 100
Reservoir storage (1,000 acre-feet)									
Lake Powell									
Average end-of-analysis	17,463	17,463	17,605	17,605	17,605	17,605	17,605	17,605	17,646
Lowest	6,700	6,700	6,800	6,800	6,800	6,800	6,800	6,700	6,800
Lake Mead									
Average end-of-analysis	14,045	14,045	14,404	14,404	14,404	14,404	14,404	14,653	14,415
Lowest	8,200	8,200	8,100	8,100	8,100	8,100	8,100	8,500	8,100
Water allocation annual deliveries (1,000 acre-feet)									
Upper Basin average	4,562	4,562	4,562	4,562	4,562	4,562	4,562	4,562	4,562
Lower Basin average	8,090	8,090	8,075	8,075	8,075	8,075	8,075	8,078	8,087
Mexico average	2,133	2,133	2,126	2,126	2,126	2,126	2,126	2,111	2,109
Upper Basin yield determination (1,000 acre-feet)									
Upper Basin annual yield	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000
New Mexico interim annual excess	69	69	69	69	69	69	69	69	69
Water quality									
At normal reservoir level (>3590 feet elevation)	No effect	No effect	No effect	No effect	No effect	No effect	No effect	No effect	No effect

[1] Assuming the increased storage capacity method of reducing flood frequency.

[2] CRSS computer model results (except for Upper Basin yield determination and water quality).

[3] Effects of habitat maintenance flows on monthly volumes are not included. Such flows would approximately double March or April volumes and reduce other monthly volumes 5 to 10 percent in years when the reservoir is low (about half the years). None of the parameters on this table would be affected.

[4] Impacts of endangered fish research flows (during years when they occur) would be similar to those described under the Seasonally Adjusted Steady Flow Alternative.

used in motorized recreation on the lake. Other factors, such as future Upper Colorado River Basin depletions, development, and land use, may also influence water quality in Lake Powell and downstream.

Extended droughts cause low reservoir conditions (Lake Powell storage at or below half its capacity, or less than elevation 3590 feet) 5 percent or less of the time. When this does occur, intakes may draw water from nearer the reservoir surface, and large areas of delta may be exposed.

As a result of these events:

- Release temperatures may increase by 3 °F or less
- Release lead and dissolved oxygen (DO) concentrations may increase
- Release salinity, nutrient, mercury, and selenium concentrations may decrease compared to hypolimnetic release concentrations

Unrestricted Fluctuating Flows

No Action Alternative

Streamflow. Annual, monthly, and hourly streamflows and daily fluctuations, and ramp rates below Glen Canyon Dam would remain as defined in chapters II (No Action Alternative) and III (WATER).

Projected annual release patterns are similar to the historic patterns summarized in chapter II. The average annual release would be 10.16 million acre-feet (maf), and the projected median would be 9.37 maf. The minimum release of 8.23 maf would be expected to occur about 30 percent of the time in the next 20 years and 46 percent of the time in the next 50 years. Projected monthly release volumes, presented in table IV-2, are similar to the historic patterns discussed in chapters II and III.

The median monthly releases would range from 568,000 acre-feet in October to 1,045,000 acre-feet in July for the 50-year analysis. Figure IV-1 shows the 50-year projected distribution of monthly

Table IV-2.—Projected median monthly release volumes under the No Action Alternative in 1,000 acre-feet

	20-year	50-year
Fall (October)	568	568
Winter (January)	1,045	899
Spring (May)	715	587
Summer (July)	1,032	1,045

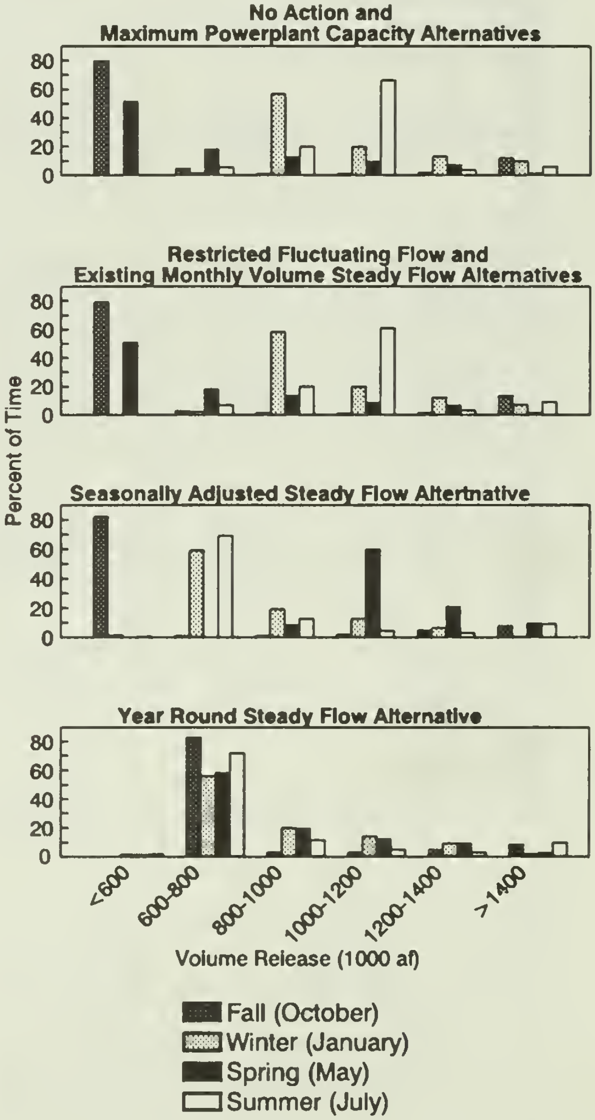


Figure IV-1.—Fifty-year projected distribution of monthly volume releases (flood frequency reduced by increasing height of spillway gates).

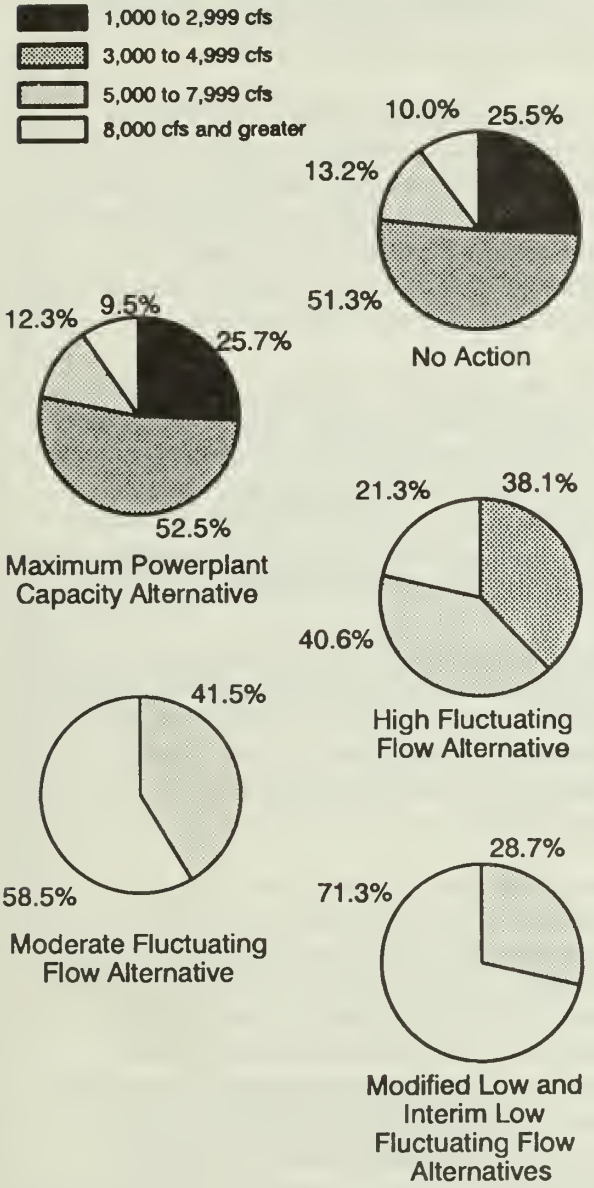


Figure IV-2.—Projected 20-year minimum hourly releases under the fluctuating flow alternatives (percentage of days that the minimums would occur).

flows under all alternatives. Effects of habitat maintenance flows are not included in this figure.

The results of the peak-shaving model 20-year projections of daily minimum and daily maximum flows and daily fluctuations are shown in figures IV-2, IV-3, and IV-4, respectively, along with projections for the restricted fluctuating flow alternatives. Effects of habitat maintenance flows are not included in these figures. Under the No Action Alternative, the minimum releases are projected to be less than 3,000 cubic feet per second (cfs) about 26 percent of the days and less

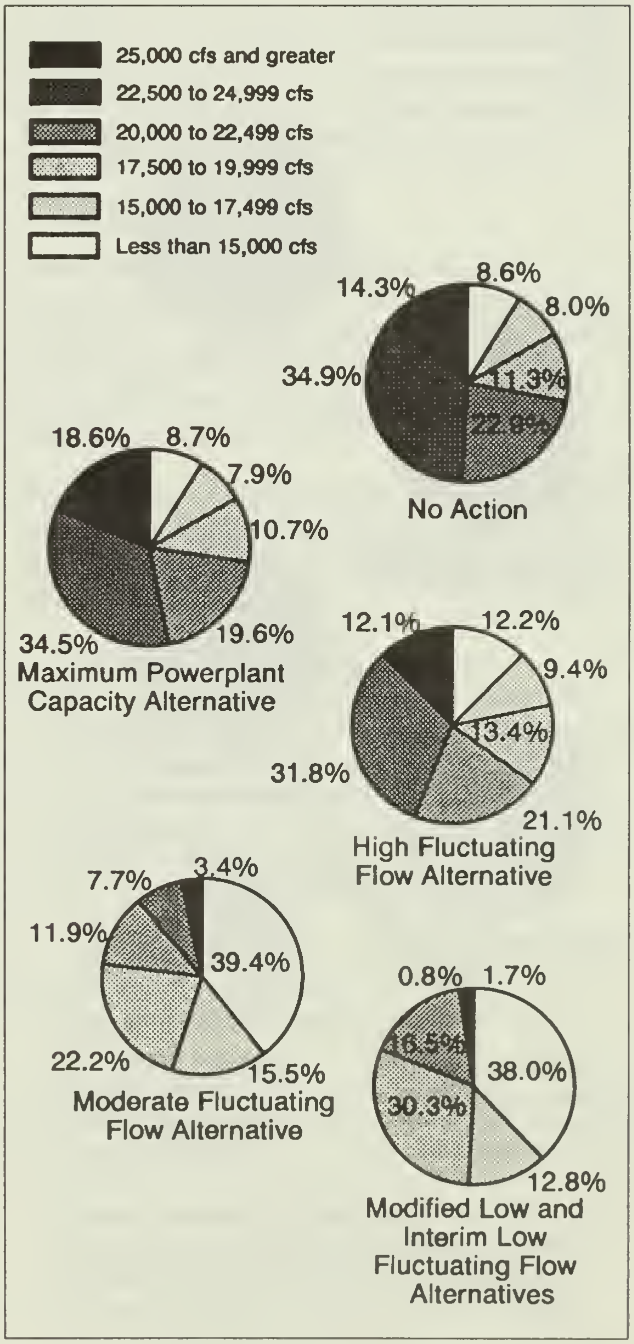
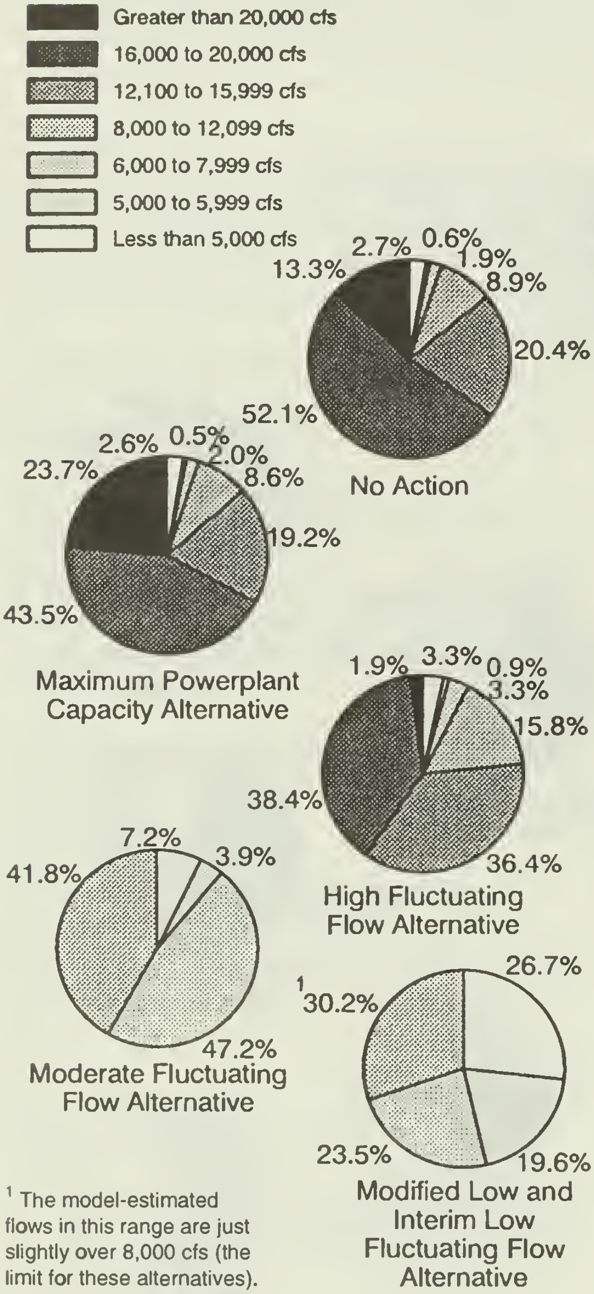


Figure IV-3.—Projected 20-year maximum hourly releases under the fluctuating flow alternatives (percentage of days that the maximums would occur).



[1] The model-estimated flows in this range are just slightly over 8,000 cfs (the limit for these alternatives).

Figure IV-4.—Projected daily fluctuations under the fluctuating flow alternatives (percentage of days that the specified fluctuation would occur).

than 8,000 cfs about 90 percent of the days. Maximum flows are projected to be greater than 25,000 cfs 14 percent of the days and greater than 20,000 cfs about 72 percent of the days. Daily fluctuations would be greater than 20,000 cfs about 13 percent of the days and greater than 8,000 cfs about 95 percent of the days.

Floodflows and Other Spills. Floodflows are releases in excess of the powerplant capacity of 33,200 cfs. Spills other than floodflows 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.

Under the No Action Alternative, frequencies of floodflows in excess of 45,000 cfs are projected to be once in 30 years for the 20-year period and once in 40 years for the 50-year period of analysis. (Frequencies of floodflows in excess of 33,200 cfs would be about once in 20 years for both the 20- and 50-year periods of analysis.)

Median annual water release patterns are used as indicators of the extent to which spills other than floodflows may be of concern under each of the alternatives. The expected no action median 20- and 50-year annual releases would be 9.4 and 8.6 maf, respectively.

Reservoir Storage. Historic water storage in Lakes Powell and Mead was discussed in chapter III, WATER. Future storage levels are difficult to project because they depend on annual streamflow, which is highly variable and uncertain. The CRSS model used 85 possible future hydrologic scenarios (traces) in estimating future conditions. To demonstrate the possible range of future annual storage, storage levels under three hydrologic scenarios were plotted in figure IV-5 for Lakes Powell and Mead. Annual storage levels are projected to be essentially the same for all alternatives using either of the two methods of reducing flood frequency. The 85 scenario average end-of-analysis (20-year) Lake Powell storage is projected to be 18.6 maf, with the lowest projected at 9.5 maf. For the 50-year study, the corresponding figures are 17.5 and 6.7 maf, respectively. The corresponding Lake Mead storage is 18.7 and 9.4 maf for the 20-year study and 14.0 and 8.2 maf for the 50-year study.

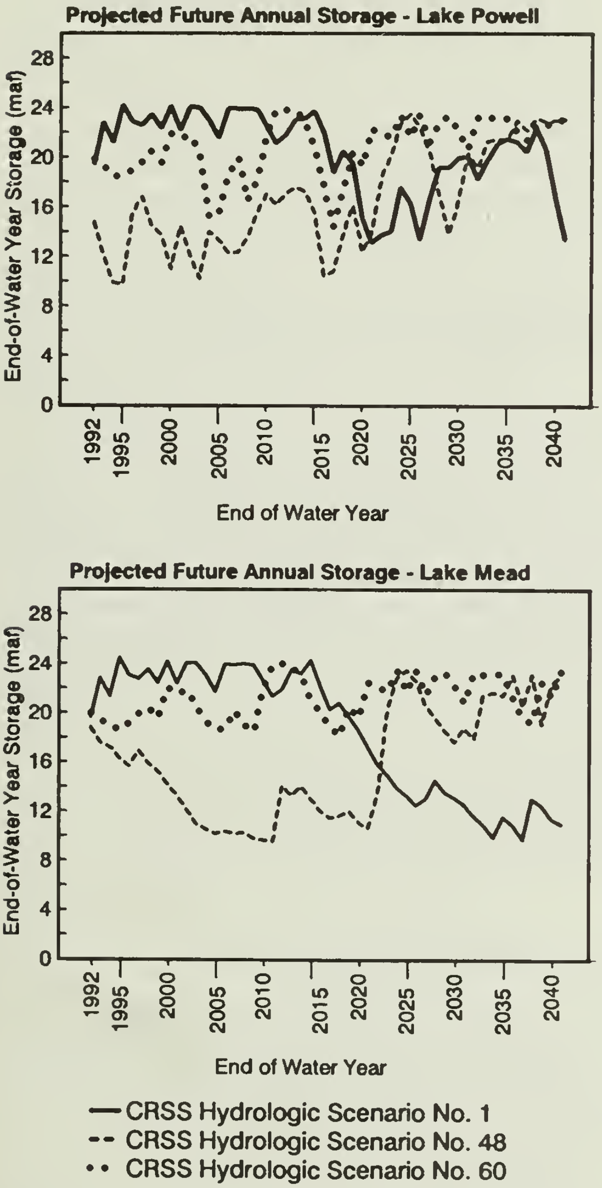


Figure IV-5.—Projected annual storage levels in Lakes Powell and Mead under three hydrologic scenarios.

Water Allocation Deliveries. Water apportionments among the Upper and Lower Colorado River Basin States are defined by the Colorado River Compact, and apportionments to Mexico are defined by treaty. The ability to provide these deliveries depends on maintaining conservation storage in and avoiding anticipated spills from Lake Powell.

Average annual Upper Basin consumptive use (excluding evaporation) is expected to be 4.2 maf and 4.6 maf for the 20- and 50-year periods of analysis.[1] Corresponding Lower Basin annual averages are 8.1 maf for both periods. The values for deliveries to Mexico are 2.2 and 2.1 maf, respectively. Tables III-5 and III-6 in chapter III show the historic Upper and Lower Basin and Mexico consumptive uses.

Upper Basin Yield Determination. The yield determination for the Upper Basin was discussed in chapter III. Under no action, the yield to the entire Upper Basin is determined to be 6.0 maf. The interim excess yield available to New Mexico from Navajo Reservoir is 69,000 acre-feet.

Water Quality. Under normal or higher reservoir inflow and elevation, the No Action Alternative is not expected to further affect existing reservoir or release water quality.

Extended droughts (a natural hydrologic variation) that cause low reservoir conditions are expected to occur less than 5 percent of the time. The magnitude of such drought-related water quality changes would depend on the amount of reservoir drawdown, inflow, circulation, and other factors. As the reservoir refills and reaches normal levels, changes are expected to diminish.

As discussed in chapter III, WATER, and Appendix C, Water Quality, the following changes may occur when Lake Powell is low.

Rather than withdrawing water from the hypolimnion,[2] which is nearly constant in temperature and chemical composition, the intakes may withdraw water from nearer the surface in the middle layer, the metalimnion, or even the top layer, the epilimnion. Since water quality in the upper layers differs from that in the hypolimnion, changes in reservoir and release water quality would result.

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[1] The maximum Upper Basin use of 6.0 maf (including evaporation) is not expected to be achieved until the year 2040.

[2] Lake Powell typically divides into three layers: the epilimnion, metalimnion, and the hypolimnion. Water quality varies with depth in the three layers, and the variations are explained in chapter III, Water Quality.

Release temperatures may increase by 3 °F or less. Warmer discharges may benefit both native and non-native fish species in the Colorado River. Downstream productivity may increase, but phosphorus reductions may limit these gains. Evidence shows that warmer river temperatures may enhance upstream advancement of *Oscillatoria*, potentially replacing *Cladophora* and its associated diatoms (see discussion of aquatic food base under FISH in this chapter.) Disease and parasites in downstream fisheries also may increase.

Additional lead withdrawn from nearer the reservoir surface would increase downstream concentrations, but salinity, selenium, and mercury concentrations may decrease. Limited data precludes predicting the amount of change in these concentrations (see chapter III).

Although dissolved oxygen (DO) concentrations are usually higher nearer the surface, an oxygen minimum layer sometimes forms in the metalimnion during the summer and fall. Depending on this layer's depth and Lake Powell's elevation, the intakes could withdraw water from this layer. Data have shown that releases with relatively low DO content approach saturation by the time the flows reach Lees Ferry. Since low reservoir conditions are expected to be rare events, intercepting the DO minimum layer would be even rarer. Higher DO concentrations in dam releases would tend to increase river concentrations in the Glen Canyon reach, with potential benefits for fisheries.

Changes in Lake Powell water quality would generally be the reverse of the release water quality. When intakes withdraw water from higher layers in Lake Powell, the overall reservoir temperature may be reduced, which could decrease aquatic productivity, evaporation, and some fish populations, such as the threadfin shad. DO concentrations in the upper layers may be reduced. Water with higher concentrations of salinity, nutrients, mercury, and selenium would be left in Lake Powell. Over time, concentrations of these constituents may increase since less water containing low concentrations would be available to dilute it.

When Lake Powell is low, most water quality trends observed in Glen and Grand Canyons might extend into the inflow area of Lake Mead. River temperatures and lead concentrations may increase, and the influx of nutrients, salinity, selenium, and mercury may decrease; however, DO concentration changes would not extend as far downstream as Lake Mead.

Maximum Powerplant Capacity Alternative

Annual and monthly **streamflow** patterns under this alternative would be the same as under the No Action Alternative. The results of the peak-shaving model projections of daily minimum and daily maximum flows and daily fluctuations are shown in figures IV-2, IV-3, and IV-4, respectively. These hourly minimums, maximums, and fluctuations would differ little from no action.

Effects on **floodflows and other spills**, **reservoir storage** patterns, **water allocation deliveries**, **Upper Basin yield determination**, and **water quality** would all be the same as under the No Action Alternative.

Restricted Fluctuating Flows

The four restricted fluctuating flow alternatives would result in some common impacts, which are discussed in this section. Differences among alternatives are described under the individual alternatives that follow this section.

Hourly **streamflow** patterns under each of the restricted fluctuating flow alternatives would differ from those of the No Action Alternative (and those of each other) and are therefore discussed individually below. The annual patterns would be essentially the same as no action; monthly patterns would differ negligibly from no action, since the manner of scheduling monthly volumes would be the same. However, habitat maintenance flows (under the Moderate and Modified Low Fluctuating Flow Alternatives) and beach/habitat building flows would about double March or April releases in years when the reservoir is low. Other monthly volumes would be reduced by about 5 to 10 percent under such circumstances.

Figure IV-1 shows the projected monthly patterns for the 50-year analysis without habitat maintenance or beach/habitat-building flows. Further, as shown in table IV-1, the projected median annual and monthly volumes are similar to those of no action. Tools are not available for projecting the frequencies of ramp rates, but ramp rates for all alternatives would be limited as defined in chapter II.

The expected frequency and magnitude of **floodflows** under the restricted fluctuating flow alternatives would be reduced to less than 1 in 100 years due to the addition of flood frequency reduction measures. Reclamation, in consultation with the Colorado River Management Work Group, would devise specific operating methods to achieve frequencies no greater than once in 100 years.

Annual water release patterns from Lake Powell have been used as an indicator of the extent to which **spills other than floodflows** may be of concern when flood frequency reduction measures are added. The projected median annual releases would be essentially the same as under no action for both the 20- and-50 year analyses using either method of reducing flood frequency. Therefore, the alternatives would have a negligible effect on spills other than floodflows.

Long-term monthly and annual **reservoir storage** would be the same under the restricted fluctuating flow alternatives as under the No Action Alternative for both Lakes Powell and Mead, except for slight differences due to addition of flood frequency reduction measures and habitat maintenance and beach/habitat-building flows. The lowest storage projected for the next 50 years would be the same as under the No Action Alternative for all restricted fluctuating flow alternatives. The end-of-analysis storages would be very nearly the same as no action (table IV-1). Generally, storage effects would be negligible to minor.

Water allocation deliveries under the restricted fluctuating flow alternatives would be essentially the same as under no action.

To understand the effects of the alternatives on **Upper Basin yield determination** some background information is necessary. All of the alternatives except the No Action and Maximum Powerplant Capacity Alternatives include measures to decrease the frequency of flood releases from the dam. Two example methods for accomplishing this reduction are:

1. Providing more capacity by increasing the height of the spillway gates
2. Reserving exclusive flood control space in the reservoir by using lower storage levels

Under no action, Lake Powell elevations would not normally exceed 3700 feet. However, when the spillway gates were extended by 8 feet under emergency conditions in 1983, the lake elevation reached 3708.3 feet and inundated an additional 6,840 acres of land. (The extensions were subsequently removed.) Raising the height of the four spillway gates potentially would allow the level of Lake Powell to increase by 4.5 feet (to elevation 3704.5 feet) over no action. This increase would inundate an additional 3,710 acres (2-percent increase) for about 1 or 2 months at an expected frequency of once in 20 to 40 years. Since the 8-foot increase in 1983 did not affect Rainbow Bridge National Monument, this increase would not affect the monument.

CRSS analyses indicated that under projected depletion levels, water allocation deliveries in the Upper Basin for the next 20 and 50 years would be affected negligibly by either of these methods of reducing flood frequency. However, if Upper Basin depletions would reach the levels permitted in the Colorado River Compact, a reduction in maximum allowable storage by reserving exclusive flood control space in Lake Powell would have a measurable impact on consumptive use. The reservoir system yield available for Upper Basin depletion would be reduced. This yield is defined as the sustainable annual quantity of water that could be depleted by the Upper

Basin while making the required releases to the Lower Basin during periods of Upper Basin drought.

Using the critical 25-year hydrologic period 1953-77 and assuming full reservoir starting conditions, the current estimated annual yield is 6 maf. The impact of lower storage levels on yield can be estimated as follows: a 1-maf reduction in available storage would reduce the yield by 40,000 acre-feet per year (1 maf divided by 25 years). This would be only 0.67 percent of the total Upper Basin yield but would be 58 percent of New Mexico's interim excess yield. Reducing flood frequency by increasing the height of the spillways would have no effect on Upper Basin yield determination. The increased spillway height method was assumed for impact analyses. U.S. Department of the Interior (1989) provides a more thorough explanation of yield methodology.

Effects on the Upper Basin yield limit the ultimate amount of water that each State in the Upper Basin can deplete. This is particularly critical in New Mexico, where uses are approaching their compact allocation. Thus, even though the Upper Basin yield would be reduced by only 0.67 percent, the water users who could receive a reduced or no allocation due to the overall reduction would be impacted substantially.

High Fluctuating Flow Alternative

Hourly **streamflow** patterns, daily fluctuations, and ramp rates would differ slightly from those under the No Action Alternative. The frequencies of minimum and maximum daily flows and daily fluctuations are summarized in figures IV-2, IV-3, and IV-4.

Moderate Fluctuating Flow Alternative

Hourly **streamflow** patterns, daily fluctuations, and ramp rates would differ from those under the No Action Alternative. The frequencies of minimum and maximum daily flows and daily fluctuations are summarized in figures IV-2, IV-3, and IV-4. The effects of habitat maintenance flows are not shown in these figures. However, such flows would increase the maximums and minimums and reduce fluctuations in March or April when the reservoir is low (about half the years).

During the habitat maintenance flow period, increases in turbidity are likely, which would decrease the depth that sunlight reaches in the water and thus affect **water quality**. Primary productivity may be temporarily reduced. However, resuspending sediment and organic material also may reintroduce nutrients and other constituents associated with the particles into the water. These nutrients may stimulate algal growth.

The river stage would not be significantly reduced by shifting water from one month to another for habitat maintenance flows. Thus, instream temperatures and *Cladophora* exposure would not change from no action.

Modified Low Fluctuating Flow Alternative

Hourly **streamflow** patterns, daily fluctuations, and ramp rates would differ from those under the No Action Alternative. The frequencies of minimum and maximum daily flows and daily fluctuations are summarized in figures IV-2, IV-3, and IV-4. The effects of habitat maintenance flows are not shown in these figures. However, such flows would increase the maximums and minimums and reduce fluctuations in March or April when the reservoir is low (about half the years).

Habitat maintenance flows would result in a **water quality** scenario similar to that described under the Moderate Fluctuating Flow Alternative.

In years when they occur, endangered fish research flows would have impacts on water similar to those described under the Seasonally Adjusted Steady Flow Alternative.

Interim Low Fluctuating Flow Alternative

Hourly **streamflow** patterns, daily fluctuations, and ramp rates would differ from those under the No Action Alternative. The frequencies of minimum and maximum daily flows and daily fluctuations are summarized in figures IV-2, IV-3, and IV-4.

Steady Flows

Projected impacts to the water resource differ under each steady flow alternative. Therefore, no general steady flows discussion is presented, and results for each alternative are described individually below.

Existing Monthly Volume Steady Flow Alternative

Annual and monthly release volumes under this alternative would differ negligibly from no action. **Streamflows** in the Colorado River below Glen Canyon Dam would be steady (subject to a plus or minus 1,000 cfs fluctuation for power system regulation), except during transitions from one month to the next. The median monthly values for 4 seasons are shown in table IV-3 along with their cfs equivalents. The second graph in figure IV-1 shows the monthly volume distributions for 4 representative months. Figure IV-6 shows the frequencies of flows in cfs for the same 4 months.

Floodflows and other spills under the Existing Monthly Volume Steady Flow Alternative would be the same as under the restricted fluctuating flow alternatives.

Since monthly release volumes under the Existing Monthly Volume Steady Flow Alternative would be the same as they are under the restricted fluctuating flow alternatives, monthly and annual **reservoir storage** and the corresponding impacts on Lakes Powell and Mead would be negligible.

Monthly release volumes would be the same as under the restricted fluctuating flow alternatives, so impacts on **water allocation deliveries** under this alternative would be negligible. Also, the **Upper Basin yield determination** would be essentially the same as no action.

Water quality impacts would not vary substantially from no action. Steady, lower flows may allow for a relatively small increase in river temperatures, particularly during the summer, but this increase has not been quantified (see chapter IV, FISH). Temperatures in Lake Mead would not increase significantly.

Seasonally Adjusted Steady Flow Alternative

The annual release averages and medians would be the same as under the No Action Alternative using the increased spillway height method of reducing flood frequency and would differ negligibly using the lower storage method. Therefore, this alternative would have a negligible effect on annual releases.

Monthly release volumes are based on the steady schedules for the alternative as defined in chapter II. **Streamflows** would be steady, except during transitions from one month to the next. The median monthly values for 4 months are shown in table IV-4, along with their steady cfs equivalents. The fourth graph in figure IV-1 shows the monthly volume distribution for those 4 representative months. Also, figure IV-7 shows the frequencies of the steady flows in cfs for the same 4 months. The monthly distributions would differ in years when habitat maintenance or beach/habitat-building flows are scheduled. March or April volumes would about double, and other monthly volumes would decrease between 5 and 10 percent.

Table IV-3.—Existing Monthly Volume Steady Flow Alternative projected median streamflows

	20-year analysis		50-year analysis	
	1,000 acre-feet	cfs	1,000 acre-feet	cfs
Fall (October)	568	9,200	568	9,200
Winter (January)	1,021	16,600	899	14,600
Spring (May)	712	11,600	579	9,400
Summer (July)	1,012	16,500	1,045	17,000

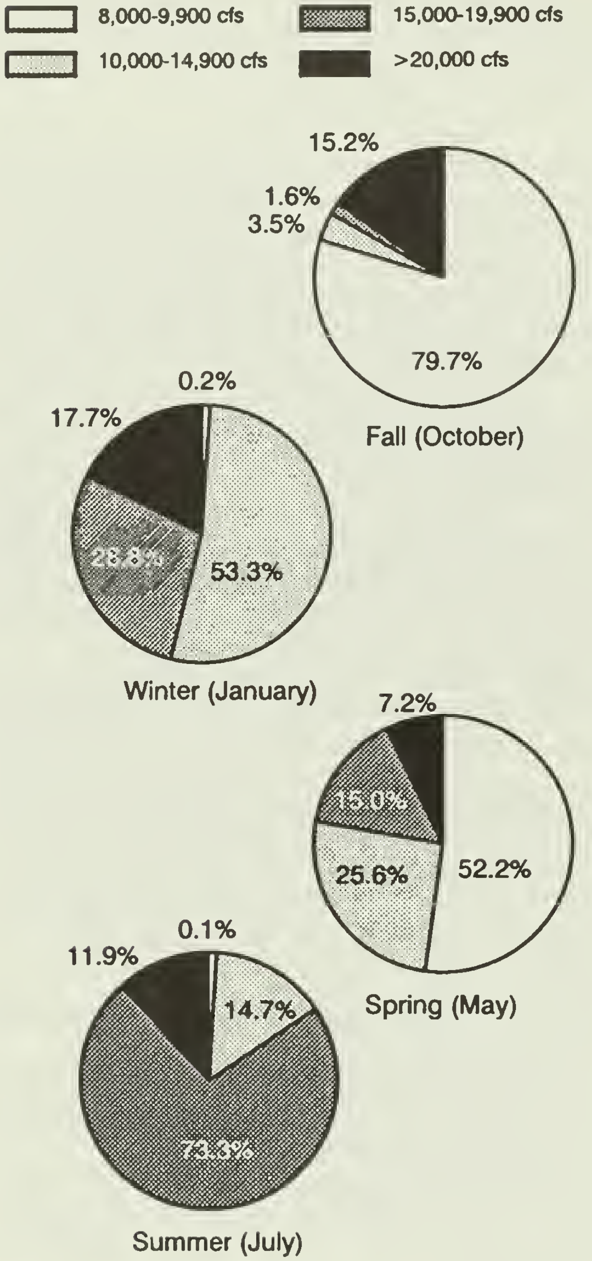


Figure IV-6.—Projected release patterns under the Existing Monthly Volume Steady Flow Alternative (50-year analysis, percent of months that specified releases are projected to occur).

The expected frequency of **floodflows** under the Seasonally Adjusted Steady Flow Alternative would be reduced to less than 1 in 100 years because of the addition of flood frequency reduction measures. Annual water release patterns from Lake Powell are used as an indicator of **spills other than floodflows**. The annual release patterns under this alternative would differ negligibly from the No Action Alternative.

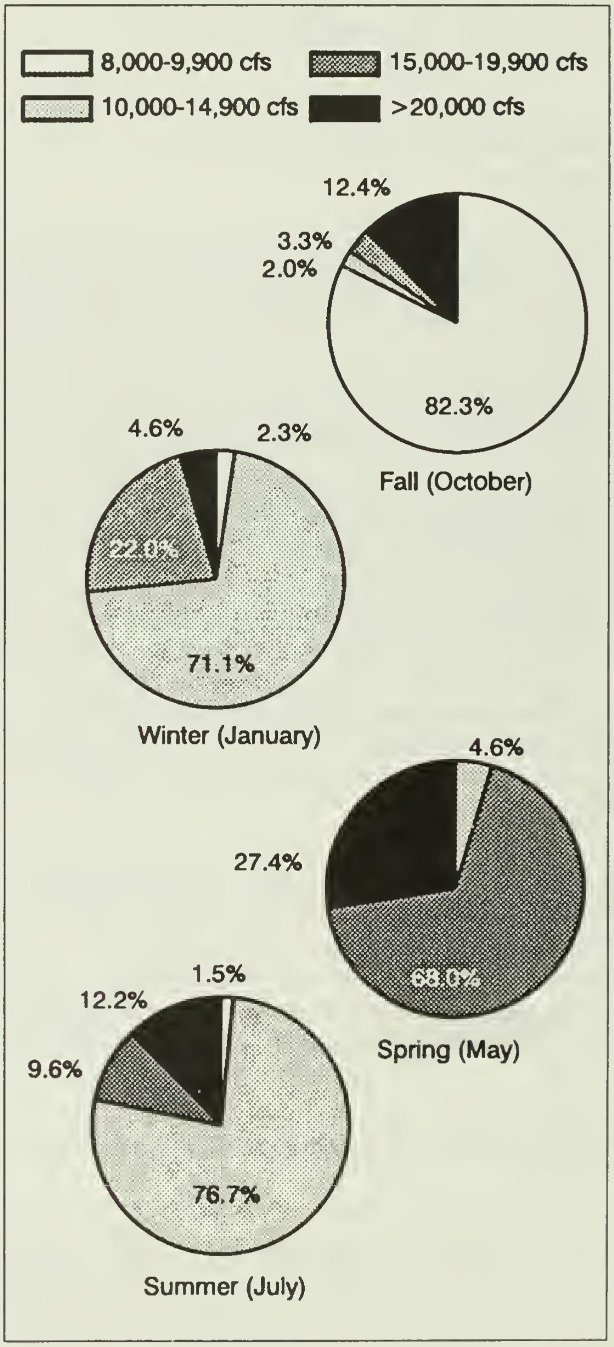


Figure IV-7.—Projected release patterns under the Seasonally Adjusted Steady Flow Alternative (50-year analysis, flood frequency reduced by raising spillway gates). Figure shows the percentage of months that the specified releases are projected to occur.

Table IV-4.—Seasonally Adjusted Steady Flow Alternative projected median streamflows

	20-year analysis		50-year analysis	
	1,000 acre-feet	cfs	1,000 acre-feet	cfs
Fall (October)	492	8,000	492	8,000
Winter (January)	798	13,000	676	11,000
Spring (May)	1,156	18,800	1,106	18,000
Summer (July)	768	12,500	768	12,500

Since monthly release volumes would be different under the Seasonally Adjusted Steady Flow Alternative than under no action, monthly **reservoir storage** (within each year) also would be different for both Lakes Powell and Mead. Median elevation differences at Lake Mead would be 4 feet lower than under no action in February and 4 feet higher in June. Median elevation differences at Lake Powell would range from about 4 feet more than no action in February to 4 feet less than no action in June. Figure IV-8 shows storage and elevation for the steady flow alternatives compared to no action for example water year 1989.

Detailed frequencies of monthly storages are presented in appendix B. End-of-analysis storage values would be nearly the same as no action for the lower rule curve method of reducing flood frequencies, but the lakes would see a 100,000- to 400,000-acre-foot increase in average end-of-analysis (50-year) storage using the increased capacity method. Lowest storage would be the same as under the No Action Alternative. The effects on annual storage would range from a negligible decrease to a minor increase over no action, depending on streamflow conditions.

Since monthly release schedules could be relaxed under high storage or inaccurate streamflow forecast circumstances, **water allocation deliveries** under this alternative would be the same as under no action. Flood frequency reduction by increasing the height of the spillways would not affect water allocation deliveries. Upper Basin deliveries are projected to be the same as under the No Action Alternative, and Lower Basin deliveries would differ negligibly. Deliveries to Mexico also would differ negligibly from no action.

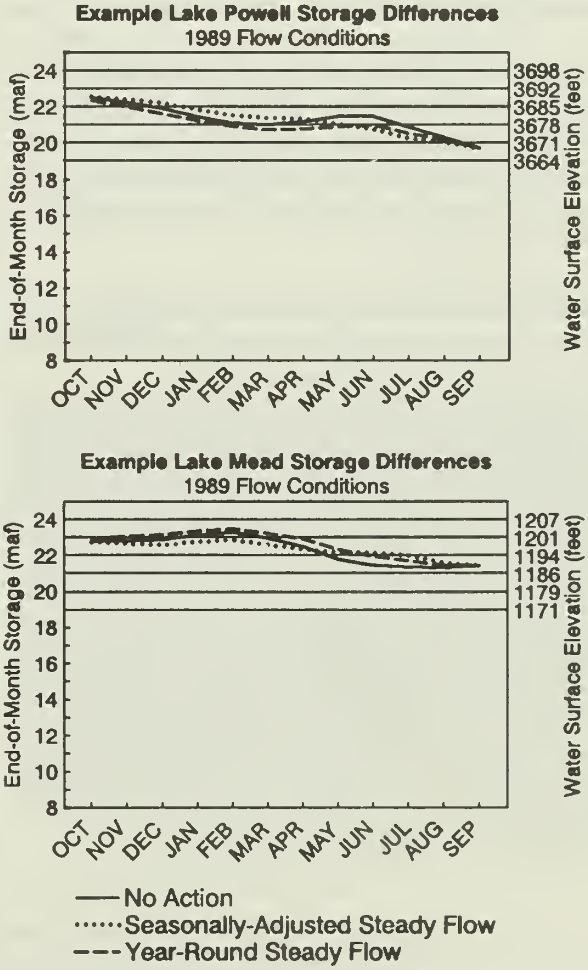


Figure IV-8.—Comparison of monthly storage (1989 flow conditions) under the steady flow alternatives and no action.

Since monthly release schedules could be relaxed under certain circumstances, the **Upper Basin yield determination** would not be affected.

Water quality impacts would not vary significantly from no action under normal hydrologic conditions. Under low reservoir conditions, monthly reservoir levels would be approximately 2 to 8 feet lower than under no action from May through July. Additional reductions in reservoir levels due to seasonally adjusted steady flows may intensify impacts associated with low reservoir conditions (see Water Quality discussion in chapter III and appendix C). As the reservoir refilled and reached normal levels, some of these impacts would be expected to diminish.

Steady, lower flows may allow for increased river temperatures, particularly during the summer, but this increase has not been quantified (see chapter IV, FISH). Greater minimum releases would increase flow depth, which may enhance *Cladophora* growth.

Habitat maintenance flows would result in a scenario similar to that described under the Moderate Fluctuating Flow Alternative.

Year-Round Steady Flow Alternative

The annual release averages and medians would be the same as under the No Action Alternative. Monthly release volumes are based on the steady schedules for the alternative as defined in chapter II. **Streamflows** would be steady under the Year-Round Steady Flow Alternative, except during transitions from one month to the next. The median monthly values for 4 months in acre-feet and cfs are shown in table IV-5. The fifth graph in figure IV-1 shows the monthly volume distribu- tion for those 4 representative months. Also, figure IV-9 shows the frequencies of flows in cfs for the same representative months.

The expected frequency of **floodflows** under the Year-Round Steady Flow Alternative would be reduced to less than 1 in 100 years by the addition of flood frequency reduction measures. **Spills other than floodflows** would differ negligibly from no action.

Since monthly release volumes would be different under the Year-Round Steady Flow Alternative than under the No Action Alternative, monthly **reservoir storage** also would be different within each year for both Lakes Powell and Mead. The monthly storage patterns within the year are found in appendix B. Median elevation differences at Lake Powell would range from about 3 feet less in June to no change from no action in September. Elevation differences at Lake Mead would be about the same except that the lake would be 3 feet higher than under no action in June. Figure IV-8 shows example storage and elevation differences for the steady flow alternatives compared to no action for example water year 1989.

End-of-analysis storage values would be nearly the same as under the No Action Alternative for the lower rule curve method of reducing flood frequencies. With higher spillway gates, the lakes would have a 100,000- to 400,000-acre-foot increase in average end-of-analysis storage. Lowest storage would be essentially the same as under the No Action Alternative. Effects on annual storage would range from a negligible decrease to a minor increase, depending on streamflow conditions.

Table IV-5.—Year-Round Steady Flow Alternative projected median streamflows

	20-year analysis		50-year analysis	
	1,000 acre-feet	cfs	1,000 acre-feet	cfs
Fall (October)	699	11,400	699	11,400
Winter (January)	835	13,600	703	11,400
Spring (May)	820	13,300	699	11,400
Summer (July)	699	11,400	699	11,400

Since monthly release schedules could be relaxed under high storage or inaccurate streamflow forecast conditions, **water allocation deliveries** under this alternative would be the same as under no action. Flood frequency reduction measures would not affect water allocation deliveries. Upper Basin deliveries are projected to be the same as under the No Action Alternative; Lower Basin and Mexico deliveries would differ negligibly.

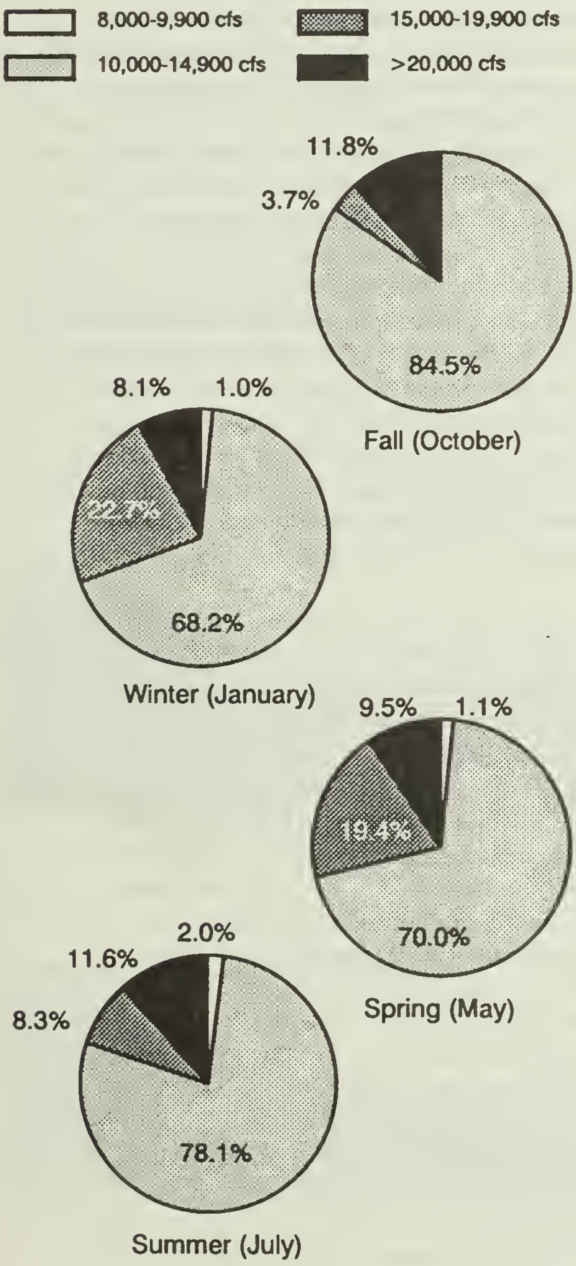


Figure IV-9.—Projected release patterns under the Year-Round Steady Flow Alternative (50-year analysis, percent of months that the specified releases are projected to occur).

Since monthly release schedules could be relaxed under certain circumstances, the **Upper Basin yield determination** would not be affected.

Impacts on **water quality** would be essentially the same as no action under normal hydrologic conditions. Under low reservoir conditions, monthly reservoir levels would be approximately 1 to 5 feet lower from May through July. Water quality changes would be comparable to those discussed under the Seasonally Adjusted Steady Flow Alternative.

SEDIMENT

Issue:

How do flows 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**

This analysis of impacts to sediment resources is limited to the following areas:

- Colorado River corridor between Glen Canyon Dam and Lake Mead
- Deltas in Lake Powell and Lake Mead

Direct impacts to sediment resources are those that vary with riverflow. These include changes in riverbed sand storage, aggradation and degradation of sandbars, and changes in capacity to move large boulders from rapids.

Short-term impacts to sediment resources would occur within 20 years after an alternative is implemented. Flood releases are assumed not to occur in the short term. In the absence of floods, sediment resources would be affected primarily by the magnitude, pattern, and duration of powerplant releases from Glen Canyon Dam.

Long-term impacts (20 to 50 years) would occur as sediment resources reached a state of dynamic equilibrium. Dynamic equilibrium means that the average sediment load transported by the Colorado River is in balance with the sediment loads being supplied by its tributaries. Sediment deposits (including sandbars) would increase and decrease in size and number as transport capacity and tributary supply varied, but monthly and annual changes would balance out, resulting in no net change over the long term.

Flood releases may result in immediate and potentially large changes that diminish over a decade. Floods transport sand stored in the riverbed, erode low elevation sandbars, aggrade and erode high elevation bars, and widen the channel at debris fans and rapids. Floodflows greater than 45,000 cfs are assumed to occur over the long term.

Analysis Methods

To the extent possible, a "system" approach, as discussed in the resource linkages section of this chapter, was used to evaluate impacts. Sediment resources, such as riverbed sand and sandbars, are linked—just as most other resources discussed in this EIS are linked to sediment. Impacts were analyzed on the basis of the following categories of information provided by the GCES program:

- Records of river stage, streamflow, and sediment discharge at U.S. Geological Survey (USGS) gauging stations along the river and on the principal sediment-producing tributaries
- Measurements and observations at selected sites during floods, various powerplant operations, specially designed research flows, and interim flows
- Scientific conclusions about depositional and erosional processes that result in riverbed sand storage changes
- Results from the CRSS and peak-shaving models (see WATER in this chapter)

A comprehensive, mathematical flow and sediment-transport model of the river and associated eddies is under development in GCES. The model should be useful in the Adaptive Management Program. Some preliminary results from model development—wave transformation and reach-averaged hydraulic properties—were available for use in this impact analysis.

Sand deposits (and sand-dependent resources) are affected by the amount of riverbed sand transported under a given alternative. A long-term net loss of riverbed sand would result in long-term loss in the number and size of sandbars, with corresponding changes in aquatic and riparian habitat. Future changes in riverbed sand depend primarily on tributary sand supply and the magnitude, frequency, and duration of floods.

Riverbed sand also would vary with the water volume and release pattern of the alternative implemented. The exact amounts of future tributary sand supply and water release volumes are unknown but can be expressed using probabilities, as demonstrated by Smillie, Jackson, and Tucker (1993). A mass-balance model was developed to estimate the impacts to riverbed sand (Randle et al., 1993). This model used 85 different hydrologic scenarios (50 years each) to evaluate changes in riverbed sand. These scenarios matched projected releases from Glen Canyon Dam (based on historic flows in the Upper Basin from 1906 to 1990) with Grand Canyon tributary flows from 1941 to 1990. Details about this analysis and the assumptions used are described in Appendix D, Sediment.

Information is not available to predict impacts to individual sandbars. On the basis of empirical studies at specific sandbars, however, predictions can be made for comparison of alternatives. Long-term losses in the number and size of sandbars are assumed to result from a long-term loss of riverbed sand. That would occur if the sand-transport capacity of the river exceeds the long-term supply from tributaries.

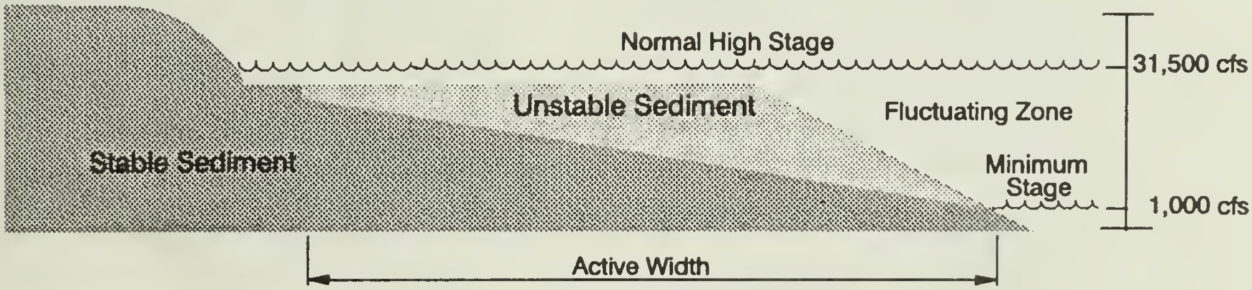
Impacts to sandbars were determined using the principles of slope stability developed for Grand Canyon sandbars by Budhu (written communication, 1992). An illustration of these principles is shown in figure IV-10. Sand and smaller-size sediment is deposited during high river stages at slopes of about 26 degrees. As the river stage recedes, this slope may be unstable due to seepage, high velocities, or wave action. Under any of these conditions, erosion would likely occur until a stable slope of about 11 degrees was achieved. Assuming sufficient quantities of riverbed sand, an eroded sandbar would likely rebuild during subsequent periods of high river stage.

The active width of a sandbar is that part of the bar subjected to cycles of deposition and erosion—the hydrologically active zone. Estimates of average active widths are computed from average differences in river stage corresponding to changes in discharge. The modeling effort by Randle and Pemberton (1987) was extended to compute average daily and annual differences in river stage by reach for each alternative (see appendix D). The results compared well with independent computations by Smith and Wiele (written communication, 1992) for a somewhat different delineation of reaches.

Summary of Impacts: Sediment

The impacts of the alternatives on sediment resources are summarized in table IV-6. Numerical values, based on sources of

a. No Action



b. Restricted Fluctuating and Steady Flows

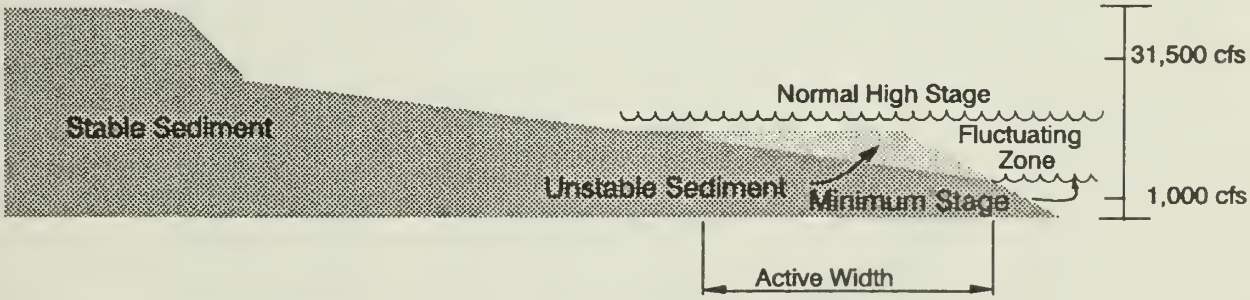


Figure IV-10.—Cross section of sandbar affected by no action and by restricted fluctuating and steady flows. As the fluctuating zone is reduced, so too is the zone of unstable sediment and sandbar heights.

Table IV-6.—Summary of anticipated impacts on SEDIMENT by alternative

SEDIMENT	No Action	Maximum Powerplant Capacity	High Fluctuating Flow	Moderate Fluctuating Flow	Modified Low Fluctuating Flow[4]	Interim Low Fluctuating Flow	Existing Monthly Volume Steady Flow	Seasonally Adjusted Steady Flow	Year-Round Steady Flow
Riverbed sand (percent probability of net gain)									
After 20 years	50	49	53	61	64	69	71	71	74
After 50 years	41	36	45	70	73	76	82	82	100
Sandbars (feet)[1]									
Active width	44-74	47-77	44-70	28-47	24-41	24-41	10-19	16-29	0
With habitat maintenance flows				41-66	41-66			37-60	
Potential height[2]	10-15	10-16	10-15	6-10	6-9	6-9	3-5	4-7	0-1
With habitat maintenance flows[3]				9-15	9-14			9-13	
High terraces (adjacent to river)									
Frequency of flood erosion	1:40	1:40	1:100	1:100	1:100	1:100	1:100	1:100	1:100
Debris fans and rapids									
River's capacity to move boulders as a percentage of 1983 flood capacity	12	13	12	10	10	5	3	10	2
Lake delta (crest elevation in feet)									
Lake Powell	3662	3662	3662	3662	3662	3662	3662	3660	3660
Lake Mead	1167	1167	1167	1167	1167	1167	1167	1168	1168

All values calculated for 8.23 maf annual release and include effects of flood frequency reduction, as appropriate. Effects of beach/habitat-building flows are not included (see text).

[1] Active widths and potential heights do not take into account the availability of riverbed sand.

[2] Difference in water-surface elevations at minimum and maximum flow.

[3] Difference in water-surface elevations at minimum flow and 30,000 cfs.

[4] Impacts of endangered fish research flows (during years when they occur) would be within the range of impacts between the Modified Low Fluctuating (without these research flows) and Seasonally Adjusted Steady Flow Alternatives.

information previously listed, were used as indicators of impacts for all sediment resources.

Some uncertainty exists in the numerical values in table IV-6 and in the subsequent discussion of alternatives. Indicators of riverbed sand are mainly derived from modeling, and sandbar indicators are mainly the result of empirical measurements and observations; each has a different kind of uncertainty. In general, however, the uncertainty does not affect relative differences between alternatives.

Initially, endangered fish research flows would be included in the Modified Low Fluctuating Flow Alternative during minimum release years. The extent to which steady flows would be permanently incorporated would depend on evaluation of the research results. Because these 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 table of impacts. Endangered fish research flows (when they occur) would have impacts on sediment that fall within the range of impacts between the Modified Low Fluctuating and Seasonally Adjusted Steady Flow Alternatives.

General impacts to riverbed sand, sandbars, high terraces, debris fans and rapids, and lake deltas are discussed below. Specific impacts to these resources are discussed under each alternative. The effects of flood frequency reduction are included in the analyses of the restricted fluctuating and steady flow alternatives.

Riverbed Sand

A long-term net loss of riverbed sand would result in long-term loss in the number and size of sandbars. In the Glen Canyon reach (RM -15.5-0), there is essentially no resupply of sand, and that reach would only continue to lose sand under any alternative. However, remaining sand deposits in this reach are fairly well protected; therefore, future erosion rates would be relatively low under any alternative.

The reach between Lees Ferry (RM O) and the Little Colorado River (LCR) (RM 61) is much more vulnerable to net sand loss than the river downstream from the LCR because of the limited sources of supply—mainly the Paria River. Downstream from the LCR, where the long-term sand supply and transport capacity would be expected to remain in equilibrium, changes in riverbed sand would be negligible under any of the alternatives identified for detailed analysis. Some changes would occur from year to year, but net changes would be expected to balance out (dynamic equilibrium). Over the long term (20 years or more), the total amount of sand transported past Phantom Ranch (RM 88) would approximately equal the average annual tributary supply regardless of the alternative.

The probabilities of a net gain in riverbed sand at the end of 20 and 50 years for the reach between the USGS gauges at Lees Ferry and the LCR are listed in table IV-6. Tables listing the probabilities of a net gain in storage in a low, moderate, and high release year (water years 1989, 1987, and 1984) are included in appendix D.

The probabilities were computed as described above under "Analysis Methods." The 20- and 50-year simulations include sequences of the wide variety of hydrologic conditions—normal, wet, dry—that occurred between 1906 and 1990. The probabilities are computed as the ratio of the number of simulations ending with a net gain in riverbed sand to 85 (the number of simulations). For both the 20- and 50-year periods, the No Action, Maximum Powerplant Capacity, and High Fluctuating Flow Alternatives have relatively low probabilities of a net increase in riverbed sand; all other alternatives have relatively high probabilities.

Sand transport capacity and probability of net gain in riverbed sand for each alterative are listed in table IV-7. The differences due to habitat maintenance flows also are listed for the three alternatives that include them. During a minimum release year, such flows generally would result in a net increase in sand transport capacity of about 30 percent and a decrease in the probability of net gain in sand storage of about 11 percent during that year.

Table IV-7.—Sand transport capacity and probability of net gain in sand storage in the Colorado River between the Paria River (RM 0) and the Little Colorado River (RM 61), for a minimum release year (8.23 maf)

Alternative	Sand transport capacity (1,000 tons)	Probability of net gain in sand storage (percent)	Difference due to habitat maintenance flow: Sand transport capacity (1,000 tons)	Difference due to habitat maintenance flow: Probability of net gain in sand storage (percent)
No action	517	47	—	—
Maximum powerplant capacity	530	45	—	—
High fluctuating flow	463	55	—	—
Moderate fluctuating flow	434	58	+116	-12
Modified low fluctuating flow	424	59	+117	-11
Interim low fluctuating flow	307	70	—	—
Existing monthly volume steady flow	259	77	—	—
Seasonally adjusted steady flow	390	64	+124	-11
Year-round steady flow	196	82	—	—

The following conclusions from a mathematical sand transport model developed under GCES by Bennett (1993) support basic assumptions used in this EIS to evaluate the impacts of the alternatives on riverbed sand and sandbars.

- For a given release volume, alternatives with greater flow fluctuations generally leave less total sand mass in the river channel but result in higher-elevation sandbars. Sandbars tend to aggrade during high flows and erode during low flows.
- Sand transport capacity increased more rapidly than sand supply when the annual release volume increased from 8.23 to 10.5 maf. This resulted in a net decrease in the amount of sand retained in the river channel but sandbar deposition at higher elevations within the eddy storage zones.
- A beach/habitat-building flow following a high fluctuating flow would deposit higher-elevation sandbars than when following a lower fluctuating or steady flow. Sandbars that start out higher will end up higher.
- Results are inconclusive concerning the optimum duration of the beach/habitat-building flow. Sandbars initially may build and later erode if the duration is too long (perhaps more than 2 weeks).

In all simulations, the amount of sand stored in the eddies is relatively small, seldom exceeding more than 30 percent of the total in the reach.

Sandbars (Beaches and Backwaters)

If sufficient quantities of riverbed sand are available, the trade-off with sandbars under the various alternatives is whether to have higher bars with steeper, less stable slopes or lower bars with flatter, more stable slopes. Less stable sandbars would experience greater and more frequent cycles of deposition and erosion than more stable sandbars. Sandbars that existed prior to Glen Canyon Dam were very unstable—building during floods and rapidly eroding following the return to lower flows.

The long-term maintenance of sandbars requires deposition during high flows. Over the long term, the parts of sandbars higher than the peak river stage of an alternative (including beach/habitat-building flow) would experience net erosion.

Eddy backwaters are dependent on the formation of reattachment bars. Initially, the number and size of backwaters would depend on the level of discharge (see FISH section of this chapter). However, return-current channels that form backwaters would tend to fill with sediment and later re-form during the next beach/habitat-building flow or flood release.

Annual range of sandbar active width and potential height for the widest and narrowest reaches are shown for a minimum release year in table IV-6. Active widths are used as an indicator of areas generally not suitable for establishment of vegetation, although vegetation may grow in this zone if flow fluctuations are small. Complete tabulations of average sandbar active widths and heights for 11 reaches under each alternative are included in appendix D.

The potential sandbar heights listed on two lines of table IV-6 are differences between water surface elevations. These represent the range in potential height of sand deposition if there is a sufficient supply. One line lists differences between elevations under normal minimum and maximum flows for the alternatives. The other line lists differences between elevations under normal minimum flow and 30,000 cfs for the three alternatives with habitat maintenance flows.

The values in table IV-6 and the graphs in figure IV-11 show the general relationship between sandbar height and the probability of net gain in riverbed sand. Alternatives that include

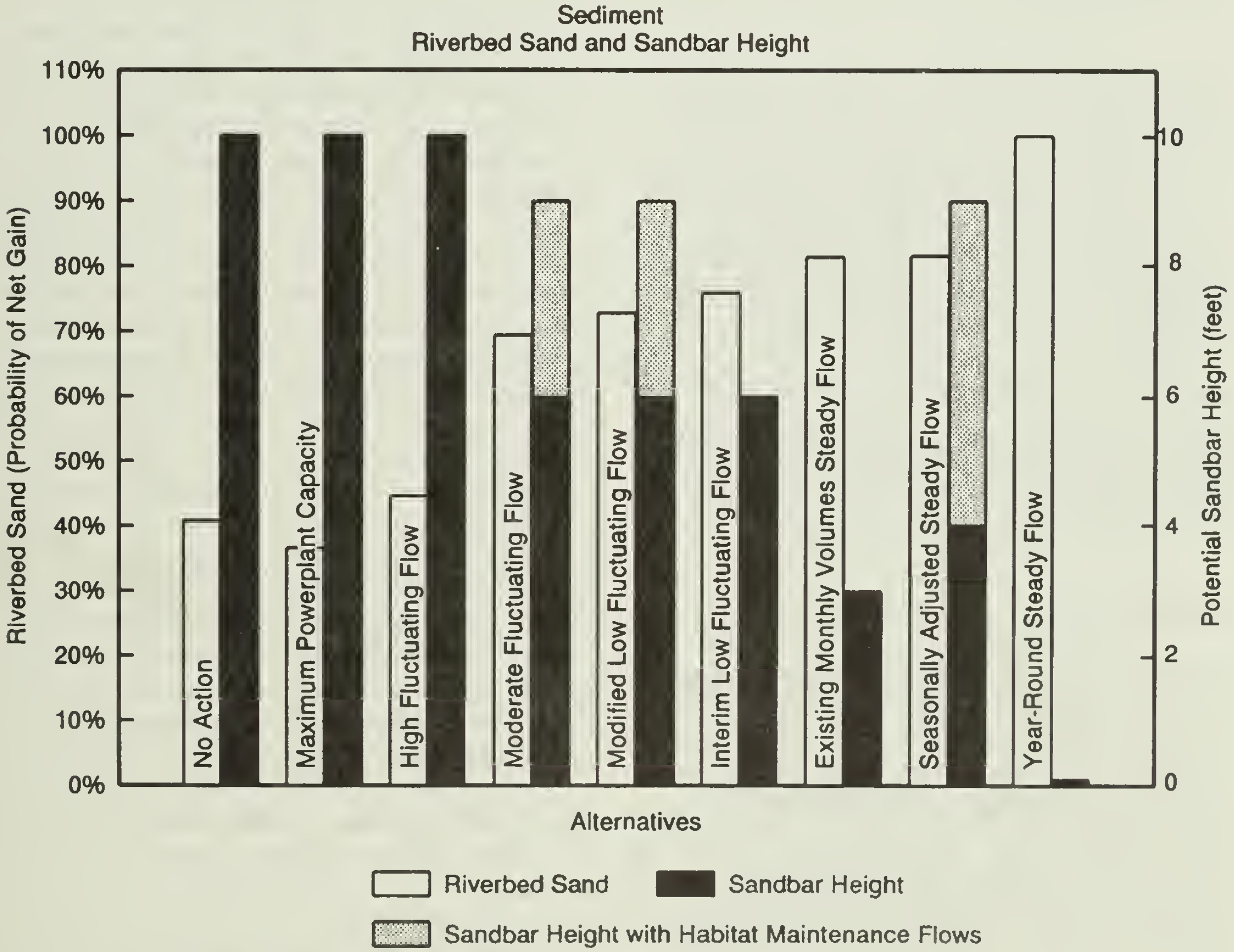


Figure IV-11.—Probability of a net gain in riverbed sand in the reach RM 0-61 after 50 years, and potential sandbar heights in wide reaches (without beach/habitat-building flows) for each alternative. The probability of a net gain in riverbed sand and the potential sandbar heights depend on the magnitude and frequency of an alternative's normal peak discharge. The No Action Alternative could potentially deposit high sandbars but would have relatively little sand to deposit. In contrast, the Year-Round Steady Flow Alternative would have ample riverbed sand to deposit but relatively little potential to deposit it at high elevations. Beach/habitat-building flows would infrequently increase these potential sandbars heights.

habitat maintenance flows have potential sandbar heights nearly the same as under no action, but with much higher probabilities of net gain in riverbed sand. Habitat maintenance flows would provide some dynamics of a natural system (deposition and erosion). Sand previously stored on the riverbed would be transported, and sandbar deposition would occur in low velocity areas along the channel. Other deposits exposed to figure IV-11 high velocities would be reworked and may experience net erosion. Overall, net deposition would be expected at higher-than-normal elevations. These new deposits would erode at an unknown rate following the return to more normal flows.

Beach/habitat-building flows might be as high as 45,000 cfs; more information is needed about the effects of these flows and the subsequent stability of the aggraded sandbars. Such information would be obtained from long-term monitoring and research under the Adaptive Management Program. Tables of potential sandbar heights for these flows in each of the 11 reaches under each alternative are included in appendix D.

Downstream from RM 236 in Lower Granite Gorge, sediment deposition and erosion along the channel margins are primarily driven by changes in the level of Lake Mead (see discussion under "Lake Deltas").

High Terraces

In the absence of extremely large sediment-laden floods (greater than 100,000 cfs), the fate of high terraces is gradual erosion, regardless of the alternative implemented (see chapter III, SEDIMENT). Beach/habitat-building flows and habitat maintenance flows may slow or somewhat reduce erosion of high terraces; however, the effects of such flows are not well known. Habitat maintenance flows under the Moderate and Modified Low Fluctuating and Seasonally Adjusted Steady Flow Alternatives would help to maintain sandbars (up to the river stage corresponding to 30,000 cfs) in certain locations, where they may protect high terraces from erosion by riverflows.

Some high terraces (mostly between the dam and RM 36) are subject to direct erosion from floodflows. This happens where there are no sandbars between the terrace and river (usually on the outside of a river bend) and, thus, no buffer against erosion. Therefore, an indicator of impacts to this type of terrace is the frequency of floods greater than 45,000 cfs: 1 in 40 years for the No Action and Maximum Powerplant Capacity Alternatives and 1 in 100 years for the other alternatives.

Debris Fans and Rapids

Changes in debris fans and rapids depend on tributary debris flows and discharge from the dam. While debris flows are independent of dam operations, the resulting debris fans historically have been reworked (boulders and smaller sediment moved downstream) by high flows, especially large floods (see chapter III, SEDIMENT).

Impacts to debris fans and rapids are considered here because of the concern that releases within powerplant capacity may not be large enough to move large boulders that constrict the channel and thus affect white-water boating safety. The relative capacity of the normal peak discharge to move boulders is used as an indicator of impacts to debris fans and rapids (see table IV-6). The percentages were calculated by dividing the square of the normal peak discharge in a minimum release year by the square of the 1983 peak discharge (92,600 cfs) and multiplying by 100. Beach/habitat-building flows were not considered because they would not occur every year, although such flows would remove larger material than could be removed by normal flows.

The relative numbers in table IV-6 show that maximum flows under all alternatives have much smaller capacity to move boulders than the predam annual floods, which were about the same magnitude as the 1983 flood. There probably is no measurable difference in capacity between alternatives with indicator values of 10 to 13 or between alternatives with values of 2 to 5. Further, the difference between these two groups probably is slight, but measurable.

Even with beach/habitat-building flows or habitat maintenance flows, none of the alternatives is expected to result in significant impacts to debris fans and rapids over the short term. Over the long term, new debris flows are expected to aggrade debris fans and further constrict rapids. Steady flow alternatives and the Interim Low Fluctuating Flow Alternative would have relatively less capacity to remove material from aggraded debris fans than other alternatives.

Lake Deltas

The size of deltas depends on the amount of total sediment transported to the lake. Delta elevation depends on average lake elevation, which varies with the amount of inflow and monthly release patterns. Delta crest elevation therefore can be used as an indicator of the elevation of the delta surface to compare impacts between alternatives. Beach/habitat-building flows and habitat maintenance flows would result in a 2- to 3-foot decrease in Lake Powell and a similar increase in Lake Mead over a 1- to 2-week period. These changes in lake levels are not expected to result in measurable impacts to sediment deposits in either lake.

Lake Powell. The rate of growth of Lake Powell deltas is independent of dam operations. Delta crests elevations are represented by the 20- and 50-year averages of projected monthly median lake elevations during April-August (3665 and 3662 feet above sea level). Annual release volumes are the same under all alternatives, and monthly releases volumes are the same under all but two—Seasonally Adjusted and Year-Round Steady Flow Alternatives. Delta crest elevations under these two alternatives would be either the same as no action or as much as 2 feet lower (see table IV-6).

Elevations of the delta crests surveyed in 1986, after a period of high inflow and full reservoir, were higher than either the 20- or 50-year projected average lake elevations. Lake Powell deltas would continue to build downstream with new crests forming at lower elevations. Although Lake Powell tributaries would likely cut a relatively narrow channel through these deltas, most sediment would remain in place and become vegetated.

Lake Mead. Lake deltas consist of clay, silt, and sand. All sediment sizes must be considered when predicting impacts. The amount of clay and silt transported to the Lake Mead delta depends on upstream tributary supply and does not significantly vary among alternatives. However, the amount of sand transported to the delta over the short term does depend on the alternative.

Short-term sediment delivery from the Colorado River to Lake Mead would be greater under fluctuating than under steady flow alternatives. The differences between short-term delivery rates of the various alternatives are indicated by the difference in riverbed sand storage. Over the long term, the river will adjust its sediment load to match the tributary supply, regardless of the alternative implemented. The long-term sediment delivery rate to Lake Mead is expected to equal 12 million tons per year, of which about 3 million tons would be sand—equivalent to the long-term average supplied by the Paria River and the LCR.

The elevation of the delta crest in Lake Mead depends on lake elevation, which varies with the amount of inflow, as well as monthly release patterns at Hoover Dam. The indicator used to compare alternatives is the elevation of the delta crest, represented by the 20- and 50-year averages of projected monthly median lake elevations during July-October (1175 and 1167 feet above sea level). Annual release volumes are the same under all alternatives, and monthly release volumes are the same under all but two—Seasonally Adjusted and Year-Round Steady Flow Alternatives. Under these two alternatives, elevations of the delta crests would be either the same as no action or as much as 1 foot higher (see table IV-6).

Sediment deposition and erosion along the channel margins downstream from RM 236 in Lower Granite Gorge depend on Lake Mead water level and do not vary measurably among alternatives. Under all alternatives, deposition when lake levels are high is expected to be followed by erosion (including bank caving) during subsequent periods of lower lake levels.

Unrestricted Fluctuating Flows

No Action Alternative

Peak river stages associated with daily flow fluctuations under this alternative would have the potential to maintain high elevation sandbars (within normal peak river stage). However, the amount of riverbed sand would likely decline over time, and sandbars upstream of the LCR would experience net erosion.

Riverbed Sand. Probabilities of a net gain in riverbed sand are not high during a low water year and decrease with increases in annual release volumes (see appendix D). The probability of a net gain in sand storage (in the reach between the Paria River and LCR) is 50 percent at the end of 20 years and 41 percent at the end of 50 years. The sand balance downstream from the LCR would be expected to remain in a state of dynamic equilibrium. While some changes may occur from year to year, they would be expected to balance out over the long term.

Sandbars (Beaches and Backwaters). Sandbars would continue to be dynamic (cycles of deposition and erosion) under this alternative; they would change more rapidly as a result of floodflows. Some bars may be completely lost, and new bars may form. High elevation sandbars (separation bars above normal peak discharge) would be expected to erode during periods of normal operations. Low elevation bars (reattachment bars) downstream from Lees Ferry would be expected to aggrade in wide reaches of the canyon. During unanticipated floods, high elevation sandbars would be expected to aggrade in wide reaches. However, low elevation bars would be expected to erode. These predictions are based on analyses of historical data by Schmidt (written communication, 1992).

Sandbars would continue to undergo cycles of deposition and erosion (see chapter III, SEDIMENT). Erosion would occur throughout the canyon due the large daily changes in river stage and rapid decreases in stage upstream from the LCR. Seepage-induced erosion would increase during periods of lower minimum releases and reduced fluctuations, such as weekends and holidays.

The large daily changes in river stage would maintain existing active sandbar widths of unvegetated sand. Rapid increases in river stage would have little or no effect on sandbars. Sandbars in the Glen Canyon reach tend to exist in naturally protected areas but would likely experience slow rates of erosion over the long term. Sandbars eroded from this reach would not be rebuilt.

Both the number and size of sandbars between Lees Ferry and the LCR would be expected to decline to some new equilibrium due to reduced riverbed sand. Generally, net erosion would decrease downstream, with the addition of sand from tributaries and reduced daily fluctuations.

Normal Operations.—The cycles of sandbar deposition and erosion would result in relatively large active widths of unvegetated sandbars. Daily discharge fluctuations from 1,000 to 24,000 cfs would result in river stage fluctuations ranging from about 7 feet in reach 5 to about 12 feet in reach 2. Active sandbar widths corresponding to these daily discharge fluctuations would range from 32 to 58 feet.

Over the course of a minimum release year, river stage fluctuations (potential sandbar heights above level of minimum flow) would range from about 10 feet in reach 5 to about 15 feet in reaches 2 and 6. Active sandbar width would range from 44 feet (reach 5) to 74 feet (reach 2). Sand would not deposit above the 31,500-cfs river stage during normal operations.

Eddy backwaters (open return-current channels) are dependent on the formation of reattachment bars. In the short term, the number and size of stable backwaters would vary with discharge (see FISH section in this chapter). Over the long term, backwaters would tend to fill with sediment and later re-form during the next flood release (an average of once in 40 years for floods 45,000 cfs and greater).

Erosion due to natural forces such as runoff from local rainfall, wind, and tributary flash floods would continue (not influenced by dam operations). However, sandbars eroded by sudden natural events may eventually be rebuilt by river-supplied sand. Debris flows would cover some sandbars with cobbles and boulders.

Unanticipated Floods.—Large unanticipated floods of sediment-free water generally have a much more dramatic and immediate impact on sandbars than releases under normal operations. The magnitude and extent of the effects depend upon the magnitude and duration of the flood and prior storage of riverbed sand, and the effects on individual sandbars would vary greatly. Floods of short duration (days or weeks) may result in net deposition, but floods of long duration (months) or occurring too frequently would result in net erosion. If flood releases continue for several years in a row, as happened during 1983-86, sandbars of all types would be expected to erode upstream from the LCR.

High elevation sandbars deposited during flood releases would erode again under normal operations, with initially high rates of erosion becoming less with time. The greater the aggradation during floods, the greater the loss of sand during subsequent lower flows (Schmidt, written communication, 1992).

Some sandbars may be irretrievably lost during floods. In the Glen Canyon reach, sandbars eroded during floods would not be rebuilt. Loss of sand from some bars between Lees Ferry and the LCR also might be permanent; the likelihood of irretrievable loss of sand downstream from the LCR is much less.

High Terraces. High terraces in direct contact with the river would erode during floods greater than 45,000 cfs. On the basis of current information, such terraces exist mainly upstream of RM 36. Terraces on the outside of river bends would be most vulnerable.

Debris Fans and Rapids. Within the cycle of aggrading debris flows and eroding flood releases from Glen Canyon Dam, a new dynamic equilibrium would be established which would include some rapids that are narrower and steeper. Effects on channel width, vertical drop, and velocity at rapids would vary considerably from site to site. The channel could become narrow, and the elevation drop could increase to the point of adversely affecting river navigation (see RECREATION in this chapter).

The 1983 flood with a peak discharge of 92,600 cfs reworked many rapids in Grand Canyon. In the absence of large floods, limited capacity to reshape debris fans would exist because very high velocities are needed to widen the channel and decrease the elevation drop at major rapids (Kieffer, 1987; 1990). Under normal operations, capacity of the normal peak discharge to move boulders at debris fans would be reduced to about 12 percent, relative to the 1983 flood. Some debris fans aggraded by smaller debris flows would be reworked by the maximum 31,500-cfs fluctuating flows, which might have velocities high enough to move some boulders. Even with maximum riverflows of 31,500 cfs, it is likely that most of the largest material deposited by new debris flows would remain on the debris fans. Flood releases that can move larger boulders are expected to occur an average of once in 40 years.

Lake Deltas. The profile shape and position of sediment delta crests are controlled primarily by changes in lake surface elevation and the amount of sediment transported into the lake.

Lake Powell.—The quantity of sediment flowing into the Lake Powell area is independent of Glen Canyon Dam operations. When the lake elevation is high, sediment would be deposited in the upstream parts of the deltas. When lake elevation is low, the inflowing sediment would be carried much farther into the lake. Lake Powell elevations would fluctuate seasonally (typically 15 to 30 feet) and tend to be lowest from February to April and highest from June to August.

Over the short and long term, delta crest elevations would tend to be lower than their present levels and would approximately equal the average of April through August median lake elevations. These elevations are projected to be 3665 and 3662 feet above sea level over the next 20 and 50 years. Lake Powell tributaries would cut relatively narrow channels across the deltas and transport some sediment downstream. However, most of the sediment deposits would tend to remain in place and would become vegetated.

Sediment depositing in Lake Powell may contain trace metals and organic pollutants. However, the sediment chemistry and the potential for these pollutants to be released into the lake are unknown (see the discussion of water quality in the WATER section of this chapter).

Lake Mead.—Short-term sediment delivery rates to the Colorado River delta in Lake Mead under this alternative would be among the highest of any alternative. Over the long term, the average rate of sediment accumulation in Lake Mead would equal the average total sediment load of Grand Canyon tributaries (approximately 12 million tons per year).

Seasonal and annual changes in lake elevation mainly depend on changes in storage of Lakes Powell and Mead. Lake elevations would fluctuate seasonally (typically 10 to 12 feet) and would tend to be lowest in summer and highest in winter. Most sediment would enter Lake Mead during the summer and fall (July through October). Delta crest elevation would be about the same as present levels and would approximately equal the average of July through October median lake elevations. These lake elevations are projected to be 1175 and 1167 feet above sea level over the next 20 and 50 years, respectively.

Maximum Powerplant Capacity Alternative

Under this alternative, impacts on all sediment resources are essentially the same as those under the No Action Alternative. Maximum releases higher than permitted under no action (31,500 cfs) would be possible when the elevation of Lake Powell is at or above 3641 feet, combined with a high demand for electrical power. These higher maximum releases would result in a negligible decrease in the quantities of **riverbed sand** storage in either the short or long term compared to no action. Corresponding increases in river stage between 31,500 cfs and 33,200 cfs would be about 0.5 foot. This would result in a negligible increase in active width and height of **sandbars**, compared to the No Action Alternative (see appendix D).

Impacts to **high terraces, debris fans and rapids**, and to **lake deltas** would be essentially the same as those under no action.

Restricted Fluctuating Flows

Impacts to sediment resources under the High, Moderate, Modified Low, and Interim Low Fluctuating Flow Alternatives are described in this section. An overview of common impacts of these alternatives is presented first, followed by specific details about individual alternatives.

Riverbed Sand

More riverbed sand would be stored under the restricted fluctuating flow alternatives than under either the No Action or Maximum Powerplant Capacity Alternatives but less than under the steady flow alternatives. Storage of riverbed sand increases as the allowable daily fluctuation range becomes more restricted. Net accumulation would tend to be greater in wider reaches, where velocities are relatively low, than in narrower reaches. Because of flood frequency reduction measures, unanticipated floods would likely result in increased deposition relative to the floods under the No Action or Maximum Powerplant Capacity Alternatives.

Sandbars (Beaches and Backwaters)

Under the restricted fluctuating flow alternatives, sandbars would be dynamic (cycles of erosion and deposition) but more stable than under the No Action or Maximum Powerplant Capacity Alternatives. Sandbar heights would be less, but the amount of riverbed sand available for deposition would increase over time. Sandbar heights and active widths would be greater than under steady flow conditions, except the Seasonally Adjusted Steady Flow Alternative with habitat maintenance flows.

Beach/habitat-building flows under the restricted fluctuating flow alternatives would have the potential to rebuild high elevation sandbars, and sand deposition may bury existing vegetation at some locations. Beach/habitat-building flows would be scheduled only when sufficient amounts of riverbed sand are available and would not disrupt the long-term sand balance. The optimum discharge, duration, and frequency of these events would have to be determined experimentally through careful monitoring and control.

Releases resulting from emergency exception criteria are assumed typically to be of small magnitude and short duration or infrequent and of short duration, with negligible effects.

High Terraces

Erosion of high terraces in direct contact with the river would be less than under no action because the frequency of flood-caused erosion would average only 1 in 100 years.

Debris Fans and Rapids

Impacts to debris fans and rapids under the fluctuating flow alternatives would be similar to those described under the No Action Alternative. In the absence of large floods, there would be limited capacity to reshape debris fans because very high velocities are needed to widen the channel and decrease the elevation drop at major rapids (Kieffer, 1987; 1990).

Channel width, vertical drop, and velocity at some rapids associated with new debris flows would be affected. The channel width would narrow, and the elevation drop would increase to the point of adversely affecting river navigation. The capacity to move boulders is assumed to be proportional to the normal peak discharge squared relative to the 1983 peak discharge (92,600 cfs) squared. The capacity of the normal peak discharge to move boulders at debris fans during minimum release years would be about 12 to 5 percent of the capacity of the 1983 peak discharge as shown below.

Alternative	Normal peak discharge (cfs)	Capacity to move boulders relative to 1983 flood (percent)
High fluctuating flow	31,500	12
Moderate fluctuating flow	30,000	10
Modified low fluctuating flow	30,000	10
Interim low fluctuating flow	20,000	5

Lake Deltas

Lake delta crest elevations under the restricted fluctuating flow alternatives would be the same as elevations under the No Action Alternative because annual and monthly lake elevations would be the same.

The Lake Mead delta would continue to increase in size and progress downstream toward Hoover Dam. Over the short term, the amount of sand and gravel reaching Lake Mead would be less under the restricted fluctuating flow alternatives than under the No Action or Maximum Powerplant Capacity Alternatives. Over the long term, the average rate of total sediment accumulation in Lake Mead would be equal to the average total sediment load supplied by Grand Canyon tributaries.

High Fluctuating Flow Alternative

Impacts to sediment resources under this alternative would be similar to those described under the No Action Alternative. However, there would be differences primarily due to the restrictions in the range of daily flow fluctuations. More **riverbed sand** would be stored but sandbar heights and active widths would remain about the same as no action.

The probability of a net gain in sand storage (in the reach between the Paria River and LCR) is 53 percent at the end of 20 years and 45 percent at the end of 50 years. The relatively high percentage of days with maximum hourly flows greater than 20,000 cfs would likely result in little, if any, net gain in riverbed sand.

Sandbars would continue to be dynamic with large active widths. Seepage-induced erosion would continue, especially during weekends and holidays when minimum flows would be lower.

Daily discharge fluctuations from 3,000 to 23,000 cfs would result in river stage fluctuations from about 7 feet in reaches 5 and 11 to about 11 feet in reaches 2 and 6. Active sandbar widths corresponding to these daily discharge fluctuations would range from 30 to 51 feet. Over the course of a minimum release year, potential sandbar height above the level of minimum flow would range from about 10 feet in reach 5 to about 15 feet in reach 6, with active sandbar width ranging from 44 to 70 feet (see appendix D). Sand would not deposit above the river stage corresponding to 31,500 cfs during normal operations.

When Lake Powell storage is 19 maf or less, beach/habitat-building flows of 41,500 cfs would be expected to aggrade sandbars in all major eddies to elevations 3 to 4 feet higher than the normal peak river stage (see appendix D).

Moderate Fluctuating Flow Alternative

More **riverbed sand** would be stored and **sandbars** would become more stable under this alternative than under the No Action, Maximum Powerplant Capacity, or High Fluctuating Flow Alternatives. Peak river stages would have less capacity to rebuild eroded sandbars, but seepage-induced erosion would be reduced.

The probability of a net gain in sand storage (in the reach between the Paria River and LCR) is 61 percent at the end of 20 years and 70 percent at the end of 50 years. Effects of habitat maintenance flows are included; they increase the annual sand transport capacity by about 117,000 tons and reduce the probability of net increase in riverbed sand by about 12 percent in years when they occur.

With habitat maintenance flows, sandbars would be dynamic, but less subject to long-term erosion than under the No Action, Maximum Powerplant Capacity, and High Fluctuating Flow Alternatives. Seepage-induced erosion would be less because of the reduced daily range in fluctuations, reduced down ramp rates, and because minimum flow criteria would be constant within each month (weekend minimum flows would not be less than allowable weekday minimum flows). Also, the shape and size of the recirculation zones would be more stable, but they would tend to gradually fill with sediment and become vegetated. Effects of wave-induced erosion would be distributed within a narrower range of fluctuating river stage than under the No Action or High Fluctuating Flow Alternatives.

Daily discharge fluctuations from 5,000 to 13,200 cfs would result in river stage fluctuations ranging from about 3 feet in reaches 5 and 11 to about 5 feet in reaches 2, 3, and 6. Active sandbar widths corresponding to these daily fluctuations would range from 10 to 21 feet. Over the course of a minimum release year, normal river stage fluctuations would range from about 6 feet in reach 5 to about 10 feet in reach 6, with active sandbar width ranging from 28 to 47 feet. With habitat maintenance flows, potential sandbar heights would be about 4 feet higher, and active widths about 13 to 19 feet wider. Beach/habitat- building flows of 40,000 cfs would be expected to aggrade sandbars in all major eddies to elevations 3 to 5 feet higher than the normal peak river stage (appendix D).

Modified Low Fluctuating Flow Alternative

More **riverbed sand** would be stored under this alternative than under the No Action, Maximum Powerplant Capacity, High or Moderate Fluctuating Flow Alternatives. **Sandbars** would tend to be stable. With habitat maintenance flows, peak river stages would have the capability to rebuild eroded sandbars. Seepage-induced erosion generally would be reduced; however, some would still occur during weekends and holidays due to lower minimum flows and reduced fluctuations.

The probability of a net gain in sand storage (in the reach between the Paria River and LCR) is 64 percent at the end of 20 years and 73 percent at the end of 50 years. Effects of habitat maintenance flows are included. They increase the annual sand transport capacity by about 118,000 tons and reduce the probability of net gain in riverbed sand by about 11 percent in years when they occur.

With habitat maintenance flows, sandbars would tend to be dynamic on an annual basis, but otherwise would be more stable and exist at lower elevations than under the other fluctuating flow alternatives. The shape and size of the recirculation zones would be similar to the other fluctuating flow alternatives.

With maximum down ramp rates of 1,500 cfs per hour, seepage-induced erosion would still occur but would be greatly reduced. Seepage-induced erosion would be most noticeable during periods of prolonged low releases, such as weekends and holidays. Maximum up ramps of 2,500 cfs would have little or no effect on sandbars. Effects of wave-induced erosion would be distributed within a narrower range of fluctuating river stage than under other fluctuating flow alternatives.

Daily discharge fluctuations from 5,000 to 10,000 cfs would result in river stage fluctuations ranging from about 1 foot in reach 11 to about 3 feet in reaches 1, 2, 3, and 6. Active sandbar widths corresponding to these daily discharge fluctuations would range from 1 to 12 feet. Over the course of a minimum release year, normal river stage fluctuations would range from about 6 feet in reaches 4 and 5 to about 9 feet in reach 6, with active sandbar width ranging from 24 to 41 feet. With habitat maintenance flows, potential sandbar heights would be about 7 to 11 feet higher, and active widths about 42 to 57 feet wider (see appendix D).

Beach/habitat-building flows of 40,000 cfs would be expected to aggrade sandbars in all major eddies to elevations 3 to 5 feet higher than the normal peak river stage.

Normal flows during low and moderate release years have less capacity to reshape debris fans under this alternative than under other fluctuating flow alternatives. With habitat maintenance flows, this alternative's capacity to move boulders would be approximately equal to that under no action. Generally, the constrictions at rapids would remain the same or become narrower and steeper when new debris flows occur.

In years when they occur, endangered fish research flows would have impacts on sediment that fall within the range of impacts between this alternative and the Seasonally Adjusted Steady Flow Alternative.

Interim Low Fluctuating Flow Alternative

More **riverbed sand** would be stored under this alternative than under the No Action, Maximum Powerplant Capacity, High, Moderate, or Modified Low Fluctuating Flow Alternatives. **Sandbars** would tend to be stable. Peak river stages would have limited capability to rebuild eroded sandbars, and seepage-induced erosion would be reduced. However, some seepage-induced erosion would still occur during weekends and holidays due to lower minimum flows and reduced fluctuations.

The probability of a net gain in sand storage (in the reach between the Paria River and LCR) is 69 percent at the end of 20 years and 76 percent at the end of 50 years.

Sandbars would tend to be more stable and exist at lower elevations than under the other fluctuating flow alternatives. The shape and size of the recirculation zones would be more stable than under the other fluctuating flow alternatives, but would more rapidly fill with sediment and become vegetated.

With maximum down ramp rates of 1,500 cfs per hour, seepage-induced erosion would still occur but would be greatly reduced. Seepage-induced erosion would be most noticeable during periods of prolonged low discharge releases, such as weekends and holidays. Effects of wave-induced erosion would be distributed within a narrower range of fluctuating river stage than under other fluctuating flow alternatives.

Daily discharge fluctuations from 5,000 to 10,000 cfs would result in river stage fluctuations ranging from about 1 foot in reach 11 to about 3 feet in reaches 1, 2, 3, and 6. Active sandbar widths corresponding to these daily discharge fluctuations would range from 1 to 12 feet (see appendix D).

Over the course of a minimum release year, river stage fluctuations would range from about 6 feet in reaches 4 and 5 to about 9 feet in reach 6, with active sandbar width ranging from 24 to 41 feet. Potential sandbar heights above the minimum river stage would range from 6 to 9 feet. Sand would not deposit above the 20,000-cfs river stage during a minimum release year.

Beach/habitat-building flows of 40,000 cfs would be expected to aggrade sandbars in all major eddies to elevations 3 to 5 feet higher than the normal peak river stage (see appendix D).

Flows during low and moderate release years have less capacity to reshape debris fans under this alternative than under other fluctuating flow alternatives. Generally, the constrictions at rapids would remain the same or become narrower and steeper when new debris flows occur.

Steady Flows

Impacts to sediment resources under the Existing Monthly Volume, Seasonally Adjusted, and Year-Round Steady Flow Alternatives are described in this section. An overview of common impacts from these alternatives is presented first, followed by specific details about individual alternatives.

Riverbed Sand

When compared to other alternatives, steady flow alternatives would store the greatest amounts of riverbed sand. Larger accumulations of riverbed sand would mean greater potential for bar-building during high flows. Annual peak river stages would vary under the steady flow alternatives but would be less than those under the other alternatives, resulting in sandbars being rebuilt at relatively low elevations. However, seepage-induced erosion would no longer occur, and other erosion rates generally would be low.

Between Lees Ferry and the LCR, the river would accumulate sand and gravel over time. Net accumulation would tend to be greater in wider reaches, where velocities are relatively low, than in narrower reaches. The sand balance in the reach between the LCR and Diamond Creek would be expected to remain in a state of dynamic equilibrium.

Sandbars (Beaches and Backwaters)

Sandbars would tend to be more stable and at lower elevations under the Existing Monthly Volume and Year-Round Steady Flow Alternatives than under any of the fluctuating flow alternatives. Under the Seasonally Adjusted Steady Flow Alternative, sandbars would be dynamic (due to habitat maintenance flows) but more stable than under the No Action Alternative. Sandbar heights would be about the same as under no action.

Sandbars would be subject to seasonal cycles of erosion and deposition due to seasonal variations in releases. Sand would tend to deposit on bars at slopes approaching 26 degrees during high river stage periods. The effects of allowable daily changes (plus or minus 1,000 cfs) for power system load changes would be negligible. Because of wave transformation and changes in channel width, the variation would be about plus or minus 500 cfs at Lees Ferry (plus or minus 0.2-foot river stage change) and would disappear from the hydrograph at some point between Lees Ferry and the LCR. Annual peak discharges under steady flow alternatives would have relatively little capability to rebuild eroded sandbars. Erosion caused by riverflow would be minimal, and seepage-induced erosion would no longer occur.

Beach/habitat-building flows would have the potential to rebuild high elevation sandbars and would also re-form backwater return-current channels. Habitat maintenance flows under the Seasonally Adjusted Steady Flow Alternative also would rebuild sandbars and re-form return-current channels.

The effects of unanticipated floods would be similar to those under no action. However, because of flood frequency reduction measures, unanticipated floods would likely result in net deposition of sandbars. More sand would be available for transport and deposition during floods because of increased capacity to store sand during normal operations. High elevation sandbars would be expected to aggrade in wide reaches; low elevation bars would be expected to erode (Schmidt, written communication, 1992).

Releases resulting from emergency exception criteria are assumed typically to be of small magnitude and short duration or infrequent and of short duration, with negligible effects.

High Terraces

High terraces in direct contact with the river would erode less than under no action because the frequency of flood-caused erosion would average only 1 in 100 years.

Debris Fans and Rapids

Impacts to debris fans and rapids under the steady flow alternatives would be greater than those under the fluctuating flow alternatives. Generally, the constrictions at rapids would remain the same or become narrower and steeper when new debris flows occur.

Annual peak discharges under the Existing Monthly Volume and Year-Round Steady Flow Alternatives have the least capacity to remove sediment from debris fans, and some rapids would become even more constricted. The capacity of the normal peak discharge to move boulders on debris fans during minimum release years would be about 3 percent of the capacity of the 1983 peak discharge. With habitat maintenance flows, the Seasonally Adjusted Steady Flow Alternative would have a relatively higher capacity to move boulders. Normal peak discharges and capacity to move boulders for the steady flow alternatives are listed below.

Steady flow alternative	Normal peak discharge (cfs)	Capacity to move boulders relative to 1983 flood (percent)
Existing monthly volume	16,300	3
Seasonally adjusted	30,000	10
Year-round	11,900	2

Lake Deltas

Impacts to lake deltas under the steady flow alternatives would be the same as or similar to those under no action because annual lake elevations would be the same. Monthly lake elevations under the Existing Monthly Volume Steady Flow Alternative would be the same as no action; monthly lake elevations under the other two steady flow alternatives would be different.

Lake Powell. The average of the median monthly water surface elevations for Lake Powell for April through August over the next 20 and 50 years are shown below.

Steady flow alternative	Lake Powell elevations (feet) 20 Years	50 Years
Existing monthly volume	3665	3662
Seasonally adjusted	3664	3660
Year-round	3664	3660

Lake Mead. The average of the median monthly Lake Mead water surface elevations for July through October projected over the next 20 and 50 years are shown below.

Steady flow alternative	Lake Mead elevations (feet) 20 Years	50 Years
Existing monthly volume	1175	1167
Seasonally adjusted	1176	1168
Year-round	1176	1168

Over the short term, the amount of sand and gravel reaching Lake Mead would be less under the steady flow alternatives than under any of the fluctuating flow alternatives. Over the long term, the average rate of total sediment accumulation in Lake Mead would be equal to the average total sediment load supplied by Grand Canyon tributaries (approximately 12 million tons per year).

Existing Monthly Volume Steady Flow Alternative

The amount of **riverbed sand** transported under this alternative would be less than under the fluctuating flow alternatives and the Seasonally Adjusted Steady Flow Alternative. Conversely, the amount of sand and gravel stored as riverbed material within the channel pools and eddies would be greater than under those alternatives.

The probability of a net gain in sand storage (in the reach between the Paria River and LCR) is 71 percent at the end of 20 years and 82 percent at the end of 50 years.

Sandbars would tend to be more stable and exist at lower elevations under this alternative than under all but the Year-Round and Seasonally Adjusted Steady Flow Alternatives. The shape and size of the recirculation zones also would be more stable, but would tend to fill more rapidly with sediment and become vegetated.

The channel would aggrade at a higher rate between the Paria River and the LCR than under all of the fluctuating flow alternatives. With greater amounts of stored sand, there is greater potential for aggradation of sandbars and less potential for net degradation of sandbars during spills.

Over the course of a minimum release year, monthly changes in river stage would range from about 3 to 5 feet, with active sandbar width ranging from about 10 to 19 feet. Sandbar heights above the minimum river stage would range from 3 to 5 feet. Sand would not deposit above the river stage corresponding to 16,300 cfs during a minimum release year (see appendix D).

Beach/habitat-building flows of 26,300 cfs would be expected to aggrade sandbars in all major eddies to elevations 3 to 5 feet higher than the normal maximum river stage if there is adequate sand supply in the river channel. Sand deposition may bury existing vegetation at some locations.

During low and moderate release years, flows would have less capacity to reshape **debris fans** than under all but the Year-Round Steady Flow Alternative. The constrictions at **rapids** would remain the same or become narrower and steeper when new debris flows occur.

Lake Powell elevations would fluctuate seasonally (typically 15 to 30 feet) and tend to be lowest from February to April and highest from June to August. Lake Mead elevations would fluctuate less (typically 10 to 12 feet) and would tend to be lowest in summer and highest in winter.

Seasonally Adjusted Steady Flow Alternative

During normal operations, **riverbed sand** would be stored at lower elevations within the eddies than under the fluctuating flow alternatives because of the lower discharge and river stage.

The probability of a net gain in sand storage in the reach between the Paria River and LCR is 71 percent at the end of 20 years and 82 percent at the end of 50 years. Effects of habitat maintenance flows are included. They increase the annual sand transport capacity by about 124,000 tons and reduce the probability of net gain in riverbed sand by about 11 percent in years when they occur.

Over the course of a minimum release year, seasonal changes in river stage would range from about 4 feet to about 7 feet, with active **sandbar** width ranging from 16 to 29 feet. With habitat maintenance flows, potential sandbar heights would be about 4 to 6 feet higher, and active widths about 21 to 31 feet wider (see appendix D).

Beach/habitat-building flows of 40,000 cfs under this alternative would be expected to aggrade sandbars in all major eddies to elevations 3 to 5 feet higher than the normal maximum river stage, if there is adequate sand supply in the river channel. Sand deposition may bury existing vegetation at some locations.

During low and moderate release years, normal flows under this alternative would have less capacity to reshape **debris fans** than those under all fluctuating flow alternatives. With habitat maintenance flows, this alternative would have a capacity to move boulders approximately equal to that under no action. Generally, the constrictions at **rapids** would remain the same or become narrower and steeper at some sites when new debris flows occur.

Lake Powell elevations would fluctuate seasonally and tend to be 1 to 4 feet higher than under no action from December through May and 1 to 2 feet lower from June through August. Lake Mead elevations would typically be 1 to 2 feet lower from January through April and 1 to 2 feet higher from June through August than lake elevations under no action.

Year-Round Steady Flow Alternative

Compared to all other alternatives, flows under this alternative would transport the least amount of **riverbed sand** but would store the greatest amount of sand and gravel within the main channel and eddies. Larger accumulations of sand in the river would mean greater potential for bar-building during high flows. During normal operations, sand would be stored at lower elevations within the eddies since this alternative has the lowest discharge and river stage.

The probability of a net gain in sand storage in the reach between the Paria River and LCR is 74 percent at the end of 20 years and 100 percent at the end of 50 years.

Sandbars would tend to be more stable and exist at lower elevations under this alternative than under any other alternative. The shape and size of the recirculation zones would be more stable and would more rapidly fill with sediment and become vegetated than under the other alternatives. Steady flows under this alternative would expose the greatest amount of sandbar area above normal high water. However, most reattachment bars would be submerged much of the time.

Over the course of a minimum release year, river stages would fluctuate less than 1 foot, with virtually no active widths. Sandbar heights above the minimum river stage would range from 0 to 1 foot. Sand would not deposit above the river stage corresponding to 11,900 cfs during a minimum release year.

Beach/habitat-building flows of 21,900 cfs under this alternative would be expected to aggrade sandbars in all major eddies to elevations 4 to 6 feet higher than the normal peak river stage.

Flows under this alternative have the least capacity to remove sediment from **debris fans**. Debris fans would aggrade and **rapids** would become steeper and more constricted under this alternative compared to conditions under no action.

Lake Powell elevations would fluctuate seasonally and tend to be 1 to 2 feet lower than no action elevations from April through July. Lake Mead elevations would typically be 1 to 2 feet higher during April, May, and June than lake elevations under no action.

FISH

Issue:

How do flows affect FISH—their life cycles, their habitat, and their 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**
Reproduction, recruitment, and growth of **trout**

The focus of this impact assessment is on selected warmwater native fish, non-native warmwater and coolwater fish, and trout. The native fish considered in this section include the flannelmouth sucker (being considered for listing as a federally endangered species), bluehead sucker, and speckled dace. Detailed analysis of the response of humpback chub and razorback sucker is presented in the ENDANGERED AND OTHER SPECIAL STATUS SPECIES section of this chapter.

The analysis of effects on fishes is based on their basic life requirements and is directed at:

- Direct sources of mortality
- Potential to reproduce and recruit (survive to adulthood)
- Potential for growth

Because physical characteristics of the environment (temperature, reliable flow, turbidity, etc.) determine the limit to which fish and other organisms can develop, it is necessary to assess biological productivity of the environment, as well as its physical characteristics when evaluating impacts to fish under each alternative.

An indicator of aquatic ecosystem productivity in Glen and Grand Canyons is the river's capacity to support *Cladophora* and associated diatoms. Because of its response to river stage and flow characteristics, *Cladophora* was used as the indicator for the aquatic food base. The minimum reliable river stages (flow) and wetted perimeters below Glen Canyon Dam and at Lees Ferry are used to indicate the areas that can be colonized by aquatic food base. The aquatic food base is the indicator for growth and condition of fishes. A phenomenon known as wave transformation (chapter III, WATER) elevates the minimum stage encountered in downstream reaches under fluctuating flow conditions. Minimum reliable stage noted at Glen Canyon Dam and Lees Ferry under fluctuating flows may be relatively higher below the LCR because of this effect.

Each alternative results in physical effects to the aquatic environment that alter fish habitats in Glen and Grand Canyons. These effects are direct if they alter conditions necessary for the growth, survival, or health of a population. Mainstream water temperature, for example, has a direct effect on the ability of warmwater native fish to successfully reproduce or for young to survive. Effects are indirect if they influence one component of the aquatic community that then affects another. Reliable minimum flows of an alternative may directly influence *Cladophora* and, in turn, indirectly affect fish because of their influence on the availability of food resources. Likewise, effects may be short term or long term. Short-term effects influence only 1 or 2 reproductive years. Long-term effects are influences that extend up to or beyond the generation time of an individual (from hatching of an egg through the reproductive life of that individual). These effects may be retrievable or reversible. For example, loss of 1 year's reproduction for a long-lived fish may be made up in a subsequent year when conditions are favorable. On the other hand, the same kinds of effects may be irretrievable or irreversible if they consistently occur.

Summary of Impacts: Fish

A summary of impacts to fish resulting from each alternative is shown in table IV-8.

None of the alternatives under analysis changes the temperature of the water released from Glen Canyon Dam. This single fact constrains the ability of warmwater fish to successfully reproduce in the main channel and limits the likelihood that young native fish would grow to reproductive size. This condition emphasizes the importance of warm tributaries, return-current channel backwaters, and shallow nearshore areas as recruitment sites under current conditions (Maddux et al., 1987; Angradi et al., 1992; Valdez, Masslich, and Leibfried, 1992).

Because of limited warming of the main channel, backwaters, and nearshore areas, effects on main channel reproduction for native fish are considered identical under all alternatives including no action. Overall, warmwater native and non-native fish would continue to rely on tributaries for reproduction. Access to tributaries may not be limited by minimum releases of 5,000 cfs or more, though this has not been fully documented. Recruitment of these fish would depend upon warm tributaries and the processes that develop and maintain backwaters and shallow nearshore areas capable of warming separate from the main channel. The rate of growth of warmwater native and non-native fish is determined by water temperature and the quality and availability of their food base.

FISH	No Action	Maximum Power-plant Capacity	High Fluctuating Flow	Moderate Fluctuating Flow	Modified Low Fluctuating Flow[3]	Interim Low Fluctuating Flow	Existing Monthly Volume Steady Flow	Seasonally Adjusted Steady Flow	Year-Round Steady Flow
Aquatic food base	Limited by reliable wetted perimeter	Same as no action	Minor increase	Moderate increase	Potentially major increase	Potentially major increase	Major increase	Major increase	Major increase
Native fish	Stable to declining	Same as no action	Same as no action	Same as no action	Potential minor increase	Potential minor increase	Potential minor increase	Potential major increase	Potential minor increase
Mainstem reproduction[1]	None	None	None	None	None	None	None	None	None
Tributary reproduction	Access limited at low flows	Same as no action	Same as no action	Access not limited	Access not limited	Access not limited	Access not limited	Access not limited	Access not limited
Mainstem recruitment and growth	Limited by temperature and daily fluctuations in habitats	Same as no action	Temperature limited	Temperature limited	Temperature limited, more stable nearshore habitats, summer minimums limit backwaters	Temperature limited, more stable nearshore habitats, summer minimums limit backwaters	Temperature limited, stable nearshore habitats, summer minimums limit backwaters	Temperature limited, stable backwaters and nearshore habitats	Temperature limited, near-shore habitats stabilized, backwaters likely inundated
Non-native warm-water and cool-water fish	Stable to declining	Same as no action	Same as no action	Same as no action	Potential minor increase	Potential minor increase	Potential minor increase	Potential major increase	Potential minor increase
Reproduction and recruitment	Limited or none in the mainstem, tributary dependent	Same as no action	Same as no action	Same as no action	Nearshore habitat stability increased	Nearshore habitat stability increased	Very stable nearshore habitats	Stable backwaters and nearshore habitats	Very stable near-shore habitats, backwaters likely inundated
Growth (see aquatic food base above)	Limited by temperature and available food base	Same as no action	Temperature limited, increased food base	Temperature limited, increased food base	Food base increased	Food base increased	Food base increased	Food base increased	Food base increased
Trout[1]	Stocking-dependent	Same as no action	Same as no action	Increased growth potential, stocking-dependent	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
Adult stranding mortality	11 major stranding pools	Same as no action	Stranding pools reduced 20%	Stranding pools reduced > 20%	Stranding pools reduced > 20%	Stranding pools reduced > 20%	Stranding pools reduced > 55%	Stranding pools reduced > 55%	Stranding pools reduced > 55%
Glen Canyon reproduction and recruitment	90% of redd sites affected	Same as no action	60-90% of redd sites affected	83% of redd sites affected	83% of redd sites affected	83% of redd sites affected	Redd sites unaffected, stable fry habitat	Redd sites unaffected, stable fry habitat	Redd sites unaffected, stable fry habitat
Downstream reproduction and recruitment	Adequate tributary access, limited by minimum flows	Same as no action	Increase in reliable access	Increase in reliable access	Increase in reliable access	Increase in reliable access	Increase in reliable access	Increase in reliable access	Increase in reliable access

[1] While some habitat components used by native fish would improve, cold water temperatures in the mainstem would continue to restrict spawning to suitable tributaries under all alternatives.

[2] Growth and condition of trout would parallel effects described for the aquatic food base under each alternative. It should be noted that growth and condition could be compromised by fish health problems under any alternative. The type of potential problem or their cause cannot be predicted.

[3] Impacts of endangered fish research flows (during years when they occur) would be similar to those described under the Seasonally Adjusted Steady Flow Alternative.

Figure IV-12 compares impacts to the aquatic food base, using reliable wetted perimeter as the indicator of effects.

Initially, endangered fish research flows would be included in the Modified Low Fluctuating Flow Alternative during minimum release years. The extent to which steady flows would be permanently incorporated would depend on evaluation of the research results. Because these 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 table of impacts. Endangered fish research flows (when they occur) would have impacts on fish similar to those described for the Seasonally Adjusted Steady Flow Alternative.

While the cold water releases limit the ability of warmwater fishes to reproduce and grow in the main channel, existing water temperatures are adequate for coldwater fish, including rainbow and brown trout. Because the temperature of releases is the same among alternatives, no temperature limitation for trout spawning is assumed for any alternative. Lack of seasonal warming may limit trout growth rate and probably limits the diversity of aquatic invertebrates available as trout forage.

Because direct effects of daily fluctuations on trout reproduction and survival are concentrated in the first 16 miles of river below Glen Canyon Dam, impacts downstream of this reach are indirect and center on tributary access. Access to spawning tributaries may not be limited when minimum releases are 5,000 cfs or more.

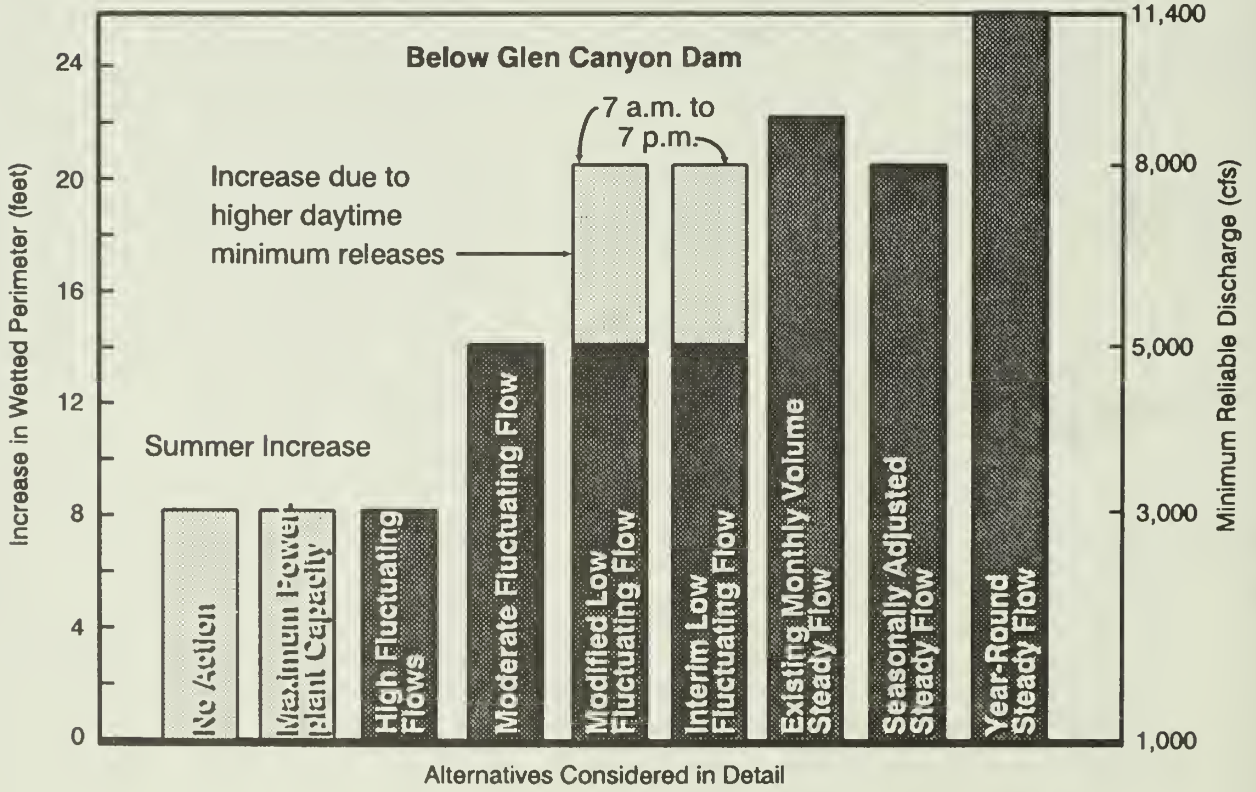


Figure IV-12.—Comparison of impacts to the aquatic food base by alternative, using reliable wetted perimeter near Glen Canyon Dam as the indicator of effects.

Flood frequency reduction measures may have mixed effects on native fish. Floodflows may inundate backwaters that are important as rearing areas in the short term. At the same time, native fish of the Southwest are well-adapted to flood events, and high flows rebuild and maintain backwaters. Floods may displace non-native competitors and predators, potentially enhancing native fish populations (Minckley, 1991). However, the effects of non-native displacement are short term and reversible.

High flows associated with floods create and maintain return-current channel backwaters (figure III-16), which tend to fill with sediment and vegetation in the absence of periodic disturbance. Uncontrolled floods accelerate the loss of fine sediment from the river channel, leading to armoring. Lack of a long-term sediment balance would result in an irreversible, irretrievable loss of backwater rearing habitats, further confining reproduction and recruitment of native fish to the tributaries. Flood control does serve to maintain a net sediment balance and preserve fine sediments that typically form backwater habitats.

Without some high flow disturbances, return-current channel backwaters eventually would fill with sediment and vegetation. Habitat maintenance and beach/habitat-building flows, acting as planned floods, have the potential to restructure and maintain these backwater habitats. The frequency and duration of such flows necessary to maintain these habitats is still unknown. Several factors must be considered in scheduling maintenance and beach/habitat-building flows:

- The balance between the need to maintain the geomorphology of backwaters and their aquatic productivity
- The presence of strong year classes of native fishes
- The rearing periods for native fish

Reattachment bar heights (see the SEDIMENT section of this chapter) provide some insight into maintenance of backwaters under normal operations. Reattachment bar heights with a habitat maintenance or beach/habitat-building event indicate the potential of these "simulated floods" to restore return-current channel backwaters. In the absence of high flow events, the number and area of backwaters would likely decrease due to filling and vegetation growth.

Unrestricted Fluctuated Flows

No Action Alternative

Aquatic Food Base. *Cladophora* production in the Glen Canyon reach provides the food base for lower reaches of the river. Thus, the productive band of shoreline (wetted perimeter) that can be occupied by this important alga serves as the indicator for the condition of the aquatic food base as a whole. Three index points are presented for comparison in table IV-9: a point just below Glen Canyon Dam, a shallow riffle area downstream of the dam, and a point at Lees Ferry. The difference in change in wetted perimeter with change in stage between deeper, low gradient areas and the shallow, higher gradient areas illustrates the greater productive capacity of shallow, cobble riffles.

Prolonged exposure (greater than 12 hours) of shoreline would limit the potential of that shoreline zone to support *Cladophora* (Angradi et al., 1992, Blinn and Cole, 1991). Therefore, extended low flow periods (weekends) determine the area occupied by *Cladophora* and, in turn, the rest of the aquatic food base that directly or indirectly benefits from it—especially in shallow cobble bars. The river's productive capacity could be estimated only tenuously, but with no action conditions as baseline, comparison of zones of reliable inundation of at least 12 hours (in vertical feet of stage and wetted perimeter near Lees Ferry) may index the proportional difference between no action and the other alternatives.

Reliable minimum flows under no action are 1,000 cfs during winter months (Labor Day through Easter) and 3,000 cfs during the remainder of the year. Winter minimums, especially weekends, determine the reliable river stage that would support *Cladophora*. Higher summer minimums would support limited recovery of *Cladophora* in the zone up to the river stage corresponding to 3,000 cfs but would again expose it following the Labor Day weekend. River stage and wetted perimeter associated with reliable minimum flows under the No Action Alternative at three sites below Glen Canyon Dam are shown in table IV-9.

As successive daily release waves pass downstream (below Lees Ferry), troughs between waves tend to increase, resulting in minimum flows higher than those released at the dam (see chapter III, WATER).

Native Fish. The absence of mainstem reproduction, impeded access to spawning tributaries, disrupted main channel nursery areas, disrupted gonadal maturation (temperature-related), and limited growth potential (temperature-related) would result in a stable to gradually declining abundance of native fish.

Tributary Reproduction.—Owing to low water temperatures, successful reproduction in the mainstem does not occur (Valdez, 1991; Maddux et al., 1987).

Table IV-9.—Change in river stage and wetted perimeter associated with reliable minimum flows under each alternative at three sites below Glen Canyon Dam

	Near Glen Canyon Dam		A shallow, narrow riffle in Glen Canyon		Near Lees Ferry	
Alternative/reliable minimum flow	River stage (feet)	Wetted perimeter (feet)	River stage (feet)	Wetted perimeter (feet)	River stage (feet)	Wetted perimeter (feet)
No action						
1,000 cfs (winter)	3128.9	580.3	3123.9	141.4	3110.9	380.4
3,000 cfs (summer)	3130.9	588.5	3126.6	240.4	3112.4	389.1
High fluctuating flow						
3,000 cfs	+2.0	+8.2	+2.7	+99	+1.5	+8.7
Moderate fluctuating flow						
5,000 cfs	+3.5	+14.1	+4.2	+153.4	+2.4	+14.1
Modified low fluctuating flow						
5,000 cfs	+3.5	+14.1	+4.2	+153.4	+2.4	+14.1
8,000 cfs	+5.3	+20.5	+5.9	+193.5	+3.4	+20.2
Interim low fluctuating flow						
5,000 cfs	+3.5	+14.1	+4.2	+153.4	+2.4	+14.1
8,000 cfs	+5.3	+20.5	+5.9	+193.5	+3.4	+20.2
Existing monthly volume steady flow						
9,000 cfs	+5.8	+22.2	+6.5	+203.6	+3.7	+21.8
Seasonally adjusted steady flow						
8,000 cfs	+5.3	+20.5	+5.9	+193.5	+3.4	+20.2
Year-round steady flow						
11,400 cfs	+6.9	+25.9	+7.6	+287.2	+4.3	+25.4

According to Valdez (1991), daily fluctuations under no action may impede tributary access. Low flows of 1,000 cfs (Labor Day until Easter) and potentially 3,000 cfs (Easter until Labor Day) may limit access to tributaries (except perhaps the LCR), especially if low river stage at tributary mouths occurs at night when adult spawners would likely be moving. Indirectly, this fluctuation pattern may further limit reproduction of native fish.

Eggs and larval fish can be flushed into the mainstem by periodic tributary flood events. Temperature shock to eggs and larval fish acclimated to warmer water in tributaries may be fatal (Maddux et al., 1987). Loss or reduction of a single year-class may not be irretrievable; however, successive losses of year-classes may be irreversible. Short-lived fish, such as speckled dace, are most susceptible to this effect. The longer-lived bluehead sucker also is affected if the condition persists uninterrupted.

Mainstem Recruitment and Growth.—Backwaters and shallow nearshore areas along the main channel are important nurseries for young native fish exiting tributaries. Native fish require the shallow, productive, warm refuges provided by these slackwater areas during their first 2 years of life. Daily fluctuations under this alternative would continue to destabilize these areas (Valdez, 1991) by both periodically drying and flooding them with cold waters. Forcing juvenile native fish into the main channel may result in direct mortality from several causes: temperature shock, high energy expenditures resulting from movements in high velocity, cold water, and exposure to non-native predators.

Return-current channel backwaters must be recreated periodically by high flow events. Otherwise, they would eventually fill and be eliminated as a habitat type. Beach/habitat-building flows would not be applied to no action, and return-current channel backwaters would not be restructured under this alternative except during unanticipated floods.

Non-Native Warmwater and Coolwater Fish. The constraints on reproduction, recruitment, and growth of warmwater non-native fish in the main channel are very similar to those limiting native fish. The single most important difference is the large pool of potential immigrants to Glen and Grand Canyons from Lakes Mead and Powell. None of the alternatives would eliminate the possibility of non-native fish reestablishing if suitable habitat conditions present themselves.

The effects of the No Action Alternative on warmwater non-native fish are very similar to those for warmwater native fish. Cold water releases from Glen Canyon Dam, and possibly daily fluctuations and flood events, have considerably reduced the numbers of individuals and numbers of species (Minckley, 1991). Main channel habitat conditions for all warmwater non-natives are marginal. Channel catfish, common carp, and fathead minnow persist, but rely upon tributary spawning (and backwater spawning in the case of fathead minnow) to maintain their populations.

Conditions continue to favor persistence of rainbow trout and brown trout in upper reaches and common carp and channel catfish in lower reaches of the river. As a result, rainbow trout are the most common non-native fish in Glen Canyon and upper Grand Canyon, while common carp and channel catfish are the most common non-natives in lower Grand Canyon.

Striped bass ascend into Grand Canyon from Lake Mead, but do not appear to be establishing themselves. Their presence is seasonal and limited in duration (Valdez, Masslich, and Leibfried, 1992).

Reproduction, Recruitment, and Growth.—Spawning and rearing habitat for warmwater non-natives is limited in the main channel due to perennially cold releases. Factors that limit the native fish likewise constrain the warmwater non-natives, and their growth is similarly limited.

Trout. Growth and condition of trout is related to *Cladophora* in Glen Canyon (Angradi et al., 1992). Extended low flow periods (weekends) determine the aquatic food base available to trout and, in turn, the growth potential of the fish that directly or indirectly benefit from it. (See description of aquatic food base.) Effects on growth and growth potential are indirect and potentially reversible.

Under no action, the trout population is limited to low natural reproduction in the Glen Canyon reach where it is dependent upon main channel spawning. Stranding of adult fish is expected at all 11 of the evaluated stranding sites under minimum flows, and growth potential is the baseline condition determined by the aquatic food base. Downstream trout reproduction may be limited by access to tributaries, but peak flows likely would provide adequate access, particularly in high water volume winter months.

Adult Stranding Mortality.—Because stranded adults typically are spawning fish, the effects are twofold:

1. Relatively large individuals, the result of several years of accumulated growth in the river and of value to anglers, are removed from the population.
2. Potential reproductive contribution to the population is lost.

Under the No Action Alternative, all 11 stranding pools would continue to isolate fish and result in mortality. These effects are direct and irretrievable. Davis (1991) suggested that careful strain selection for stocking could reduce the incidence of adult stranding. A recently domesticated strain of trout may spawn in late spring and early summer, taking advantage of higher water volume months.

Mainstem Reproduction and Recruitment.—Angradi et al. (1992) reported that fewer than 10 percent of the redd sites they mapped in the Glen Canyon reach were unaffected by minimum flows as low as 3,000 cfs. These data suggest that at least 90 percent of the utilized spawning habitat was within the zone of potential daily fluctuation under no action and, if used by trout, the spawn would likely fail. Actual minimums during peak trout spawning seasons could be as low as 1,000 cfs. Natural reproduction is directly affected and minimized under this alternative, and population size is maintained through stocking and regulation. These effects are direct, but potentially can be compensated for by stocking.

Downstream Reproduction and Recruitment.—Trout access to tributaries is a result of both riverflow and tributary flow. High peak flows in the river during winter months provide access into tributaries that have sufficient flow for trout use. As with native fish, low minimums may limit trout accessibility to a tributary (flows at or below 2,000 cfs). The population of rainbow and brown trout in downstream reaches reflects natural reproduction in tributaries.

Maximum Powerplant Capacity Alternative

Impacts of this alternative would differ from no action only because it could increase the duration of low flows. This could intensify problems with access to tributaries.

The Maximum Powerplant Capacity Alternative could, in some ways, affect **non-native warmwater and coolwater fish** more than **native fish**. Native fish are adapted to existence in systems prone to severe flood events. It has been hypothesized (Minckley, 1991; Valdez, 1991) that wider fluctuations or flood events could temporarily destabilize and displace non-native fish in canyon-bound southwestern streams. The effects of fluctuation would be direct but, because of the large pool of potential immigrants to Glen and Grand Canyons from Lakes Mead and Powell, the effect would be short term and reversible.

Restricted Fluctuating Flows

Some effects on fish under the restricted fluctuating flow alternatives share similarities and are discussed in this section. Effects that differ from this general response are described separately under the individual discussions that follow.

Successful spawning of native fish in the main channel apparently would be prevented by the unchanged temperature of releases from Glen Canyon Dam. Larval and young-of-year nurseries (backwater areas and tributary mouths) would be affected by these alternatives in much the same ways as under no action, particularly during the high volume months of July, August, and September when young fish require warm, sheltered areas.

While the aquatic food base might increase somewhat due to higher minimum flows, that effect could be offset. Daily fluctuations and ramp rates under these alternatives could force movements of both adult and juvenile native fish from preferred sites, directly causing individuals to expend energy and potentially limiting their growth, survival, and reproduction, as under no action (Valdez, 1991).

Beach/habitat-building flows are included in these alternatives, and habitat maintenance flows would occur under the Moderate and Modified Low Fluctuating Flow Alternatives. These flows could reverse the long-term trend toward filling of return-current channel backwaters. It is assumed that these scheduled flows would maintain backwaters as a habitat type.

High Fluctuating Flow Alternative

Reliable minimum flows under the High Fluctuating Flow Alternative are 3,000 cfs throughout the year. Minimum flows increase to 5,000 cfs or 8,000 cfs in higher volume months with appropriate market conditions, but ultimately would return to the minimum reliable 3,000 cfs after a 2- to 3-month increase. Three-day weekend (holiday) periods during low volume-unfavorable market months would determine the reliable river stage that would support *Cladophora*, indicator for the **aquatic food base** as a whole.

Increases in river stage and wetted perimeter associated with the increased reliable minimum flow of the High Fluctuating Flow Alternative at three sites below Glen Canyon Dam are listed in table IV-9.

Wave transformation effects increase minimum discharges (thus minimum stage and wetted perimeter) in downstream reaches.

The effects of high fluctuating flows on **native fish** would be very similar to no action, with the exception of increases to the aquatic food base. Flood control offered under this alternative would provide limited assurance that riverbed sand would be available for backwater maintenance. Populations would be expected to range from stable to gradually declining. Effects on **non-native warmwater and coolwater fish** would be very similar to those described for no action.

Higher minimum flows under this alternative could reduce the effects of trout redd exposure over short periods. At each successive minimum flow described by the alternative, a smaller proportion of the redd sites evaluated by Angradi et al. (1992) would be exposed daily, as shown below.

Minimum flow (cfs)	Redds exposed daily (percent)
3,000	90
5,000	83
8,000	59

The trout hatching period can range from 3 to 7 weeks and could probably be accommodated within high volume winter months. However, successful hatching and rearing from larval stages to a size capable of negotiating the fluctuating water velocities would be less likely. Larval trout and fry would still be forced to move among rearing habitats as river stage fluctuated every day, reducing the likelihood of survival (Persons et al., 1985). Limitations on survival of larval trout and fry would be direct effects of fluctuations. The effects potentially could be offset through stocking and regulation.

Similar to no action, trout likely would have adequate access to tributaries for spawning. Access probably would be possible at higher flows; it is unknown if the increased minimum flows would enhance access.

The aquatic food base for trout is projected to increase with the increased reliable minimum flow, as would the growth potential for trout (see "Aquatic Food Base").

The High Fluctuating Flow Alternative would result in a slight reduction in stranding, imperceptible change in recruitment from mainstem spawning, no change in access to spawning tributaries for downstream populations, and minor increase in growth potential for trout.

Moderate Fluctuating Flow Alternative

The **aquatic food base** would increase over no action and high fluctuating flows under the Moderate Fluctuating Flow Alternative. Reliable minimum flows under this alternative would be 5,000 cfs throughout the year. Because the daily range of fluctuations would be set as a symmetrical band around a mean monthly flow (set for the entire month based on the monthly volume), minimum flows in higher volume months would be higher than the described minimum of 5,000 cfs. (Projected minimum flows for December, January, and July are above 7,000 cfs.) Ultimately, low flows would return to the minimum reliable 5,000 cfs after a 2- to 3-month increase.

Increases in river stage and wetted perimeter associated with the increased reliable minimum flow of the Moderate Fluctuating Flow Alternative at three sites below Glen Canyon Dam are shown in table IV-2.

Wave transformation effects increase minimum discharges (thus minimum stage and wetted perimeter) in downstream reaches.

The effects of moderate fluctuating flow on **native fish** would be very similar to no action, with the exception of increases to the aquatic food base. Populations are expected to range from stable to gradually declining.

Without some type of disturbance—such as periodic high flows—return-current channels that support backwaters will eventually fill with sediment, become colonized with vegetation, and lose their habitat value for native fish. Periodic high flows are assumed to re-form return-current channels and thus maintain conditions favorable for native fish at these sites.

Some cautions must be observed when scheduling habitat maintenance flows since the frequency and duration needed to maintain backwaters is unknown. First, a balance must be identified between the need to maintain the physical structure of return-current channels and the aquatic productivity of backwaters. Second, maintenance flows should perhaps be foregone in years with strong year classes of native fish. Finally, habitat maintenance flows should be scheduled in order to minimize potential conflicts with native fish rearing periods.

Without some type of disturbance, backwater habitat would become progressively more stable and thus more suitable for **non-native and coolwater fish**. Fathead minnow and common carp, in particular, could dominate in very stable backwaters (Maddux et al., 1987). Lower fluctuations and protection from floodflows under this alternative would be beneficial to non-native fish over no action conditions. However, habitat maintenance flows would offset these assumed benefits and cause some displacement of individual non-native fish.

Under the Moderate Fluctuating Flow Alternative, the daily range of fluctuation would be decreased, and the minimum flow would be increased. Both of these factors could prove beneficial to **trout**. Higher reliable minimum flows would reduce the degree of stranding from that experienced under no action. Monthly minimums of 5,000 cfs would have isolated only 80 percent of the trout stranding pools evaluated by Angradi et al. (1992). Additionally, because the daily range would be limited by the mean daily release from Glen Canyon Dam, the absolute minimum would increase during high volume months. (Projected minimum flows for December, January, and July are above 7,000 cfs.) As a result, potentially fewer trout stranding pools would become isolated, especially during high volume months.

Higher minimum flows under this alternative would reduce the effects of trout redd exposure over short periods. A minimum flow of 5,000 cfs would have exposed approximately 83 percent of the trout redd sites evaluated by Angradi et al. (1992), and because the daily range would be constrained under this alternative, the actual minimum flow realized might be greater than the required minimum. The daily range may also limit the realized maximum flow and force trout to select redd sites lower on gravel bars. These sites might be proportionately less susceptible to exposure. Two of three factors that negatively correlated with year class strength of trout at Lees Ferry (Persons et al., 1985) would be addressed by this alternative. The number of days with flows below 3,000 cfs would be eliminated, and the daily range of fluctuation would be constrained to less than 12,000 cfs per day.

Similar to no action, trout likely would have adequate access to tributaries for spawning. Access likely would be possible at higher flows, and it is unknown if the increased minimum flows would enhance their access. The aquatic food base for trout would increase with the increased reliable minimum flow, as would the growth potential for trout.

Overall effects of the Moderate Fluctuating Flow Alternative on trout include a reduction in stranding effects, a potential increase in recruitment from mainstem spawning, no change in access to spawning tributaries for downstream populations, and moderate increase in growth potential.

Modified Low Fluctuating Flow Alternative

Dam release patterns under the Modified Low Fluctuating Flow Alternative would be identical to those under the Interim Low Fluctuating Flow Alternative except for the habitat maintenance flows included under the preferred alternative. Effects under these two alternatives would be similar except that maintenance flows would re-form backwaters and help maintain these important sites for young fish.

In years when they occur, endangered fish research flows would have impacts on fish similar to those described under the Seasonally Adjusted Steady Flow Alternative.

Under this alternative, reliable minimum flows would be 5,000 cfs throughout the year, with flows no less than 8,000 cfs from 7 a.m. to 7 p.m. As a result, shoreline zones between the reliable river stages associated with 5,000-cfs and 8,000-cfs releases would support an **aquatic food base**. The quality of the aquatic food base associated with that zone would not be expected to be comparable to the zone below 5,000 cfs because of its periodic, seasonal exposure. Areas just above the 5,000-cfs stage would be better maintained than areas just below the 8,000-cfs stage because the latter would be exposed for greater periods.

Because the daily range of fluctuations would be limited, minimum flows in high volume months would be higher than 5,000 cfs. However, when releases could be held to a minimum (weekends), limited development of the aquatic food base would take place above 8,000-cfs river stage.

Increases in river stage and wetted perimeter associated with the increased reliable minimum flow of this alternative at three sites below Glen Canyon Dam are in table IV-9.

As with other fluctuating flow release patterns, wave transformation effects increase minimum discharges (thus minimum stage and wetted perimeter) in downstream reaches.

In general, the effects of this alternative on **native fish** would be somewhat similar to other fluctuating flow alternatives, in particular the Moderate Fluctuating Flow Alternative, which also incorporates a habitat maintenance flow. Some increases in the aquatic food base and increases in stability of backwater and nearshore nursery areas would be expected. The increased stability of nursery habitats could be offset by the higher minimum flows released during July and August, which could inundate backwaters and reduce their numbers. Increases in the aquatic food base and decreases in fluctuation would result in the potential for minor population increases.

One of the primary objectives of habitat maintenance flows is to re-form and maintain backwaters in a productive state for native fishes. Without such flows, it is assumed that backwaters would fill with sediment, become colonized by vegetation, and progressively lose their habitat value for young native fish.

Without disturbance, nearshore habitats become progressively more stabilized. This increasing stability is assumed to improve habitat conditions for **non-native warmwater and coolwater fish**. In addition to re-forming and interrupting trends toward backwater stabilization, maintenance flows may also displace individual non-native fish from the system.

Impacts on **trout** would include reduced stranding, potential increase in recruitment from mainstem spawning, and potential moderate increase in growth potential.

Minimum flows under this alternative would reduce the degree of stranding experienced in the Glen Canyon reach. Monthly minimums of 5,000 cfs would have isolated only 80 percent of the pools evaluated by Angradi et al. (1992). The requirement to increase minimum flows to 8,000 cfs between 7 a.m. and 7 p.m. could also limit the period of isolation for some stranding pools. Stranding pools recaptured by the river during this 12-hour period could not cause the same rate of mortality. Angradi et al. (1992) showed that stranded trout died in 4 to 64 hours after stranding.

Higher minimum flows under this alternative would reduce effects on trout redd and trout fry habitat similarly to the Moderate Fluctuating Flow Alternative. In addition, the aquatic food base for trout would increase with the increased reliable minimum flow, as would trout growth potential.

Interim Low Fluctuating Flow Alternative

Dam release patterns under this alternative and the Modified Low Fluctuating Flow Alternative would be identical except for the inclusion of a habitat maintenance flow under modified low fluctuating flows. Effects, except those associated with maintenance flows, would be similar. These similar effects involve the **aquatic food base** and **trout** and are discussed under the Modified Low Fluctuating Flow Alternative.

Increases in river stage and wetted perimeter associated with the increased reliable minimum flow of the Low Fluctuating Flow Alternative at three sites below Glen Canyon Dam are shown in table IV-9.

Wave transformation effects increase minimum discharges (thus minimum stage and wetted perimeter) in downstream reaches.

The effects of low fluctuating flows on **native fish** would be somewhat similar to no action, with the exception of moderate increases in the aquatic food base and increased stability of backwater and nearshore nursery areas. The increased stability of nursery habitats could be offset by the higher minimum flows released during July and August, which could inundate backwaters and reduce their numbers. Increases in the aquatic food base and decreases in fluctuation would result in the potential for minor population increases.

The effects of the Low Fluctuating Flow Alternative on **non-native warmwater and coolwater fish** would differ from those under no action and the other fluctuating flow alternatives in one respect: the advantage of progressively more stable backwaters. As backwaters increase in stability, they would become progressively more suitable for some non-native fish. Fathead minnow, in particular, could come to dominate very stable backwaters (Maddux et al., 1987) and might reflect a minor increase in the abundance of non-native warmwater fish. Factors that limit non-native warmwater fish would be very similar to those that constrain native warmwater fish, and their responses could be similar. Because the daily range of fluctuation would be reduced, this alternative would be less likely to displace individual non-native fish.

Impacts on **trout** include a reduction in stranding, potential increase in recruitment from mainstem spawning, and potential moderate increase in growth potential as discussed under the Modified Low Fluctuating Flow Alternative.

Steady Flows

Many of the impacts of the steady flow alternatives on fish share similarities, and these are discussed in this section. Effects that differ from this general response are described separately under the individual discussions of alternatives that follow.

Aquatic Food Base

Reliable minimum flows under the steady flow alternatives all would equal or exceed 8,000 cfs. As a result, shoreline zones up to at least the reliable river stage associated with 8,000-cfs releases would support an aquatic food base. Shoreline zones inundated seasonally or monthly could be recolonized by diatoms, but that portion of the aquatic food base would not be as stable as in zones below the reliable minimum river stage.

Successive daily release waves would not be generated without fluctuating flows. As a result, steady flows released from Glen Canyon Dam would not progressively increase in stage downstream except for contributions from tributary flow.

The absence of water velocity changes typical of fluctuating flows could reduce the amount of *Cladophora* and invertebrate drift, which could reduce the availability of trout forage and slow its transport downstream. Leibfried and Blinn (1988) showed a positive connection between increasing range of discharges and the drift of *Gammarus* during transition from steady flows to fluctuating flows. *Cladophora* and chironomid larvae did not show similar responses. Angradi et al. (1992) showed increases in concentration of coarse particulate organic matter (largely *Cladophora* debris) associated with increasing daily flow. The magnitude and significance of less fluctuation-induced drift is unknown.

Native Fish

Successful spawning in the main channel would be limited by the unchanged temperature of releases from Glen Canyon Dam under all steady flow alternatives. While moderately stable backwaters could warm somewhat, there is no evidence that they provide spawning habitat.

Beach/habitat-building flows are included in all of the steady flow alternatives. Such flows would be assumed to maintain return-current channel backwaters as habitat.

Non-Native Warmwater and Coolwater Fish

As under the fluctuating flow alternatives and no action, increased stability of backwaters favors some non-native warmwater fish as well as native fish. Fathead minnow and common carp, in particular, could benefit from stable backwaters (Maddux et al., 1987). Growth of warmwater non-natives and natives would be limited by temperature. Stable backwater areas could benefit competitive growth for some non-native fish.

Trout

Steady monthly flows under these alternatives could reduce the degree of stranding experienced under no action. Additionally, because the monthly flow would be steady, conditions likely to strand fish in the Glen Canyon reach would be limited to monthly or seasonal adjustments. Even then, only downward adjustments would strand fish. As a result, significantly fewer pools would become isolated. Once a pool became isolated, it would be highly unlikely for the river to recapture the pool and release stranded fish. Those stranded during seasonal flow adjustments would be unlikely to survive.

Higher steady flows under these alternatives would reduce the effects of redd exposure during at least 30-day periods. Redds would not likely be exposed without daily fluctuations. Downward adjustments in flow between months could expose redds.

Because flows would be steady and dependable over 30-day, seasonal, or annual periods, successful emergence of larval fish from redds would be likely. In the absence of daily fluctuations, larval, fry, and subadult trout would not be forced to move among rearing habitats, resulting in higher likelihood of survival. Enhanced redd success and increased recruitment would be direct effects of monthly steady flows. All three of the flow-related factors that Persons et al. (1985) noted as negatively associated with year-class strength for trout would be addressed by these alternatives.

The relatively high reliable minimum flows of these alternatives would maintain access to tributaries and increase potential growth of trout.

Existing Monthly Volume Steady Flow Alternative

Reliable minimum flows under the Existing Monthly Volume Steady Flow Alternative typically would exceed 9,000 cfs, even though the absolute minimum is 8,000 cfs. As a result, shoreline zones up to at least the reliable river stage associated with 9,000-cfs releases would support an **aquatic food base**. Shoreline zones inundated monthly by higher steady flows could be recolonized by diatoms, but that portion of the aquatic food base would not be as stable as in zones below the reliable minimum river stage.

Increases in river stage and wetted perimeter associated with the increased reliable minimum flow of the Existing Monthly Volume Steady Flow Alternative at three sites below Glen Canyon Dam are listed in table IV-9.

Many of the effects of no action on **native fish** would be unchanged under this alternative, though the mechanisms by which the effects occur would differ. For example, daily fluctuations would be replaced by discharge changes between months. While the frequency of changes in discharge would be drastically reduced under this alternative, some of the effects could still occur.

Habitats used by larval and young-of-year fish (backwater areas, nearshore habitats, and tributary mouths) would be affected somewhat differently than under the fluctuating flow alternatives. The daily flushing of backwaters would be eliminated under this alternative, but high constant flows during high volume summer months could inundate return-current channel backwaters when they would be most valuable to native fish as rearing habitats. Adjustments between months could force movement of juvenile fish, requiring energy expenditures and potentially exposing young fish to predation for relatively short periods.

Some nursery backwaters might not be formed (i.e., they would remain eddies) by the higher June, July, and August flows of this alternative. Those that did form would be stable during the month and would warm, providing rearing habitat for juvenile native fish. Rearing habitats would be only temporarily destabilized by the monthly adjustments in steady flows, though the frequency of these events would be much reduced compared to the No Action Alternative. An increased aquatic food base, along with stable backwaters (but perhaps fewer in number) would create potential for stable to increasing numbers of native fish.

Spawning and rearing habitat for **non-native warmwater and coolwater fish** would be limited in the main channel due to perennially cold releases. Factors that would limit native fish likewise would constrain the warmwater non-natives. While the number of available backwaters may be reduced due to high summer flows, the stability of the remaining backwaters could directly increase the recruitment of some non-natives (particularly fathead minnow and carp). The absence of daily fluctuations would eliminate displacement of individual non-native fish. Temporary destabilization of populations of non-native warmwater species would not be likely to result from this alternative.

Monthly steady flows likely greater than 9,000 cfs would have isolated only 45 percent of the **trout** pools evaluated by Angradi et al. (1992). Stranding would occur only during downward adjustments between months. Overall, the Existing Monthly Volume Steady Flow Alternative would greatly reduce trout stranding, greatly increase recruitment from mainstem spawning, maintain access to spawning tributaries for downstream populations, and possibly increase growth potential.

Seasonally Adjusted Steady Flow Alternative

Reliable minimum flows under the Seasonally Adjusted Steady Flow Alternative typically equal or exceed 8,000 cfs. As a result, shoreline zones up to at least the 8,000-cfs stage would support an **aquatic food base.** Shoreline zones inundated seasonally by higher steady flows could be recolonized by diatoms, but that portion of the aquatic food base would not be as stable as in zones below the reliable minimum river stage.

Increases in river stage and wetted perimeter associated with the increased reliable minimum flow of the Seasonally Adjusted Steady Flow Alternative at three sites below Glen Canyon Dam are listed in table IV-9.

The effects of this alternative on **native fish** would differ markedly from no action in many ways. While the alternative would establish some conditions that would enhance native fish, those same conditions could enhance non-native warmwater fish that compete with or prey on the natives. The two effects could offset one another.

A habitat maintenance flow in March would re-form return-current channels and prepare backwaters for later use by fish during the lower flows of summer. These flows are needed to prevent successional changes that favor non-native fish and eventually terrestrial vegetation.

According to Maddux et al. (1987), high steady flows during April, May, and June could increase spawning at tributary mouths and facilitate access to tributaries for spawning.

Stable backwaters formed by lower flows during July, August, and September would provide dependable rearing areas that warm on a daily basis, resulting in improved growth for young-of-year fish. Shallow, protected juvenile habitats associated with tributary inflows, cobble shorelines, and cobble riffles would likely be enhanced (Valdez, 1991).

Facilitated access to spawning tributaries, stabilized nursery areas, and improved aquatic food base would allow potential major increases in the abundance of native fish.

The effects of the Seasonally Adjusted Steady Flow Alternative on **non-native warmwater and coolwater fish** would differ considerably from those under no action. One area of notable difference would be the effect of stable backwaters. As backwaters stabilized, they would become progressively more suitable for some non-native fish.

The abundance of warmwater non-natives could be enhanced under this alternative. Increased late summer stability of backwaters could result in higher recruitment rates for some warmwater non-natives, particularly fathead minnow and carp. The absence of daily fluctuations would eliminate displacement of individual non-native fish.

Steady monthly flows under this alternative would reduce the degree of **trout** stranding experienced under no action. Monthly steady flows of 8,000 cfs or greater would have isolated only 45 percent of the pools evaluated by Angradi et al. (1992). Opportunities for stranding would occur during downward adjustments between seasons. On the whole, the Seasonally Adjusted Steady Flow Alternative would greatly reduce stranding effects, increase recruitment from mainstem spawning, maintain access to spawning tributaries for downstream populations, and increase trout growth potential and condition.

Year-Round Steady Flow Alternative

Reliable minimum flows under the Year-Round Steady Flow Alternative typically would equal or exceed 11,400 cfs. As a result, shoreline zones up to at least the reliable river stage associated with 11,400-cfs releases would support an **aquatic food base.**

The aquatic food base could be enhanced, though it might not be as readily swept into the drift and transported downstream in the absence of fluctuations (Angradi et al., 1992). Whether this would limit food production in downstream reaches is uncertain.

Increases in river stage and wetted perimeter associated with the increased reliable minimum flow of the Year-Round Steady Flow Alternative at three sites below Glen Canyon Dam are listed in table IV-9.

According to Valdez (1991), the moderately high constant flows (11,000 to 12,000 cfs) of this alternative under normal operations would be sufficient to provide access to tributaries by **native fish**. Because of the year-round nature of these releases, access should be available throughout the spawning period.

Some larval and young-of-year nurseries (backwater areas and tributary mouths) and juvenile habitats would likely be enhanced under this alternative. However, many return-current channel backwaters would be inundated by the high steady discharges typical of this alternative. Stability of backwaters during July, August, and September provides dependable rearing areas that warm daily, resulting in improved growth for young-of-year fish. Too much stability, however, could decrease the acceptability of backwater areas as rearing sites. Long-term stability could result in establishment of marsh vegetation and eventually riparian vegetation, ultimately eliminating these stable backwater areas as native fish rearing areas. High, flushing releases—such as the beach/habitat-building flows discussed earlier—would be necessary to maintain these habitats; however, there is disagreement concerning the desired frequency of such events.

Shallow, protected juvenile habitats associated with tributary inflows, cobble shorelines, and cobble riffles might not be enhanced under this alternative (Valdez, 1991). These sites typically would be limited at moderate to high flows.

Improved access to spawning tributaries, relatively stable nursery areas in the short term, limited habitat for juvenile fish, and potentially enhanced aquatic food base would result in stable to potentially increased numbers of native fish.

The absence of fluctuations and between month adjustments virtually would eliminate destabilization of **non-native warmwater and coolwater fish** by flow-related factors. Very stable flow conditions and reliable access to tributaries for spawning would result in population increases. Backwater habitats could be limited under this alternative because they tend to form at lower flows, but those that formed would provide very stable rearing habitats for warmwater non-natives, which could directly increase recruitment (particularly of fathead minnow and common carp).

Year-round steady flows would reduce the degree of **trout** stranding experienced under no action. Monthly steady flows of 11,400 cfs or greater would have isolated none of the pools evaluated by Angradi et al. (1992). Stranding would occur only during adjustments to accommodate forecast change. Therefore, the Year-Round Steady Flow Alternative would result in greatly reduced stranding, greatly increased recruitment from mainstem spawning, access to spawning tributaries for downstream populations, and an increase in growth potential.

VEGETATION

Issue:

How do flows affect VEGETATION throughout Glen and Grand Canyons?

Indicators:

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

Glen Canyon Dam operations affect downstream vegetation through several different mechanisms, especially daily release patterns repeated over time and major uncontrolled flood releases. Effects from these mechanisms are reflected as changes in both plant abundance and species composition. Such changes are directly linked to changes in sediment deposits that support riparian vegetation and to water release patterns that provide water for plant growth. Thus, the abundance and composition of the riparian plant community are influenced through effects on sediment and water from daily release patterns and major flood events.

Effects resulting from each alternative are represented by changes in the vegetation indicators identified in chapter III. Because models used for this analysis are still under development, the results presented here are subject to change as more information becomes available and the models are refined.

Analysis Methods

The short-term period of analysis is defined as 5 to 20 years following implementation of an alternative. During this time span, it is assumed that changes in vegetation would closely follow changes to exposed sediment deposits resulting from daily release patterns. Detailed analysis of vegetation generally is limited to the river corridor between the dam and Separation Canyon (although data are available only to Diamond Creek). Below Separation Canyon, riparian vegetation along the river corridor is linked to water levels in Lake Mead.

Although no major flood events are included in short-term analyses, different water years—ranging from low through moderate to high—are anticipated. Infrequent releases above the maximum flow identified for each alternative, habitat maintenance flows, and beach/habitat-building flows of unknown stage may occur in the short term.

It is impossible to predict the types or the sequence of water years that would occur in the future. The basic analysis assumes a sequence of minimum release years with modifications where appropriate. The reader should note that higher water volumes would result in conditions similar to alternatives with higher maximum flows. It is assumed that errors in estimates of vegetation coverage would be consistent across alternatives, and estimates are therefore appropriate and useful for comparing alternatives.

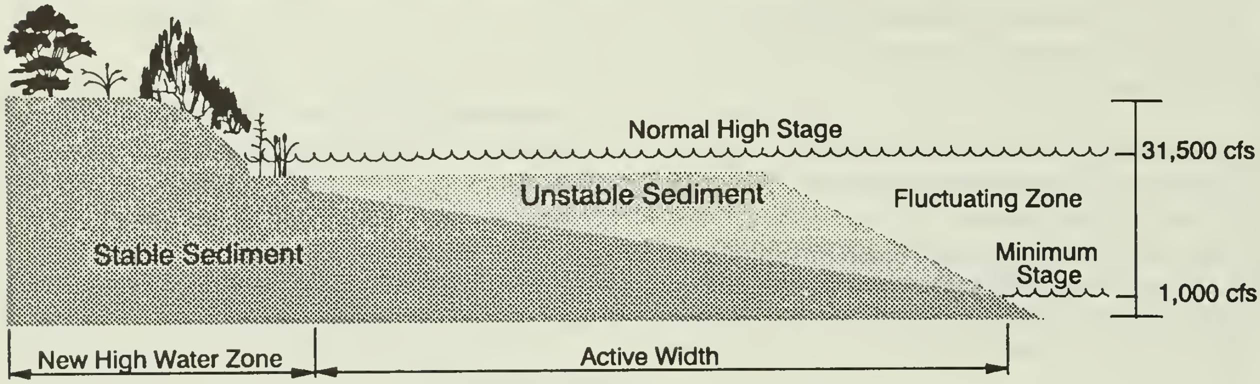
The long-term period of analyses is defined as the period from 20 to 50 years following implementation of an alternative. Changes in vegetation during this period become more difficult to predict but are assumed to closely follow changes to exposed sediment deposits. Sediment deposits are expected to reach a state of dynamic equilibrium (see chapter IV, SEDIMENT). Area coverage and species composition of vegetation during this period would stabilize within the constraints of sediment and discharge characteristics of each alternative.

Woody Plants

Analyses of change in area coverage of woody plants rely on previous analyses of active width of unstable sandbars (see chapter IV, SEDIMENT). It is assumed that the average active width of unstable sandbars computed for each of the 11 river reaches under analysis can be subtracted from no action conditions to yield an estimate of sandbar stability for each action alternative. These stabilized sandbar widths are assumed available for plant growth and provide the estimates for change in area of woody plants (figure IV-13). While the width of stabilized sandbars can be computed, such widths may not actually occur at all beaches because some parts of the canyon are too narrow. The data are useful, however, in a comparative sense. The data are presented as a range in feet and percentages from smallest river reach change to largest reach change.

Some alternatives would include an annual habitat maintenance flow designed to move and deposit sediment at higher elevations than would be possible under the alternatives' maximum flows. These flows would affect existing vegetation and those plants that would develop in areas of stabilized sandbars up to an elevation equivalent to the maintenance flow stage. However, it is assumed that because of limited duration and magnitude, such flows would not scour or drown plants. Some burial of plants would occur. Partial burial may not affect plants while complete burial may provide an advantage for plants able to grow through the covering sediment. Burial-tolerant woody plants include tamarisk, willow, and arrowweed.

a. Postdam and Future Conditions Under No Action



b. Short-Term Effects of Restricted Fluctuating and Steady Flows

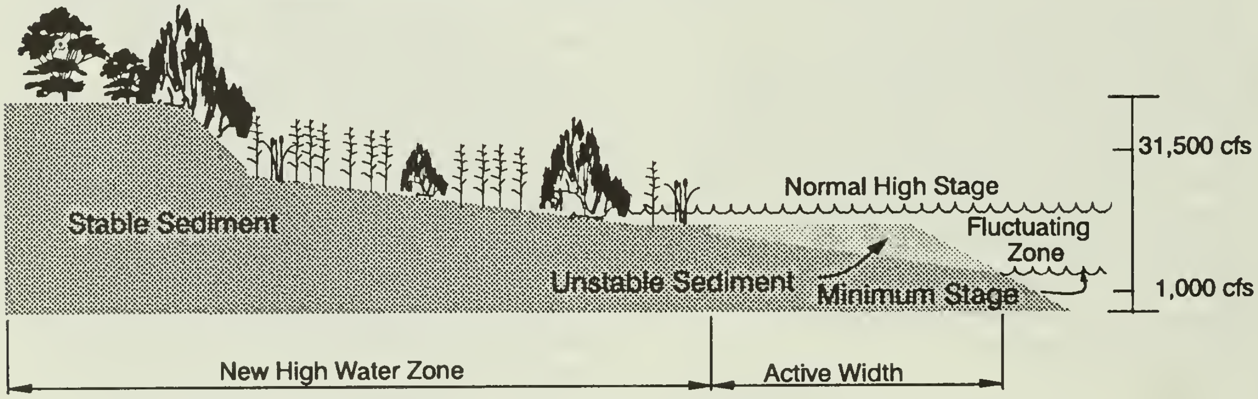


Figure IV-13.—Reduced maximum flows would affect riparian vegetation in the NHWZ by reducing the width of unstable sandbars and, thus, increasing the area of stable deposits available for plant development. In general, mesquite occupies the upper, dryer elevations with other plants occupying sites closer to the high flow stage (a). Tamarisk, willow, horsetail, and cattails also would develop on suitable sites exposed by reduced high flows (b).

The effects of habitat maintenance flows on riparian plants are speculative at this time and would be monitored closely. However, the following pattern appears reasonable based on plant responses after the 1983-86 high flows. Extensive plant burial may result from the first few maintenance flows. Plants that survive burial will grow up through new deposits and contribute to an increase in area of riparian vegetation. In time, some level of stability would develop so that plants would no longer be affected by burial.

An estimate of the maximum effect of maintenance flows, based on active width of unstable sandbars, is presented. However, it is assumed that maintenance flows would not affect the area of vegetation to the degree indicated by active width analyses. Thus, for alternatives with maintenance flows, the future area of woody riparian plants is assumed to reach some level between estimates of stabilized sandbar widths before and following such flows.

Beach/habitat-building flows would be an important element of all alternatives except the

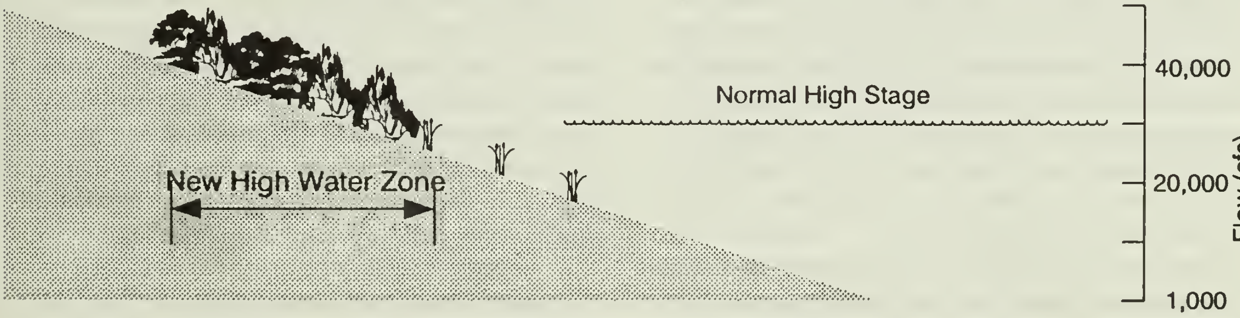
Maximum Powerplant Capacity and the No Action Alternatives. For vegetation, the magnitude and duration of these flows are important considerations. To meet the above objectives for riparian vegetation, flows would have to be high enough (at least 40,500 cfs) to deliver water to the entire new high water zone (NHWZ).

Discharges delivering water to stage elevations equivalent to 40,500 cfs or greater would affect vegetation in at least three ways. First, such flows periodically would provide water to riparian plants in the NHWZ. Second, depending upon stage and duration, beach/habitat-building flows may eliminate some plants, such as mesquite and acacia, that establish in the upper elevations of the NHWZ but cannot tolerate extended inundation. Finally, some burial of plants would occur with effects that would largely depend on the species (see chapter III, VEGETATION).

Under the restricted fluctuating and steady flow alternatives, periodic beach/habitat-building flows would disrupt the level of stability that would develop between sediment, plants, and habitat maintenance flows. A new level of stability would become established following a beach/habitat-building flow and continue until the next high flow.

The NHWZ vegetation that developed in the short term would occupy the same area and have basically the same species composition in the long term (figure IV-14). In the long term, it is assumed that stage reduction would affect woody riparian plants in the upper elevations of the NHWZ through a replacement of tamarisk, willow, and other plants by mesquite and other plants requiring less moisture. The abundance of mesquite and other plants would be influenced by beach/habitat-building flows.

a. Postdam and Future Conditions Under No Action



b. Long-Term Effects of Restricted Fluctuating and Steady Flows

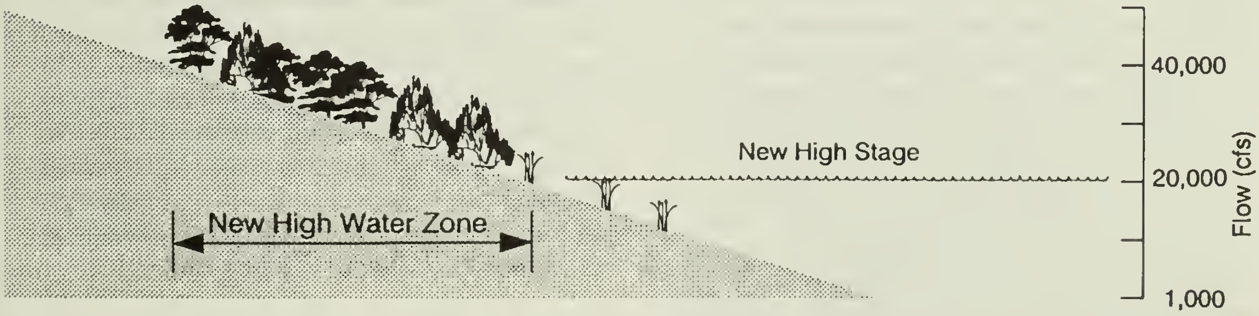


Figure IV-14.— Area coverage of woody plants would increase under alternatives with reduced maximum flows, and species composition would stabilize into similar patterns in the long term.

All alternatives except the No Action and Maximum Powerplant Capacity Alternatives include flood frequency reduction measures. Effects on the old high water zone (OHWZ) associated with reduced flood frequency are assumed to be identical for all alternatives and are discussed here rather than under each alternative.

Recruitment (addition of young plants to the population) in the OHWZ is assumed to require conditions historically created by periodic flooding. Without flooding, young plants would not be added to the OHWZ and, thus, would not be available to replace mature plants as they die. Future major flood events are expected to be so far apart that any differences in flood frequencies between alternatives would not be detected during the long-term period of analyses. Thus, for the purposes of analysis, all alternatives are assumed to contribute equally to the decline of vegetation in the OHWZ.

Because many plant species in the OHWZ are long-lived, changes would be difficult to detect during both the short- or long-term periods of analyses. A more noticeable change would be the continuing establishment of honey mesquite and other species from the OHWZ into the upper (dryer) elevations of the NHWZ. These species would be important components of the riparian zone that develops under any alternative.

It is assumed that at some future time, one or more major uncontrolled floods would occur. In this analysis, a major flood is assumed to occur after 50 years for alternatives with flood frequency reduction measures. For the No Action and Maximum Powerplant Capacity Alternatives, at least one major flood event is assumed to occur between 20 and 50 years following implementation. A flood occurring early in the long-term period of analysis would give vegetation up to 30 years to recover, while a flood later in the period would permit less time for recovery. Although the timing of a flood event cannot be predicted, for these two alternatives it is assumed that enough time would be available between a major flood and the end of the long-term period of analyses for vegetation to recover to a level similar to baseline conditions.

Although the magnitude and duration of a major flood event cannot be predicted, the effects on downstream vegetation are expected to be similar to those described in chapter III. Major (discharges above 45,000 cfs), uncontrolled (lasting longer than 1 month) floods return riparian zones to earlier successional stages. In general, vegetation initially would be lost (up to 50 percent at some sites in 1983) through scouring, drowning, or burial beneath sediment. After flood waters recede, sediment redistributed by floodflows would be available for plant expansion. Since vegetation returned to 75 percent of 1982 levels in less than 10 years (Stevens and Ayers, 1993), it is assumed that riparian vegetation would return to preflood conditions within 10 to 15 years.

Effects of uncontrolled flood releases are independent of daily dam operations and would be similar to effects described in chapter III, regardless of future dam operations. Because of the assumed similarity in effects between historic and future floods, uncontrolled floods are not addressed under each alternative. This lack of treatment, however, should not be interpreted as a statement on the lack of importance of uncontrolled floods in the dynamics of riparian plant communities. Rather, the effects of uncontrolled floods on riparian vegetation are much more important than any pattern of daily or annual dam operations under consideration.

It is assumed that water levels in Lakes Powell and Mead would rise during the short-term period of analyses and approach or reach full reservoir capacities. Lake levels are assumed to depend on regional water supply, which is dictated by climatic conditions. Rising lake levels would affect riparian vegetation that has developed during several years of low lake levels following the high flow years of 1983-86. As the lakes fill, riparian vegetation would be inundated and its nutrients recycled into the aquatic system. With another dry cycle, lake levels would recede and riparian vegetation would again increase.

The effects of changing lake levels on riparian vegetation are assumed to be similar under different dam operations and are discussed here and not under each alternative. Plants develop on delta deposits that are exposed during prolonged periods of low reservoir levels (see discussion of deltas under SEDIMENT in chapters III and IV). Cycles of low reservoir levels followed by full reservoir levels would continue into the long term. Vegetation would flourish during low reservoir periods. As the reservoirs fill, vegetation would be inundated and disappear, and nutrients would be recycled into each lake's aquatic system.

As lake levels inundate vegetation, the presence of plants causes additional sediment to aggrade deltas. Major flood events would enhance aggradation by permitting higher flows to build higher deposits. At some point in delta formation, high floodflows would aggrade sediment deposits behind the delta crest to an elevation above full reservoir water levels. Deposits located above full reservoir levels would become permanently vegetated after floodwaters recede.

The time required for delta aggradation above full reservoir levels is unknown but is assumed to be longer than 50 years. Therefore, riparian plants supported by Lakes Powell and Mead will tend to increase area coverage under all alternatives. However, it should be noted that during this long-term trend of increasing vegetation, riparian plants will disappear periodically during the processes of delta formation.

One of the proposed flood frequency reduction measures would raise the spillway gates at Glen Canyon Dam an additional 4.5 feet, increasing Lake Powell's potential surface acres by 2 percent. If implemented and ultimately used, this measure could result in infrequent and temporary flooding of riparian vegetation currently above Lake Powell's full pool elevation of 3700 feet. If such temporary flooding occurred, it would cause no adverse affects to plants; short-term inundation may even benefit these riparian plant communities.

Emergent Marsh Plants

Short-term responses of emergent marsh vegetation to certain common elements of the proposed alternatives are difficult to predict. Under baseline (no action) conditions, 95 percent of wet marsh vegetation would exist in a fluctuating flow zone between stages equivalent to 10,000 and 20,000 cfs. Elements such as flood frequency reduction measures, reduced maximum flows, habitat maintenance flows, and beach/habitat-building flows would create quite different conditions under some alternatives.

Reduced flood frequency and reduced maximum daily and/or seasonal flows would create dryer conditions for some patches of emergent marsh plants that historically have been supported by regular patterns of inundation. However, plants such as cattails can persist without inundation for extended periods—perhaps years. Although some patches would no longer have surface water, it is assumed that their presence would be maintained by habitat maintenance flows and beach/habitat-building flows in the short term (figure IV-13a).

Patches of marsh plants that lose their regular water supply would become dryer (figure 13b). While marsh plants would persist in such sites, woody plants would dominate, and wildlife use (see chapter IV, WILDLIFE AND HABITAT) would change. To help readers evaluate changes among baseline patches of marsh plants under each alternative, an analysis of the percent of change in maximum flow is compared to no action conditions. Since no relationship has been established between change in flow and change in area of marsh plants, the magnitude of these changes is unknown and assumed similar among alternatives.

Reduced flows would create additional sites at lower elevations suitable for establishment of patches of marsh plants. The exact total area of emergent marsh vegetation that would develop cannot be predicted because the area suitable for marsh plants (sites providing both water and appropriate soil/nutrient composition) is unknown. The response of vegetation to the interim flows implemented in 1991 indicates that marsh plants will rapidly develop in suitable sites exposed at lower elevations. No data exists to indicate that either fluctuating or steady flow patterns would support more or fewer additional areas of marsh plants, and the total area of marsh plants is assumed to be similar among alternatives.

Two alternatives—seasonally adjusted and year-round steady flows—would affect water levels in Lakes Powell and Mead seasonally in any water year. Elevation changes for both lakes would be within historic average annual fluctuations, with generally lower high elevations and higher low elevations for Lake Powell and higher water levels during the growing season for Lake Mead. Any differences in annual responses between these alternatives and others would be overridden by the cyclic effects of regional weather patterns as described above.

Summary of Impacts: Vegetation

Alternative operations of Glen Canyon Dam would affect riparian vegetation within the river corridor in several different ways during the short-term (5 to 20 years) period of analyses. First, reduced frequency of major uncontrolled flood releases would result in an unknown, but assumed equal, decline in area coverage of vegetation in the OHWZ under all alternatives. Some species found in the OHWZ would expand into the NHWZ to become an important part of this plant community. The OHWZ may disappear as a distinct zone of vegetation sometime in the distant future beyond 50 years.

Second, because of higher maximum flows than no action, the Maximum Powerplant Capacity Alternative would result in reduced area of riparian vegetation in the NHWZ.

Third, the No Action and High Fluctuating Flow Alternatives would affect riparian vegetation similarly because of their identical maximum discharges (31,500 cfs). Woody plants within the NHWZ would be maintained within stage boundaries equivalent to flows between about 22,000 and 40,500 cfs. Species composition would continue to develop toward an undefined equilibrium. Periodic inundation, in patterns similar to existing conditions, would permit continued maintenance of emergent marsh vegetation at sites currently occupied (stage elevations equivalent to 10,000 to 31,500-cfs flows).

The Moderate, Modified Low, and Interim Low Fluctuating Flow Alternatives, and the Existing Monthly Volume, Seasonally Adjusted, and Year-Round Steady Flow Alternatives would permit riparian vegetation to expand into sites created by reduced maximum flows (table IV-10). Area coverage of woody plants in the NHWZ would increase (figure IV-13). Some new establishment of emergent marsh plants would occur at the mouths of return-current channels and other suitable sites. Patches of emergent marsh plants that lose their water supply would be dominated by woody plants.

The Moderate and Modified Low Fluctuating Flow Alternatives and the Seasonally Adjusted Steady Flow Alternative include habitat maintenance flows. Maintenance flows are assumed to affect the area available for vegetation, but the magnitude of effect is unknown. The boundaries of potential area change, based on active width of unstable sandbars, are presented in table IV-10. It is assumed that the actual area change in woody vegetation would occur between these two estimates.

Initially, endangered fish research flows would be included in the Modified Low Fluctuating Flow Alternative during minimum release years. The extent to which steady flows would be permanently incorporated would depend on evaluation of the research results. Because these 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 table of impacts. Endangered fish research flows (when they occur) would have impacts on vegetation that fall within the range of impacts between the Modified Low Fluctuating and Seasonally Adjusted Steady Flow Alternatives.

Species composition of woody plants in the NHWZ would change during the short term under alternatives with lower maximum flows. New areas of sediment would be exposed and, thus, available for plant growth. Species that can reproduce by way of subsurface tubers or runners would have an advantage. Coyote willow, arrowweed, camelthorn, and other plants have expanded over beaches since the high flows of

Table IV-10.—Summary of anticipated impacts on VEGETATION during the short-term period of analysis by alternative

VEGETATION	No Action	Maximum Powerplant Capacity	High Fluctuating Flow	Moderate Fluctuating Flow	Modified Low Fluctuating Flow[3]	Interim Low Fluctuating Flow	Existing Monthly Volume Steady Flow	Seasonally Adjusted Steady Flow	Year-Round Steady Flow
Woody plants (area)									
Old high water zone	Undetermined reduction	Same as no action	Same as no action	Same as no action	Same as no action	Same as no action	Same as no action	Same as no action	Same as no action
New high water zone[1]	No net change	0 to 9% reduction	Same as no action	23 to 40% increase	30 to 47% increase	30 to 47% increase	45 to 65% increase	38 to 58% increase	63 to 94% increase
With habitat maintenance flows				0 to 12% increase	0 to 12% increase			0 to 12% increase	
Species composition	Tamarisk and others dominate	Tamarisk and others dominate	Tamarisk, coyote willow, arrowweed, camelthorn dominate	Tamarisk, coyote willow, arrowweed, camelthorn dominate	Tamarisk, coyote willow, arrowweed, camelthorn dominate	Tamarisk, coyote willow, arrowweed, camelthorn dominate	Tamarisk, coyote willow, arrowweed, camelthorn dominate	Tamarisk, coyote willow, arrowweed, camelthorn dominate	Tamarisk, coyote willow, arrowweed, camelthorn dominate
Emergent marsh plants New high water zone Change in maximum stage[2]	No net change	5% increase	Same as no action	29% decrease	37% decrease	37% decrease	48% decrease	43% decrease	64% decrease
Lake woody and emergent marsh plants (area)	Undetermined increase	Same as no action	Same as no action	Same as no action	Same as no action	Same as no action	Same as no action	Same as no action	Same as no action

[1] Potential area change based on change in width of unstable sandbars as compared to no action conditions. Percent changes are useful for relative comparisons among alternatives in that not all area made available would be suitable for plant growth. No relationship exists between percent changes in sandbar stability and existing area coverage of vegetation in new high water zone.

[2] Potential effects are based on change in maximum stage as compared to 31,500 cfs. Percent changes should be used only as relative comparisons among alternatives and are not estimates of future area change. Area coverage of emergent marsh vegetation under the various alternatives cannot be predicted but would likely be similar, and new patches of marsh plants would establish at the maximum discharge stage.

[3] Impacts of endangered fish research flows (during years when they occur) would be within the range of impacts described for the Modified Low Fluctuating (without these research flows) and Seasonally Adjusted Steady Flow Alternatives.

1983-86, and this trend would continue on sediment exposed by reduced flows.

Finally, beach/habitat-building flows would periodically water riparian vegetation in the NHWZ and flush out clay/silt sediment that would tend to accumulate in return-current channels in the short term.

In the long term (20 to 50 years), differences among alternatives would continue to develop. First, the No Action and Maximum Powerplant Capacity Alternatives are assumed to include at least one major flood event. Riparian vegetation would be set back to an earlier successional stage. However, woody and emergent marsh plants would recover postflood to a level comparable to baseline conditions.

The remaining action alternatives include flood frequency reduction measures throughout the long-term period of analyses. This protection would permit riparian development to follow trends begun in the short term. Habitat maintenance and beach/habitat-building flows would maintain woody and emergent marsh plants that would develop during the short term. All alternatives with flood protection would support increases in coverage of woody plants at the end of the long-term period of analyses (figure IV-14). Dryer conditions in the upper elevations of the NHWZ would shift species composition from tamarisk and willow to mesquite and other plants. Tamarisk, willow, and other plants would be favored downslope at wetter sites.

Finally, riparian vegetation supported by Lakes Powell and Mead would increase in area coverage by an unknown but assumed equal amount under all alternatives. Delta formation processes would support this long-term trend by periodically inundating and killing plants and would eventually result in permanently vegetated sediment deposits above full reservoir levels. These events would occur beyond the 50-year period of analyses.

Unrestricted Fluctuating Flows

No Action Alternative

Analyses of effects to riparian vegetation under no action conditions in the short term basically project existing trends. In the long term, it is assumed that at least one major uncontrolled flood event would affect riparian vegetation.

Woody Plants. Vegetation within the NHWZ is expected to continue to develop as described under existing conditions (see chapter III, VEGETATION) and would occupy the same sites at stage elevations equivalent to flows between 22,000 to 40,500 cfs. However, without flood control, riparian plant development would recycle following a major uncontrolled flood event. The effects on riparian vegetation from a major flood event are assumed to be similar to those reported by Stevens and Waring (1986) following the 1983 floodflows.

Because timing cannot be predicted, a flood event was assumed in the long term. This time span would permit vegetation to recover to a level similar or identical to baseline conditions. A flood event late in the analysis period would permit less recovery and, therefore, would mean a larger difference between no action conditions and the action alternatives with flood protection.

The composition of woody plants within the riparian corridor (exclusive of the OHWZ) would follow trends described in chapter III, with coyote willow, arrowweed, honey mesquite, and other species increasing in abundance.

Emergent Marsh Plants. Under the No Action Alternative, dry marsh plants would continue to expand into remaining sites suitable for their germination and growth. Thus, patches of dry marsh vegetation initially would increase in both numbers of patches and coverage until all suitable sites are occupied. Concurrently, but at a slower rate, woody vegetation would continue to expand into suitable sites. Patches of dry marsh plants on higher sites in the NHWZ would be susceptible to woody plant expansion. As shading from woody plants increases, emergent marsh plants would be eliminated. Thus, until a major uncontrolled flood event occurs, dry marsh vegetation may gradually decline by an unknown number of patches and area coverage.

Wet marsh species such as cattails and rushes have expanded into most of the suitable sites under historic conditions; any future expansion would be expected in area coverage at existing patches of wet marsh vegetation. Fluctuating flows would continue to carry sediment into return-current channels and other sites where lower water velocities permit deposition. With time (and without a major flood event or beach/habitat-building flows) these sites would fill with sediment and permit expansion of woody vegetation into them.

As with woody vegetation, it is assumed that a future major flood would greatly reduce existing patches of both dry and wet marsh vegetation before they are replaced by woody plants. However, timing of the assumed flood would permit recovery of emergent marsh plants, by the end of 50 years, to levels comparable to baseline conditions. Dry and wet marsh plants are combined here and in subsequent analyses as emergent marsh plants.

Maximum Powerplant Capacity Alternative

Because maximum flows under this alternative are higher than those under no action, the area occupied by **woody plants** would be reduced in some reaches. An area of beach up to 5 feet wide (or 0 to 9 percent of the width of unstable sandbars under no action) would become active and unstable in some reaches under this alternative; other reaches would experience no measurable changes. It is assumed that vegetation occupying unstable sites would be lost through erosion.

Under this alternative, an area between stages equivalent to 31,500 and 33,200 cfs would be inundated periodically—a 5-percent increase in maximum flow over no action. Although patches of **emergent marsh plants** are limited above the 31,500-cfs stage, they may be affected by this alternative.

No beach/habitat-building flows would occur under this alternative. As with woody vegetation, it is assumed that a major flood would greatly reduce existing patches of marsh plants before they are replaced by woody plants. However, timing of the assumed flood would permit recovery of emergent marsh vegetation, by the end of 50 years, to levels comparable to no action conditions.

Restricted Fluctuating Flows

Daily flow fluctuations would affect vegetation through two processes:

- Deposition and erosion of sediments serving as substrate
- Changes in river stage

The effects of alternative operations discussed below are presented in terms of the flow patterns anticipated during a minimum release year (8.23 maf). Based on historic data, minimum release years would occur about 40 to 50 percent of the time. During moderate or high water years, total area coverage of riparian vegetation may be reduced. Under a fluctuating release pattern, riparian vegetation under the Moderate, Modified Low, and Interim Low Fluctuating Flow Alternatives would be affected by higher water volumes because of increases in maximum stages. Higher flows would tend to shift conditions toward those under the No Action Alternative. The amount of reduction would depend upon the magnitude and frequency of high discharges and subsequent deviation from the patterns described below.

High Fluctuating Flow Alternative

The area available for expansion of **woody plants** (as represented by the difference between unstable bar width for no action and this alternative) would be the same as under no action throughout the 11 river reaches in the study area.

Because of flood control measures, plant species composition in the NHWZ would be somewhat different than under no action. Tamarisk would be concentrated near the maximum discharge stage, with honey mesquite and other native species occupying higher NHWZ elevations. Coyote willow and arrowweed would occupy sandy sites. **Emergent marsh plants** would continue to occupy current sites or expand in the short term.

Beach/habitat-building flows would maintain the above pattern. Depending on the timing of these flows, either tamarisk, native plants, or both would germinate on suitable wetted sites. With a return to normal flow patterns, native plants would dominate. New sites suitable for emergent marsh plants would be maintained or created in the short term.

Moderate Fluctuating Flow Alternative

Habitat maintenance flows under this alternative would affect **woody plants** to an unknown degree. The area available for plant expansion would approach, but be less than, the area available for expansion under identical flow patterns that do not have annual maintenance flows. Three considerations are involved in this prediction.

First, without modifications from maintenance flows, the potential maximum area available for expansion by woody plants on stabilized sandbars in each river reach would increase an average of 15 to 26 feet (23 to 40 percent) over no action.

Second, sediment transported by maintenance flows initially would bury some vegetation to an unknown extent. However, the maximum estimate is that all areas up to an elevation equivalent to the 30,000-cfs stage could be affected. Those areas unaffected by maintenance flows would average (by river reach) a 0- to 5-foot increase (0 to 12 percent) over no action conditions. It is assumed that not all vegetation would be buried.

Finally, species that tolerate burial would eventually grow through new deposits and join those plants that are not buried to expand the areas of woody plants. The relationships between discharge, sediment, and woody plants would probably require several years to stabilize to the point where plants are no longer buried by maintenance flows.

Vegetation within the NHWZ would be affected by reductions both in active width of sandbars and maximum stage under this alternative. A zone between 22,300 and 31,500 cfs would no longer be regularly inundated during minimum release years, except during maintenance flows. Coupled with flood control, this would result in dryer conditions dictating plant species composition in the NHWZ. Young tamarisk would be concentrated near the 22,300-cfs stage. Coyote willow, arrowweed, and other species would expand from higher elevations in the NHWZ to suitable sites at lower elevations. Willow and arrowweed would continue to expand on high sand deposits.

Emergent marsh plants initially would occupy historic sites and expand into suitable sites created by lower maximum flows. Patches above the stage equivalent to 22,300 cfs would no longer be subject to frequent inundation. These sites would be dry and eventually would fill with sediment transported by habitat maintenance flows. A 29-percent reduction in maximum stage would create or make available additional marsh plant sites. All of these additional sites may equal the area of emergent marsh plants under no action conditions.

Habitat maintenance flows would support this plant pattern until some other flow regime occurs. The higher discharges of periodic beach/habitat-building flows would likely disrupt any stability that would develop among sediment, plants, and maintenance flows. After a beach/habitat building flow, a new level of stability would become established and continue until the next high flow event. It is assumed that beach/habitat-building flows would also restructure return-current channels important for marsh plants below the 20,000-cfs stage.

Modified Low Fluctuating Flow Alternative

Habitat maintenance flows under this alternative would result in effects on **woody plants** similar to those discussed under the Moderate Fluctuating Flow Alternative. The area available for woody plant expansion would be between the potential maximum area of stabilized sandbars—21 to 31 feet (30 to 47 percent) over no action—and the area of sandbars unaffected by maintenance flows—0 to 5 feet (0 to 12 percent) over no action. The increase in woody plants would likely approach, but be less than, the potential maximum area of stabilized sandbars under this alternative.

A zone between 20,000 and 31,500 cfs would no longer be inundated during minimum release years, except during habitat maintenance flows. This change, along with flood control, would result in dryer conditions that would dictate plant species composition in the NHWZ. These changes in species composition would be similar to those discussed under the Moderate Fluctuating Flow Alternative.

Emergent marsh plants would respond to changes in discharge similarly to the Moderate Fluctuating Flow Alternative. Patches above the stage equivalent to 20,000 cfs would no longer be subject to frequent inundation. A 37-percent reduction in maximum stage would create or make available additional marsh plant sites. These additional sites may equal the area of emergent marsh plants under no action conditions.

Habitat maintenance flows would support this plant pattern until disrupted by a beach/habitat-building flow as discussed under the Moderate Fluctuating Flow Alternative. After a beach/habitat-building flow, a new level of stability would develop among sediment, riparian vegetation, and maintenance flows.

In years when they occur, endangered fish research flows would have impacts on vegetation that fall within the range of impacts between this alternative and the Seasonally Adjusted Steady Flow Alternative.

Interim Low Fluctuating Flow Alternative

The assumed area available for expansion by **woody plants** in the short term represents an increase of 21 to 31 feet (30 to 47 percent) over no action. Also, a zone between 20,000 and 31,500 cfs would no longer be inundated by fluctuating flows during minimum release years. Young tamarisk would be concentrated near the 20,000-cfs stage. Coyote willow, arrowweed, and other species would expand from higher elevations in the NHWZ to suitable sites at lower elevations. Willow and arrowweed would continue to expand on high sand deposits.

Emergent marsh plants would continue to occupy historic sites and expand into suitable sites created by lower maximum flows. Patches above the stage equivalent to 20,000 cfs would no longer be subject to frequent inundation. Although these sites would be dry, their plant structure would be maintained by periodic beach/habitat-building flows. A 37-percent reduction in maximum stage would create or make available additional sites suitable for marsh plants. These additional sites, plus those sites maintained by beach/habitat-building flows, would result in an increase in patches of emergent marsh plants. This prediction is consistent with plant responses to conditions created by interim flows.

Beach/habitat-building flows would maintain this plant pattern in the short term. While such flows could be timed to coincide with seed release of several different plants, it is assumed that tamarisk would be the dominant colonizer on suitable sites made available by reduced flows. However, based on observations since the 1983-86 floodflows, native plants would quickly become established and even have an advantage at newly deposited sand beaches. Beach/habitat-building flows would also maintain return-current channels important for marsh plants below the 20,000-cfs stage.

Steady Flows

The effects of steady releases on the indicators of vegetation resources would depend on stage and duration of flows. Stages lower than historic conditions would encourage expansion of woody plants into suitable sites at lower elevations.

Future responses of emergent marsh plants to steady flows are unknown. Lower maximum stages would dry out patches of wet emergent marsh plants while higher steady flows for extended periods may result in scouring or drowning of some plants. However, the following analyses are based on the same assumptions applied to all alternatives with reduced maximum stages. These assumptions, plus beach/habitat-building flows (and habitat maintenance flows under the Seasonally Adjusted Steady Flow Alternative), indicate area coverage of marsh plants would increase—as is predicted for the restricted fluctuating flow alternatives.

During moderate and high water years, the release patterns identified for steady flow alternatives could not be maintained. The Seasonally Adjusted Steady and Year-Round Steady Flow Alternatives would resemble the Existing Monthly Volume Steady Flow Alternative as releases increased. In high release years, all three steady flow alternatives would have high steady flows for extended periods, with a reduction in riparian vegetation from scouring and drowning.

In the long term, alternatives with reduced maximum flows would exhibit shifts in location of riparian plants in the NHWZ, including both replacement by plants requiring less moisture in higher elevations and expansion into suitable sites at lower elevations. These changes have been described for fluctuating flows and are assumed to be equally applicable to steady flow alternatives.

Existing Monthly Volume Steady Flow Alternative

Vegetation in the NHWZ would be affected by both a reduction in active width of sandbars and a reduction in maximum stage under conditions of this alternative. The area available for expansion by **woody plants** represents an average increase of 26 to 41 feet (45 to 65 percent) over no action conditions.

A zone between about 16,300 and 31,500 cfs would no longer be periodically inundated by fluctuating flows. Tamarisk would be concentrated near the 16,300-cfs stage. Honey mesquite and other species would expand from higher elevations into the NHWZ, and coyote willow and arrowweed would occupy sandy sites.

Under this alternative, **emergent marsh plants** would be subjected to steady flows that varied monthly. Marsh plants above the 16,300-cfs stage would lose their water supply. Any potential losses linked to conditions described above would be offset by a 48-percent reduction in maximum stage. Reduced stage would create or make available additional sites suitable for marsh plant development. These additional sites, plus those sites maintained by beach/habitat-building flows, would result in increased patches of emergent marsh plants.

Seasonally Adjusted Steady Flow Alternative

Habitat maintenance flows under this alternative would result in effects on **woody plants** similar to those discussed under the Moderate Fluctuating Flow Alternative. In the 11 river reaches, the area available for this expansion would be between the maximum area of stabilized sandbars—26 to 36 feet (38 to 58 percent) over no action, and the area of sandbars unaffected by maintenance flows—0 to 5 feet (0 to 12 percent) over no action. The increase in woody plants would likely approach, but be less than, the potential maximum area of stabilized sandbars under this alternative.

An area between 18,000 and 31,500 cfs would no longer be regularly inundated, except during annual habitat maintenance flows. This reduction in maximum stage, together with flood control, would result in dryer conditions dictating plant species composition in the NHWZ. Tamarisk would be concentrated near the 18,000-cfs stage. Honey mesquite and other species would expand from higher elevations into the NHWZ. Coyote willow and arrowweed would occupy sandy sites.

Under this alternative, **emergent marsh plants** would either completely lose their water supply for 5 months (8,000-cfs flows), be partially inundated for 5 months, or completely inundated for 2 months (along with a 1- to 2-week period of inundation to 30,000 cfs during maintenance flows). The responses of patches of marsh plants to this variable water regime are difficult to predict. For example, some patches would experience inundation in May and June (a critical growth period), while drying would occur in August through December. However, it is assumed that any potential losses linked to conditions described above would be offset by a 43-percent reduction in maximum stage. Reduced stage would create or make available additional sites suitable for marsh plant development. These additional sites may equal the area of emergent marsh plants under no action.

It is assumed that stage reduction would affect woody riparian plants as described above for the long-term period of analyses. The abundance of mesquite and other plants would be influenced by beach/habitat-building flows. The NHWZ would maintain the increase in overall area coverage described for the short term.

Year-Round Steady Flow Alternative

The area available for expansion by **woody plants** represents an average increase of 36 to 57 feet (63 to 94 percent) over no action. During a minimum release year, a zone between 11,400 and 31,500 cfs would no longer be inundated by fluctuating discharges. Such changes are quite different from the No Action Alternative (figure IV-15). Changes in woody plant species composition are assumed to be similar or identical to those predicted under the Seasonally Adjusted and Existing Monthly Volume Steady Flow Alternatives.

A reduction in maximum discharge would affect area coverage of **emergent marsh plants**. Any marsh plants below the 11,400-cfs stage would be permanently inundated and presumed lost. These

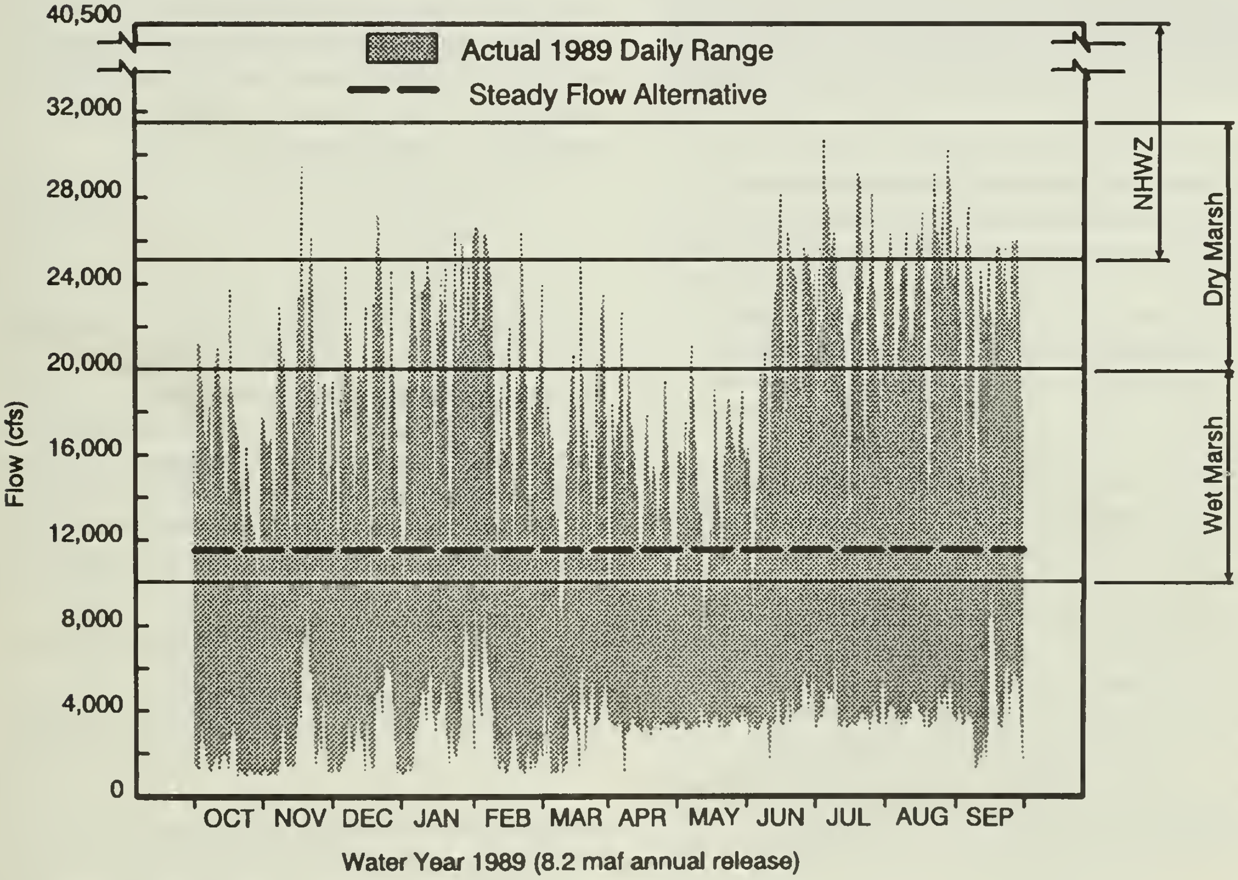


Figure IV-15.—Because of reduced maximum flows under some alternatives, area coverage of woody plants in the new high water zone would increase. The potential for increase is greatest under the Year-Round Steady Flow Alternative.

potential losses would be offset by a 64-percent reduction in maximum stage. Reduced stage would create or make available additional sites suitable for marsh plant development. These additional sites, plus those sites maintained by beach/habitat-building flows, would result in increased patches of emergent marsh plants.

WILDLIFE AND HABITAT

Issue:

How do flows affect area WILDLIFE AND their HABITAT?

Indicators:

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

This section addresses the effects of alternatives on terrestrial wildlife other than special status species. Very little wildlife population data exists for either the predam or postdam habitats found along the river corridor. However, it is assumed that almost all wildlife concerns can be addressed by considering the effects on wildlife habitat as represented by riparian vegetation.

Many species use woody plants directly as nest sites or cover or, in the case of beaver and others, use some plants as food. Other species, such as waterfowl, nest in emergent marsh plants and other suitable sites. Riparian vegetation also provides cover for insects important as food for mammals, birds, and amphibians and reptiles (herpetofauna). Therefore, no specific analyses of impacts on individual wildlife species were conducted for each alternative. Instead, it is assumed that changes in area coverage of riparian vegetation are directly linked to changes in riparian wildlife habitat.

One notable wildlife resource does not fit the above pattern. Waterfowl are attracted in winter to the Colorado River below Glen Canyon Dam by open water and the food it provides. While various species feed on different foods, it is assumed that *Cladophora* can be used as an index of food availability for wintering waterfowl. *Cladophora* and associated diatoms serve as food as well as cover for macroinvertebrates such as *Gammarus*, chironomid and simuliid larva, and others. Like the analyses presented in the FISH section, *Cladophora* is used here as an indicator of the aquatic food base available to wintering waterfowl.

This analysis of riparian habitat, as based on riparian vegetation, generally is limited to the river corridor between the dam and Separation Canyon (although only data to Diamond Creek are available). It is assumed that dam operations affect vegetation and, in turn, habitat through two processes—the dynamics of beach aggradation and degradation and prolonged change in river stage (see chapter IV, WATER, SEDIMENT, and VEGETATION). Together, these processes are reflected as changes in area coverage of woody plants and, to a lesser degree, changes in species composition. These changes affect habitat suitability for area wildlife.

Analysis Methods

During the short-term period of analysis, it is assumed that changes in wildlife habitat would closely follow changes in riparian vegetation, which would follow changes in exposed sediment deposits resulting from daily water release patterns. Infrequent releases above the maximum flow identified for each alternative, habitat maintenance flows, and beach/habitat-building flows of unknown stage may occur in the short term. Additional impacts resulting from these sources are identified where appropriate. Daily dam operations also would affect food for wintering waterfowl during the short-term period of analysis.

Major uncontrolled flood events are expected under only two alternatives during the long-term period of analyses: the No Action and Maximum Powerplant Capacity Alternatives. Flood events would affect vegetation and, in turn, habitat in ways previously described (see chapter III, VEGETATION). Habitat and its value to wildlife would be reduced until replaced through natural succession of vegetation. Most wildlife populations are resilient and able to adapt to cycles of habitat abundance. However, a few species with small populations could experience adverse impacts from flood-related reductions in habitat. These species have special status and are treated in another section (see chapter IV, ENDANGERED AND OTHER SPECIAL STATUS SPECIES).

Woody and Emergent Marsh Plants

Changes in area of emergent marsh plants resulting from implementation of any of the alternatives would depend largely on changes in river stage and duration of flows. Most patches of marsh plants occur in the NHWZ and are maintained by a water release pattern that alternately floods and then exposes them. Changes in this pattern would result in changes in area coverage of marsh plants and the habitat value of these sites.

It is assumed that Lakes Powell and Mead would cycle through periods of low and high water levels during both the short- and long-term periods of analyses. As described under VEGETATION, riparian vegetation that develops during low lake level periods would be lost and develop again (recycle) as lake levels increase and then decrease. Vegetation supported by low lake levels is important habitat for many species, especially breeding birds. Increases and decreases in habitat area would depend on regional water conditions and are, therefore, independent of all alternatives.

Aquatic Food Base

Most wintering waterfowl use occurs in the upper reaches of the river, while *Cladophora* abundance generally is highest between the dam and Lees Ferry. Over 90 percent of the 2,780 waterfowl surveyed in January 1991 were observed between the dam and the LCR (Kline, written communication, 1992). Evaluation of effects on the aquatic food base is limited to wetted perimeter data from two sites: one near the dam and one near Lees Ferry (see chapter IV, FISH). Comparisons made from these data are useful in evaluating relative differences between no action and action alternatives.

The specific effects of a major flood event on *Cladophora* and the associated aquatic food base are unknown. It is reasonable to assume, however, that effects would not be irreversible, since the *Cladophora* population survived the high flows of 1983-86.

Summary of Impacts: Wildlife and Habitat

In general, individual animals would not be directly affected by daily operations of Glen Canyon Dam. For example, mammals, birds, herpetofauna, and invertebrates occupying or using riparian habitat generally are mobile and would move as required by daily fluctuations. Birds using the riparian zone as a travel lane through Grand Canyon would not be directly affected by any of the alternatives. However, those species that nest in riparian vegetation would be indirectly affected by changes in area coverage of plants. In the short term, woody and emergent marsh plant coverage, and therefore riparian habitat, would increase under most alternatives.

A summary of impacts on wildlife and habitat, based on impacts to either riparian vegetation or the aquatic food base, is presented in table IV-11.

Initially, endangered fish research flows would be included in the Modified Low Fluctuating Flow Alternative during minimum release years. The extent to which steady flows would be permanently incorporated would depend on evaluation of the research results. Because these 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 table of impacts. Endangered fish research flows (when they occur) would have impacts on wildlife and habitat that fall within the range of impacts between the Modified Low Fluctuating and Seasonally Adjusted Steady Flow Alternatives.

Table IV-11.—Anticipated impacts to (indicators of) WILDLIFE AND HABITAT during the period of short-term analysis by alternative

WILDLIFE AND HABITAT	No Action	Maximum Powerplant Capacity	High Fluctuating Flow	Moderate Fluctuating Flow	Modified Low Fluctuating Flow[3]	Interim Low Fluctuating Flow	Existing Monthly Volume Steady Flow	Seasonally Adjusted Steady Flow	Year-Round Steady Flow
Riparian habitat[1]									
Woody plants (area)									
Old high water zone	Undetermined reduction	Same as no action	Same as no action	Same as no action	Same as no action	Same as no action	Same as no action	Same as no action	Same as no action
New high water zone									
Sandbar stability	No net change	0 to 9% reduction	Same as no action	23 to 40% increase	30 to 47% increase	30 to 47% increase	45 to 65% increase	38 to 58% increase	63 to 94% increase
With habitat maintenance flows				0 to 12% increase	0 to 12% increase			0 to 12% increase	
Species composition	Tamarisk and others dominate	Tamarisk and others dominate	Tamarisk, coyote willow, arrowweed, camelthorn dominate	Tamarisk, coyote willow, arrowweed, camelthorn dominate	Tamarisk, coyote willow, arrowweed, camelthorn dominate	Tamarisk, coyote willow, arrowweed, camelthorn dominate	Tamarisk, coyote willow, arrowweed, camelthorn dominate	Tamarisk, coyote willow, arrowweed, camelthorn dominate	Tamarisk, coyote willow, arrowweed, camelthorn dominate
Emergent marsh plants									
New high water zone									
Change in maximum stage	No net change	5% increase	Same as no action	29% decrease	37% decrease	37% decrease	48% decrease	43% decrease	64% decrease
Woody and emergent marsh plants (area)									
Lakes Powell and Mead	Undetermined increase	Same as no action	Same as no action	Same as no action	Same as no action	Same as no action	Same as no action	Same as no action	Same as no action
Aquatic food base[2] (for wintering waterfowl)	Stable	Same as no action	Same as no action	Potential increase	Potential increase	Potential increase	Potential increase	Potential increase	Potential increase

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[1] See chapter IV, VEGETATION for a description of analysis assumptions.

[2] See chapter IV, FISH for a description of analysis assumptions.

[3] Impacts of endangered fish research flows (during years when they occur) would be within the range of impacts between the Modified Low Fluctuating (without these research flows) and Seasonally Adjusted Steady Flow Alternatives.

Alternative Glen Canyon Dam operations would affect riparian vegetation, and therefore habitat, in several different ways during the short-term (5 to 20 years) period of analyses (see VEGETATION). Briefly, all alternatives would contribute to the gradual decline of the OHWZ. Two alternatives would maintain the existing riparian vegetation area, while only the Maximum Powerplant Capacity Alternative would create conditions leading to a decline in habitat area. The remaining alternatives would permit riparian vegetation to expand, in differing amounts, into sites created by reduced maximum flows.

Although no data are available on habitat patch size along the river corridor, it is assumed that as area of riparian vegetation increases so too will habitat and patch size. The ecological value of habitat to wildlife is, in part, also related to the patch size of a vegetated area. In order for a patch of habitat to be valuable to mammals, breeding birds, or herpetofauna, it must be large enough to provide adequate food resources and shelter. For example, larger patch sizes are likely to have a greater number of bird species present. Wilson and Carothers (1979) tested this hypothesis in Grand Canyon and determined that as habitat patch size decreased, bird species diversity and density were similarly reduced. As patch size increased, additional species were found to occur within the habitat.

An annual habitat maintenance flow is included in the Moderate and Modified Low Fluctuating Flow Alternatives and the Seasonally Adjusted Steady Flow Alternative in order to move and deposit sediment higher than would be possible under daily flow patterns. As discussed under VEGETATION (earlier in this chapter), some vegetation would be buried by initial maintenance flows, and thus its value as habitat reduced. Vegetation that is not buried or that grows up through new deposits would be unusable to area wildlife during the period of inundation.

In the long-term period of analyses (20 to 50 years), differences among alternatives would continue to develop. At least one major flood is assumed to occur under the No Action and Maximum Powerplant Capacity Alternatives. Succession of riparian vegetation would be set back to an earlier stage due to loss of plant coverage. However, it is assumed that woody and emergent marsh plants ultimately would recover to a level comparable to no action conditions.

The restricted fluctuating and steady flow alternatives include flood frequency reduction measures. This flood protection would permit riparian development following trends begun in the short term. All alternatives with flood control would support increases in woody plant coverage at the end of the long-term period of analysis.

Beach/habitat-building flows would continue to support existing and expanded coverage of riparian vegetation and changes in species composition initiated in the short term. Dryer conditions in the upper elevations of the NHWZ would favor a shift from tamarisk and willow to mesquite and other plants. Tamarisk, willow, and other plants would be favored downslope at wetter sites. Increases in area and diversity of plant species would mean increased habitat.

Wintering waterfowl would be affected by changes in minimum discharge. The No Action and Maximum Powerplant Capacity Alternatives have a minimum discharge of 1,000 cfs. The remaining alternatives increase minimums from 3,000 to 11,400 cfs. Increased minimum discharges, as well as brief high release periods during habitat maintenance and beach/habitat-building flows, are assumed to benefit the aquatic food base and ultimately wintering waterfowl.

Unrestricted Fluctuating Flows

No Action Alternative

Woody and Emergent Marsh Plants. The area of woody and emergent marsh plants, and thus riparian wildlife habitat, would remain similar to baseline conditions as described in chapter III.

Aquatic Food Base. *Cladophora*, representing the aquatic food base, is limited by minimum reliable flows. Under no action conditions, these flows would be 1,000 cfs, with a wetted perimeter of 580.3 feet near the sampling site at the dam and 380.4 feet at the site near Lees Ferry (see chapter IV, FISH).

Maximum Powerplant Capacity Alternative

Stage change and associated effects on **woody and emergent marsh plants** depend on local channel widths within the fluctuating zone, and thus differ among sites and reaches for the same riverflows. For each reach, an area of beach 0 to 5 feet wide (or 0 to 9 percent of the width of unstable sandbars under no action) would become active and unstable under this alternative. It is assumed that some vegetation, and thus habitat, at affected sites would be lost through erosion.

The Maximum Powerplant Capacity Alternative would have the same minimum flow as the No Action Alternative. Therefore, it is assumed that effects on the **aquatic food base** for wintering waterfowl would be identical to no action conditions.

Restricted Fluctuating Flows

Daily changes in discharge have both positive and negative affects on wildlife habitat. Alternatives with lower maximum discharges would make sites available for expansion of both woody and emergent marsh plants, and both would therefore increase in area. However, while patches of emergent marsh plants may be more abundant, many patches would no longer be inundated on a regular basis. Patches of emergent marsh plants above the maximum discharge stage would receive water only during periods of habitat maintenance and beach/habitat-building flows. These patches of vegetation would supply structural diversity to the vegetative community but would function as upland vegetation rather than as aquatic plants.

Sudden deviations from either fluctuating or steady flow patterns, as would occur during habitat maintenance and beach/habitat-building flows, could have temporary adverse effects on ground-dwelling, ground-nesting, and burrowing forms of wildlife including insects, reptiles, and small mammals.

High Fluctuating Flow Alternative

Impacts on riparian habitat, including **woody and emergent marsh plants**, would be similar to those under the No Action Alternative. The area of beach available for expansion of woody riparian plants would remain equal to no action conditions throughout the study area (see chapter IV, VEGETATION). Emergent marsh plants would continue to occupy historic sites or expand slightly in the short term. The wildlife species that use these plants would respond accordingly.

Increased minimum flows would mean benefits for the **aquatic food base** and, therefore, for wintering waterfowl. Increased minimum flows represent an additional 2,000 cfs of permanent inundation—a 1.5- (Lees Ferry) to 2.0-foot (near the dam) increase in stage and up to a 8.7-foot increase in wetted perimeter over no action.

Moderate Fluctuating Flow Alternative

Woody plants would expand into suitable sites made available by lower maximum flows. The exact extent of expansion is unknown because the relationships between sediment, riparian plants, and habitat maintenance flows are not defined at this time. As was discussed under the analysis of VEGETATION, it is assumed that the area available for woody plant expansion would approach, but be less than, the area available for expansion under identical flow patterns without annual maintenance flows. For this alternative, the upper range of beach widths available for expansion is 15 to 26 feet for the 11 river reaches (a 23- to 40-percent increase over no action conditions). The lower range, or those areas unaffected by maintenance flows, would average a 0- to 5-foot increase (0 to 12 percent) over no action conditions.

Emergent marsh plants would initially occupy historic sites and expand into suitable sites created by lower maximum flows. Patches of marsh plants above the 22,300-cfs stage would no longer be frequently inundated. These sites would be dry and would eventually fill with sediment. A 29-percent reduction in maximum stage would make additional marsh plants sites available.

Habitat maintenance flows would occur before most wildlife nesting activity. While high flows may temporarily displace some individual animals, maintenance flows would redistribute the sediment critical for riparian plant growth and thus benefit habitat.

Increased minimum flows to (5,000 cfs year-round) would translate into some benefits for the **aquatic food base** and, therefore, wintering waterfowl. Increased minimum flows represent about a 2.4-(Lees Ferry) to 3.5-foot (near the dam) increase in stage and up to a 14.1-foot increase in wetted perimeter.

Modified Low Fluctuating Flow Alternative

Effects on wildlife habitat and wintering waterfowl would be similar to those discussed under the Moderate Fluctuating Flow Alternative. First, the upper range of beach widths available for expansion of **woody plants** is 21 to 31 feet for the 11 river reaches (a 30- to 47-percent increase over no action conditions). The lower range, or those areas unaffected by maintenance flows, would average a 0- to 5-foot increase (0 to 12 percent) over no action conditions.

Second, patches of **emergent marsh plants** above the stage equivalent to 20,000 cfs would lose their source of abundant water, become dry, and eventually fill with sediment. A 37-percent reduction in maximum stage would create or make available additional sites suitable for marsh plants.

Although the daytime minimum low flow is 8,000 cfs under this alternative, it is assumed that the **aquatic food base** would be limited by the nighttime (and weekend) minimum of 5,000 cfs. This low represents a 4,000-cfs increase over no action conditions and is assumed to represent improved conditions for wintering waterfowl. This increase equates to a 2.4-foot (Lees Ferry) to 3.5-foot (near dam) increase in stage and up to a 14.1-foot increase in wetted perimeter. It is assumed that the 1- to 2-week habitat maintenance flow included in this alternative would not affect the aquatic food base or disturb wintering waterfowl.

In years when they occur, endangered fish research flows would have impacts on wildlife and habitat that fall within the range of impacts between this alternative and the Seasonally Adjusted Steady Flow Alternative.

Interim Low Fluctuating Flow Alternative

Habitat for some species would increase under this alternative as **woody plants** in the NHWZ colonize suitable beach sites down to the 20,000-cfs stage. The area of beach available for expansion of riparian habitat would average 21 to 31 feet, or a 30- to 47-percent increase over no action conditions.

A zone between 20,000 and 31,500 cfs would no longer be inundated by fluctuating flows during minimum release years. Combined with flood control, this would result in dryer conditions for NHWZ vegetation, and plants would expand into the fluctuating zone. Young tamarisk would be concentrated near the 20,000-cfs stage, while mesquite and other native species would continue to become established in upper elevations of the NHWZ.

Emergent marsh plants would continue to occupy postdam sites plus expand into suitable sites created by lower maximum flows. Patches above the 20,000-cfs stage would no longer be subject to frequent inundation. Although these sites would be dry, their plant structure would be maintained by periodic beach/habitat-building flows. A 37-percent reduction in maximum stage would create or make available additional sites suitable for marsh plants.

This alternative includes a daytime minimum of 8,000 cfs and a nightly minimum of 5,000 cfs. For purposes of analyses, the 5,000-cfs minimum is believed to limit *Cladophora* and the **aquatic food base** available to wintering waterfowl. Increased low flows represent an additional 4,000 cfs of permanent inundation over no action conditions. This increase represents a 2.4- (Lees Ferry) to 3.5-foot (near the dam) increase in stage and up to a 14.1-foot increase in wetted perimeter.

Steady Flows

The effects of steady flows on riparian vegetation and wildlife habitat would depend on stage and duration. Stages lower than no action conditions would permit expansion of riparian vegetation into suitable sites previously inundated in the fluctuating zone. Lower stages would remove water from emergent marsh plants, while higher steady flows could drown some plants.

Existing Monthly Volume Steady Flow Alternative

Area of riparian habitat for some species would increase under this alternative as **woody plants** in the NHWZ colonize suitable sites down to the 15,000-cfs stage. The area of beach available for expansion of woody riparian plants would range from 26 to 41 feet, or a 45- to 65-percent increase over no action conditions. A zone between about 16,300 and 31,500 cfs would no longer be inundated by fluctuating flows during minimum release years. Combined with flood control, this would result in dryer conditions for vegetation in the NHWZ. Young tamarisk would be concentrated near the 16,300-cfs stage, while mesquite and other native species would dominate the NHWZ.

Emergent marsh plants would continue to occupy postdam sites plus expand into suitable sites created by lower maximum flows. Patches above the stages equivalent to 16,300 cfs would no longer be subject to frequent inundation. Although these sites would be dry, their plant structure would be maintained by periodic beach/habitat-building flows. A 48-percent reduction in maximum stage would create or make available additional sites suitable for marsh plants.

Minimum flows of 8,000 cfs year-round would benefit the **aquatic food** base and, therefore, wintering waterfowl. This increase represents about a 3.4- (Lees Ferry) to 5.3-foot (near the dam) increase in stage and up to a 20.5-foot increase in wetted perimeter.

Seasonally Adjusted Steady Flow Alternative

Habitat maintenance flows under this alternative would have effects on riparian habitat similar to those discussed under the Moderate Fluctuating Flow Alternative. The area available for expansion of **woody plants** would be between the maximum area of stabilized sandbars without maintenance flows—26 to 36 feet (38 to 58 percent) over no action, and the area of sandbars unaffected by maintenance flows—0 to 5 feet (0 to 12 percent) over no action (see chapter IV, VEGETATION). The increase in woody plants, and therefore wildlife habitat, would approach the potential maximum area of stabilized sandbars under this alternative.

Under this alternative, some patches of **emergent marsh plants** and the wildlife that use these sites as habitat would (1) completely lose their water supply for 5 months, (2) be partially inundated for 5 months, or (3) be completely inundated for 2 months (plus a 1- to 2-week period of inundation to 30,000 cfs during maintenance flows). However, a 43-percent reduction in maximum stage would create or make available additional sites suitable for marsh plant development.

Increased minimum flows would translate into benefits for the **aquatic food** base and, therefore, wintering waterfowl. This increase represents about 3.4- (Lees Ferry) to 5.3-foot (near the dam) increase in stage and up to a 20.5-foot increase in wetted perimeter.

Year-Round Steady Flow Alternative

Area of riparian habitat, represented by **woody plants** in the NHWZ, would expand down to the 11,400-cfs stage during minimum release periods under this alternative. The area of beach available for expansion of woody riparian plants would average 36 to 57 feet, or a 63- to 94-percent increase over no action conditions.

A zone between about 11,400 and 31,500 cfs would no longer be inundated by fluctuating flows during minimum release years. Combined with flood control, this would result in dryer conditions for NHWZ vegetation. Young tamarisk would be concentrated near the 11,400-cfs stage, while mesquite and other native species would dominate the NHWZ.

Emergent marsh plants would continue to occupy current sites, plus expand into suitable sites created by lower maximum flows. Patches above the 11,400-cfs stage would no longer be subject to frequent inundation. Although these sites would be dry, their plant structure would be maintained by periodic beach/habitat-building flows. A 64-percent reduction in maximum stage would create or make available additional sites suitable for marsh plants.

Increased minimum flows of 11,400 cfs year-round would benefit the **aquatic food base** and, therefore, wintering waterfowl. Increased minimum flows represent an additional 10,400 cfs of permanent inundation over no action conditions. This increase represents a stage increase of about 4.3 (Lees Ferry) to 6.9 feet (near the dam) and up to a 25.9-foot increase in wetted perimeter.

ENDANGERED AND OTHER SPECIAL STATUS SPECIES

Issue:

How do flows affect the populations of ENDANGERED AND OTHER SPECIAL STATUS SPECIES throughout Glen and Grand Canyons?

Indicators:

Tributary access, backwaters, and nearshore habitat for **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**

Both aquatic and terrestrial special status species occupy or use the river corridor through Glen and Grand Canyons. Because the river is regulated by Glen Canyon Dam, special status native fish could be directly affected by changes in dam operations. For example, minimum flows below some stage may limit access to tributaries. In contrast, the effects on terrestrial species would be more indirect and occur through dam-induced changes in habitat. For example, an uncontrolled flood event could eliminate nesting habitat for the southwestern willow flycatcher and thus reduce the numbers of young flycatchers produced in Grand Canyon.

Analyses of the indicators of special status species are limited to the river corridor between Glen Canyon Dam and Separation Canyon (although data only to Diamond Creek are available). The analyses rely heavily on work presented in other sections. For example, the analysis presented in the FISH section of this chapter provides information for impact assessment relevant to the humpback chub, razorback and flannelmouth suckers, bald eagle, and belted kingfisher. Evaluation of habitat for the southwestern willow flycatcher is based on analyses presented in chapter IV, VEGETATION.

Four special status species discussed in chapter III would not be affected by changes in dam operations. These species—southwestern river otter, peregrine falcon, osprey, and Kanab ambersnail—are discussed below and are not treated under individual alternatives.

The **southwestern river otter** is a subspecies considered extirpated from the project area and will not be treated further in these analyses. Any river otter in Arizona is regarded as an escaped individual from a reintroduced population of unknown subspecies (Arizona Game and Fish Department, 1988).

Numbers of **peregrine falcons** are increasing nationwide following the prohibition on use of pesticides such as DDT in the 1970's. It is assumed that increases in peregrine numbers have occurred in Grand Canyon as well (Brown et al., 1992). Although the reasons for these apparent increases are undoubtedly complex, changes in primary productivity within the river following construction of Glen Canyon Dam and subsequent increases in the peregrine falcon's prey base (swallows, swifts, and bats) are assumed to have played a major role (Carothers and Brown, 1991).

Primary productivity within the river is controlled by many factors, but proposed alternatives would affect only light transmittance through changes in water clarity. Sediment-mixing from fluctuating releases and sediment augmentation from tributaries both affect river water clarity. The proposed alternatives may affect sediment-mixing through changes in daily fluctuation patterns. If such effects occur, they would be difficult to quantify but would be assumed to improve water clarity somewhat over no action conditions (except for the Maximum Powerplant Capacity Alternative). Improved water clarity would result in improved food conditions for peregrine falcons via food-chain linkages described in chapter III.

No data exist to indicate that peregrine falcons within Grand Canyon are limited by lack of food. In fact, recent surveys indicate that available nesting habitat may be approaching full occupancy (Brown et al., 1992). The availability of suitable nesting territories would then limit future populations. In summary, the alternatives would not affect nest sites within nesting territories and may improve food base conditions. Therefore, it is concluded that the proposed alternatives would have no effect on peregrine falcons in Grand Canyon.

Ospreys seen along the river in Grand Canyon are assumed to be transients using the river as a travel lane to other habitat. None of the alternatives would affect the river's suitability as a travel lane and, therefore, ospreys are not treated further in this report.

The Grand Canyon population of the **Kanab ambersnail** is above the fluctuating zone affected by dam operations. All alternatives except the Maximum Powerplant Capacity Alternative would either provide the same or less discharge than occur under No Action Alternative maximum releases. Therefore, daily operations would not affect the Kanab ambersnail population. Releases of 45,000 cfs or greater would probably cause some of the Kanab ambersnail population to be washed downstream. However, the flow would have to be in the 125,000- to 150,000-cfs range to adversely affect the population.

It is probable that under any of the alternatives that have lower maximum flows than the No Action Alternative, the Kanab ambersnail population could use the increasing vegetative cover and expand closer to the river. This would expose more individuals to the possibility of being washed downstream during high flows. Since this population survived the flood of 1983 (90,000 cfs), it is logical to assume that infrequent flows in the 40,000- to 50,000-cfs range would not cause lasting damage to the population of Kanab ambersnail in Grand Canyon.

Analysis Methods

Special status species occupy diverse niches in the Grand Canyon ecosystem. Unlike the topic of "wildlife," no single resource can be used as an indicator of impacts to special status species. Studies of rare species might describe parameters characteristic of remaining habitats that reflect marginal rather than optimal conditions. Management recommendations based on limited data for special status species risk perpetuating marginal conditions. The analyses approach taken here relies on the concept of linkages among resources.

Daily operations of Glen Canyon Dam would affect some special status species directly, and others indirectly during the short term. Because population data are limited for most special status species, the indicators presented at the beginning of this section will be used to evaluate effects of the alternatives on the species of concern.

Long-term effects—those that occur after a major flood—might result in direct changes to habitats of the humpback chub, razorback sucker, and flannelmouth sucker, but the direct effects to populations of these species are unknown. Native fish have evolved with natural floods in the Colorado River (Minckley and Meffe, 1987); indeed, these floods define river channel fish habitat. However, flood releases from Glen Canyon Dam are sediment-poor, and the frequency of flooding and the amount of sediment lost from various river reaches may be detrimental to special status fish species. Backwaters and other low water velocity habitat used by larval, young-of-year, and juvenile fish depend on nearshore materials such as sand for their creation and existence.

As described under SEDIMENT, flows higher than normal releases would be necessary to create and maintain backwater habitats, but frequent or long-duration floods would reduce the river's ability to develop backwater habitats. Floods also have the potential to discourage fish species not adapted to swift, turbulent riverflow, and, thus, would benefit native fish.

Because bald eagles use trout as food when available, it is assumed that impacts discussed under the short-term period of analysis (i.e., daily operations) would be identical to long-term impacts. This assumption is supported by the observation that uncontrolled flood releases historically have occurred in the spring or early summer after the period of eagle use. In addition, it is assumed that a trout fishery would be maintained in the future, and trout would continue to attempt tributary spawning if conditions permit.

Although there is no evidence that the southwestern willow flycatcher is habitat-limited in Grand Canyon, uncontrolled flood events would reduce area coverage of riparian vegetation and would probably affect habitat patch size. The relationships among habitat requirements, patch size, and willow flycatchers in Grand Canyon are not understood. However, it is reasonable to assume that a reduction in area of riparian vegetation below some threshold would affect habitat suitability for this species. Because the level of this threshold is unknown, reductions in riparian vegetation should be avoided. Such avoidance is best accomplished through flood control.

Effects on the belted kingfisher would follow effects on fish—basically the relationship between daily operations, tributary access, and the aquatic food base. Flood frequency reduction measures and beach/habitat-building flows should benefit native fish in the long term over no action conditions. Belted kingfishers would benefit from any improvement in habitat conditions for fish.

Summary of Impacts: Endangered and Other Special Status Species

Table IV-12 summarizes impacts on endangered and other special status species. The endangered and special status fish species are influenced by factors and processes similar to those described for native fish species in chapter IV, FISH.

Since Glen Canyon Dam, tributaries have provided virtually all of the reproductive habitat for special status fish in Grand Canyon, and access to tributary habitats is an important factor that may be influenced by dam operations, particularly minimum releases.

No alternative changes the cold water temperatures in the main channel; thus, no eggs would survive in the Colorado River below Glen Canyon Dam. Successful spawning would continue to be restricted to tributaries, and access to some tributaries may be restricted by some alternatives' minimum flows.

Recruitment and growth is the ability of fish to survive to the next life stage. Food resources are important to growth, as is the availability of necessary habitat conditions for each life stage (for example, young-of-year fish require low velocity areas such as backwaters and nearshore habitats). Many humpback chub have been collected within an 8.5-mile reach approximately centered on the LCR (Valdez, Masslich, and Leibfried, 1992), and larvae or young-of-year humpback chub are transported out of that tributary (RM 61.4) into the mainstream (Angradi et al., 1992).

Information on stage (fluctuations) is available for Reach 4 (lower Marble Canyon beginning at RM 36) and Reach 5 (Furnace Flats ending at RM 77). These reaches were selected for analysis since they represent important habitats for most life stages of the humpback chub. Daily fluctuations under some alternatives would destabilize and prevent warming of backwater

Table IV-12.—Summary[1] of anticipated impacts on habitat conditions for ENDANGERED AND OTHER SPECIAL STATUS SPECIES during the short-term period of analysis by alternative

ENDANGERED AND OTHER SPECIAL STATUS SPECIES	No Action	Maximum Powerplant Capacity	High Fluctuating Flow	Moderate Fluctuating Flow	Modified Low Fluctuating Flow[3]	Interim Low Fluctuating Flow	Existing Monthly Volume Steady Flow	Seasonally Adjusted Steady Flow	Year-Round Steady Flow
Endangered species									
Humpback chub[2]	Stable to declining	Same as no action	Same as no action	Same as no action	Potential minor increase	Potential minor increase	Potential minor increase	Potential major increase	Potential minor increase
Razorback sucker	Stable to declining	Same as no action	Same as no action	Same as no action	Potential minor increase	Potential minor increase	Potential minor increase	Potential minor increase	Potential minor increase
Bald eagle	Stable	Same as no action	Same as no action	Potential increase	Potential increase	Potential increase	Potential increase	Potential increase	Potential increase
Peregrine falcon	No effect	No effect	No effect	No effect	No effect	No effect	No effect	No effect	No effect
Kanab ambersnail	No effect	No effect	No effect	No effect	No effect	No effect	No effect	No effect	No effect
Candidate species									
Flannelmouth sucker	Stable to declining	Same as no action	Same as no action	Same as no action	Potential minor increase	Potential minor increase	Potential minor increase	Potential major increase	Potential minor increase
Southwestern willow flycatcher	Undetermined increase	Same as no action	Same as no action	Same as no action	Same as no action	Same as no action	Same as no action	Same as no action	Same as no action
Arizona species of concern									
Southwestern river otter	Presumed extirpated	Presumed extirpated	Presumed extirpated	Presumed extirpated	Presumed extirpated	Presumed extirpated	Presumed extirpated	Presumed extirpated	Presumed extirpated
Belted kingfisher	Stable	Same as no action	Same as no action	Potential increase	Potential increase	Potential increase	Potential increase	Potential increase	Potential increase
Osprey	No effect	No effect	No effect	No effect	No effect	No effect	No effect	No effect	No effect

[1] As discussed in the text, these summaries are based on analyses presented in chapter IV, FISH and VEGETATION.

[2] While some habitat components used by humpback chub, razorback sucker, and flannelmouth sucker would improve, cold water temperatures in the mainstem would continue to restrict spawning to suitable tributaries under all alternatives.

[3] Impacts of endangered fish research flows (during years when they occur) would be within the range of impacts described for the Modified Low Fluctuating (without these research flows) and Seasonally Adjusted Steady Flow Alternatives.

The aquatic food base is certainly important to many resources including special status native fish (see chapter IV, FISH). However, changes in wetted perimeter are used here to estimate effects on trout, which are prey for bald eagles. Baseline conditions for wetted perimeter under 1,000-cfs minimum flows are 580.3 feet near the dam and 380.4 feet near Lees Ferry.

Belted Kingfisher. It is assumed that belted kingfishers use the river and its tributaries for feeding and nest in suitable banks wherever they are found. Nesting banks would not be affected under any alternative, but low minimum flows would periodically restrict tributary access for native and non-native fish and limit the aquatic food base potential.

Food production and availability would be both benefited and disadvantaged by fluctuating flows. Fluctuations may displace *Cladophora* and associated diatoms and invertebrates and provide them as drift downstream of Glen and Marble Canyons. Excessive disturbance would reduce productivity of food resources, extended periods of extreme low flows would desiccate algae, and high flows would inundate some algae beyond the depth of usable light for photosynthesis (Angradi et al., 1992).

Southwestern Willow Flycatcher. Data are not available that can be used to interpret specific relationships between breeding willow flycatchers and woody plants used as nesting habitat in Grand Canyon. However, the analysis presented here assumes that conditions that would change the area of woody plants would result in changes in area of potential habitat for willow flycatchers. This analysis is of potential habitat only, and no data were discovered that indicate that numbers of willow flycatchers using Grand Canyon are habitat-limited.

The composition of woody plants within the riparian corridor (exclusive of the OHWZ) would follow trends described in chapter III, with coyote willow, arrowweed, honey mesquite, and other species increasing in abundance. Southwestern willow flycatchers in Grand Canyon nest in large patches of riparian vegetation. Conditions that favor increases in woody plants are assumed to favor potential habitat for this species.

Maximum Powerplant Capacity Alternative

Under this alternative, the potential range in river fluctuations is 1,000 to 33,200 cfs, an increase over no action conditions. Minimum 1,000-cfs flows would be the same as under no action; thus, tributary access for **humpback chub**, **razorback sucker**, and **flannelmouth sucker** would continue to be restricted during certain periods. (In addition, tributary access for trout used as prey by **bald eagles**, would not change from no action conditions). Wide ranges in fluctuating flows are believed to destabilize conditions found in backwaters and nearshore habitats that are favorable to native fish (see chapter IV, FISH). This alternative would increase the degree of destabilization over no action conditions.

Because minimum flows would not differ from no action under this alternative, no change would occur in the area of wetted perimeter. Therefore, conditions for the aquatic food base—important in supporting trout and other fish used as prey by bald eagles and **belted kingfishers**—would not change.

An increase in maximum stage under this alternative would affect woody plants and, therefore, may affect potential habitat of the **southwestern willow flycatcher**. Under this alternative, unstable sandbar width would increase by 0 to 9 percent (0 to 5 feet) over no action. Vegetation occupying unstable sites would be lost through erosion.

In summary, tributary access and wetted perimeter would not change. Thus, conditions for humpback chub, razorback and flannelmouth suckers, bald eagles, and belted kingfishers would not change under this alternative. However, (1) backwaters and nearshore habitats would be exposed to a larger range of destabilizing flows than under no action, and (2) woody plants that may be potential habitat for willow flycatchers would be reduced. Therefore, for special status native fish and the southwestern willow flycatcher, conditions under this alternative would be less favorable than those under no action.

Restricted Fluctuating Flows

Fluctuating flows affect special status fish species directly by restricting access to tributaries during low flow periods and by flushing young fish from backwaters, and indirectly through effects on fish and riparian vegetation. Frequent fluctuations prevent solar warming of backwaters, flush out organisms and nutrients important as food resources, and force the early life stages of native fish—such as humpback chub—out of quiet, protected waters to unfavorable mainstem conditions. Exposure to predation also is increased. Daily fluctuations could cause juvenile humpback chub to move from eddies, nearshore areas, or large backwaters to seek more suitable habitat along the mainstem. Exposure to predation and additional expenditure of energy would occur during these movements.

A reduction in flood frequency would increase protection of sediment resources needed to build and maintain backwater habitats used by humpback chub and other native fish (see SEDIMENT).

Impacts under the No Action Alternative also might be applied to the restricted fluctuating flow alternatives. The No Action and Maximum Powerplant Capacity Alternatives have the most operational flexibility, and adverse impacts to the humpback chub would be predicted to decrease with reductions in that flexibility.

Factors such as minimum discharge, which would affect numbers or availability of trout in Nankoweap Creek and to a lesser degree in the river corridor, would likely affect bald eagles. None of the alternatives would affect parameters of Nankoweap Creek—such as discharge, water temperature, or icing—that are important in determining the creek's suitability as a spawning site for trout.

Trout stranded in isolated pools would be available as food for bald eagles. Location of foraging efforts are affected by fluctuating flows; however, these patterns do not appear to affect foraging success. This impact analysis is based solely on trout access to tributaries (Nankoweap Creek) and effects on the aquatic food base. All restricted fluctuating flow alternatives have minimum flows higher than no action conditions, but only the Moderate, Modified Low, and Interim Low Fluctuating Flow Alternatives have minimum flow restrictions of 5,000 cfs or greater that would permit unlimited tributary access. Minimum discharge is also an important parameter defining the aquatic food base and, in turn, food for fish and belted kingfishers.

The effects of alternative operations on habitat for the southwestern willow flycatcher are presented in terms of anticipated flows during a minimum release year. In moderate or high water years, riparian vegetation under the Moderate, Modified Low, and Interim Low Fluctuating Flow Alternatives would be affected by higher water volumes through increases in maximum stages. During moderate or high water years, total area coverage of riparian vegetation may be reduced. Higher flows would tend to shift conditions toward no action.

High Fluctuating Flow Alternative

Analysis of impacts to **humpback chub** corresponds to the overall description of fluctuating flows. Operations would continue to constrain growth rates and reduce survival of humpback chub due to lack of warm nursery areas and continued cold mainstem temperatures. Access to tributaries is uncertain, and during low flows of less than 5,000 cfs, access may be obstructed. Daily fluctuations during high flow months of July and August are estimated to average from 7 to 8 feet in the river reaches important to humpback chub (RM 36 to RM 77). This fluctuation would be particularly adverse to larval, young-of-year, and juvenile life stages and would possibly restrict tributary access by adults. Maintenance of sediment for the above river reach is more negative than under other restricted fluctuating flow alternatives. This would reduce the opportunities to develop backwater habitats.

Increased minimum flows to 3,000 cfs year-round would mean some increase in tributary access and some benefits to *Cladophora* and the aquatic food base. These are assumed to benefit **bald eagles** and **belted kingfishers** through their linkages to trout and the aquatic food base. Increased low flows represent an additional 2,000 cfs of permanent inundation—a 1.5- (at Lees Ferry) to 2.0-foot (near the dam) increase in stage and up to a 8.7-foot increase in wetted perimeter over no action.

Under conditions of this alternative, effects on riparian vegetation would be similar to no action conditions. The area of beach available for expansion of woody plants would remain unchanged from no action (see chapter IV, VEGETATION, for a description of this analysis). Thus, no change in potential habitat for the **southwestern willow flycatcher** would occur. However, it should be noted that increases in potential habitat may not translate into increases in the numbers of flycatchers surveyed during any future monitoring program.

Moderate Fluctuating Flow Alternative

Analysis of impacts to **humpback chub** corresponds to the overall description of fluctuating flows. Tributaries would be more accessible with minimum releases of 5,000 cfs. Monthly volumes during the high flow months of July and August during an 8.23-maf water year would result in a mean flow of 16,700 cfs, with daily fluctuations not to exceed 12,000 cfs. For reaches near the LCR, the average daily range would be 5 feet. Very few backwaters would be available due to the high mean flow. The cold water of the mainstem would continue to strongly influence the remaining backwaters. Stability of nearshore habitats would be increased due to the reduced range of daily flow and ramp rates, although maximum fluctuations would occur when larval and young-of-year fishes leave the tributaries and enter the mainstem. Tributary confluences would benefit from the high mean flow but would be subject to daily fluctuations.

Increased minimum flows of 5,000 cfs year-round would mean some increase in tributary access and some benefits to *Cladophora* and the aquatic food base. These conditions also would be assumed to benefit **bald eagles** and **belted kingfishers** through their linkages to trout and the aquatic food base. Increased low flows represent an additional 4,000 cfs of permanent inundation—a 2.4- (at Lees Ferry) to 3.5-foot (near the dam) increase in stage and up to a 14.1-foot increase in wetted perimeter over no action.

Riparian vegetation would increase over no action conditions. The area of beach available for expansion of woody plants would average 0 to 6 feet, or an increase of 0 to 40 percent over no action (see chapter IV, VEGETATION). This change is assumed to indicate an increase in potential habitat for the **southwestern willow flycatcher**.

The Moderate Fluctuating Flow Alternative includes habitat maintenance flows designed to re-form beaches and backwaters. Habitat maintenance flows would provide high (30,000 cfs), steady flows for up to 2 weeks each spring when Lake Powell is not predicted to fill. The scheduling of flows in March is not intended to mimic the pattern of high spring flows that historically occurred later in the season. Instead, maintenance flows in March would prepare backwaters for use by larval and young-of-year native fish when they move into the mainstem from tributaries later in the year. Under this alternative, daily fluctuations would inundate backwaters and associated sandbars, thus reducing the assumed benefits derived from providing habitat for early life stages of native fish.

For terrestrial special status species, maintenance flows would provide unlimited access to tributaries important to spawning trout (and therefore bald eagles), support a general increase in woody plants that may be used as habitat (southwestern willow flycatcher), and have no effect on the aquatic food base (an important consideration for eagles and belted kingfishers).

In summary, both (1) tributary access—important for native fish and trout reproduction—and (2) the aquatic food base—important to bald eagles and belted kingfishers—would increase under this alternative. Thus, food conditions for bald eagles and belted kingfishers would be enhanced. For the remaining species, (3) conditions in backwaters and nearshore habitats would experience somewhat less flow fluctuations than under no action, thus improving conditions for native fish, and (4) woody plants that may be potential habitat for willow flycatchers would increase. Thus, for all special status species, habitat conditions would increase over no action. However, as under all alternatives, native fish reproduction in the mainstem river would be prevented by cold water temperatures.

Modified Low Fluctuating Flow Alternative

The draft FWS biological opinion on this preferred alternative stated that the Modified Low Fluctuating Flow Alternative would likely not jeopardize the continued existence of the bald eagle, peregrine falcon, and Kanab ambersnail but would likely jeopardize the humpback chub and razorback sucker. Therefore, the preferred alternative was designed to be consistent with the "reasonable and prudent alternative" (see attachment 4) contained in the draft biological opinion. The reasonable and prudent alternative was provided as a plan that could remove the likelihood of jeopardizing the continued existence of the humpback chub and razorback sucker in Grand Canyon.

In years when they occur, endangered fish research flows would have impacts on endangered fish similar to those described under the Seasonally Adjusted Steady Flow Alternative.

Under this alternative, the potential range in river fluctuations is 5,000 to 20,00 cfs, a reduction from no action conditions. Tributary access for **humpback chub**, **razorback sucker**, and **flannelmouth sucker** would be more accessible with minimum releases of 5,000 cfs. (In addition, tributary access for trout used as prey by **bald eagles** would not be restricted). Because this alternative would reduce the range of fluctuations, conditions found in backwaters and nearshore habitats would be more stable than no action conditions (see chapter IV, FISH).

The aquatic food base is important in supporting trout and other fish used as prey by bald eagles and **belted kingfishers**. Wetted perimeter would increase over no action 14.1 feet near the dam and 14.1 feet near Lees Ferry under this alternative. It is assumed that because both reliable minimum flows and wetted perimeter increase, conditions for the aquatic food base would also improve.

A decrease in maximum stage would affect woody plants and, therefore, may affect potential habitat of the **southwestern willow flycatcher**. Because this alternative includes habitat maintenance flows, the exact change in area of woody plants is difficult to predict. However, the area available for woody plant expansion would be between the potential maximum area of stabilized sandbars—21 to 31 feet (30- to 47-percent increase over no action) and the area unaffected by maintenance flows—0 to 5 feet (0- to 12-percent increase). It is assumed that an increase in woody plants would indicate an increase in potential habitat for the willow flycatcher.

As described under the Moderate Fluctuating Flow Alternative, habitat maintenance flows are expected to re-form and prepare backwaters for later use by larval and young-of-year native fish. However, the fluctuating flows of this alternative would reduce the assumed habitat benefits provided by backwaters. Because maximum flows under this alternative are lower, the habitat benefits that remain would be greater than those under either the Moderate Fluctuating Flow or No Action Alternatives.

Terrestrial species would experience the same effects (or lack of effects) discussed under the Moderate Fluctuating Flow Alternative.

In summary, both tributary access and the aquatic food base would increase under this alternative. Thus, conditions for trout, bald eagles, and belted kingfishers would be enhanced. Backwaters and nearshore habitats would experience less fluctuations than under no action, providing some improvement in conditions for native fish. Woody plants that may be potential habitat for willow flycatchers would increase. Therefore, for all special status species, habitat conditions would increase over no action. However, as under all alternatives, native fish reproduction in the mainstem would be prevented by cold water temperatures.

Interim Low Fluctuating Flow Alternative

Daily fluctuations are expected to average approximately 3 feet in reaches RM 36 to RM 77 during July and August, when flows range from 12,000 to 20,000 cfs. Young **humpback chub** may experience some increase in growth owing to more stable nearshore habitats. Drift of food items from upper reaches would be likely, as with other fluctuating flow alternatives.

Preliminary information from studies conducted during interim flows (operations similar to this alternative) showed that juvenile humpback chub could hold their position in reaches adjacent to the LCR and not be moved downstream (Valdez, Wasowicz, and Leibfried, 1992). Juvenile humpback chub that remain in this area might benefit from the higher food production in the upper mainstem and from the reduced numbers of fish predators compared to the lower reaches. Tributary confluences would be somewhat ponded but still subject to daily fluctuations. Humpback chub may move from some habitats, which would subject the species to some unknown energy cost; however, the cost may not be significant (Valdez, 1991).

Ramp rates of 2,500 cfs up and 1,500 cfs down, with an allowable daily change in flow between 5,000, 6,000 and 8,000 cfs, would improve habitat conditions for humpback chub. Minimum 5,000-cfs flows are 4,000 cfs greater than under no action, thus tributary access for humpback chub, **razorback sucker**, and **flannelmouth sucker** would no longer be restricted. In addition, tributary access for trout—used as prey by **bald eagles**—would not be restricted.

Wetted perimeter would increase over no action 14.1 feet near the dam and 14.1 feet near Lees Ferry under this alternative. It is assumed that because both reliable minimum flows and wetted perimeter increase, conditions for the aquatic food base would improve. The aquatic food base is important in supporting trout and other fish used as prey by bald eagles and **belted kingfishers**.

A decrease in maximum stage under this alternative would affect woody plants and, therefore, may affect potential habitat for the **southwestern willow flycatcher**. The area available for woody plant expansion would average 21 to 31 feet (30- to 47-percent increase over no action). It is assumed that an increase in woody plants indicates an increase in potential habitat for the willow flycatcher.

In summary, under the Interim Low Fluctuating Flow Alternative:

- Tributary access, important for native fish and trout reproduction, would increase.
- Aquatic food base, important to bald eagles and belted kingfishers, would increase.
- Backwaters and nearshore habitats would experience less flow fluctuations, thus providing some improvement in conditions for native fish.
- Woody plants that may be potential habitat for willow flycatchers would increase.

Therefore, habitat conditions would increase for all special status species over no action. However, as under all alternatives, native fish reproduction in the mainstem would be prevented by cold water temperatures.

Steady Flows

With the allowable daily change in flow not to exceed 2,000 cfs (1,000 cfs) per 24 hours, inundation and exposure of habitats along the channel margins would be limited. This would allow for increased warming of connected backwaters that would benefit young-of-year and other subadult humpback chub in the mainstem. Young fish using nearshore habitats might not be forced to expend energy by seeking suitable habitats when flow conditions change. Food production (zooplankton and invertebrates) in backwaters might be increased by stable water levels and higher water temperatures. Availability of food as drift from upstream reaches might be decreased due to reduced flows or ramp rates (Leibfried and Blinn, 1987).

Steady flows might adversely affect maintenance of backwaters. Backwaters become isolated and change to terrestrial habitats as they fill with sediment. Releases higher than normal operations might be necessary to maintain backwaters. Beach/habitat-building flows would be calculated and planned to redistribute sediment from pools to channel margins with a frequency, duration, and magnitude designed to maintain the sediment balance in Grand Canyon. These flows also would assist in controlling non-native fish species that might increase as conditions became more favorable for warmwater fish in general.

Tributary confluences that serve as rearing habitats for young fish would benefit from stable flow because they would not be subject to daily stage changes.

As discussed in the FISH section, improved habitat conditions for native fish species (including endangered fish) might also benefit non-native fish species that are competitors or predators of endangered fish. The impacts of a possible increase in non-native species on endangered fish are unknown. Native fish species persist over non-natives in the tributaries, and operational changes would not be expected to change this relationship. Monitoring the fish community would be an essential element of any alternative. Continued collection of data (structured as research questions) on species interactions, habitat requirements, and food resources as they relate to operations and the dynamics of a riverine system would be necessary.

General effects of steady flow patterns on tributary access and the aquatic food base were described under FISH, and effects on woody plants were described under VEGETATION.

Existing Monthly Volume Steady Flow Alternative

Low flows in March through May would be counter to historic hydrologic patterns of high spring flows that may provide "cues" to stimulate spawning in native fish such as **humpback chub** (Valdez, 1991). Under this alternative, high flows in the summer (June through August) would not support backwater areas or nursery areas in the mainstem but would contribute to tributary access. Food resources in backwaters and other nearshore habitats might not have sufficient time (1 month) to develop before flows change.

Increased minimum flows of 8,000 cfs year-round would mean increased tributary access and large benefits to *Cladophora* and the aquatic food base. These would be assumed benefits to **bald eagles** and **belted kingfishers** through linkages to trout and the aquatic food base. Increased minimum flows represent an additional 7,000 cfs of permanent inundation—a 3.4- (at Lees Ferry) to 5.3-foot (near the dam) increase in stage and up to a 20.5-foot increase in wetted perimeter over no action.

Riparian vegetation would increase over no action conditions under this alternative. The area of beach available for expansion of woody plants would average 26 to 41 feet, or an increase of 45 to 65 percent over no action. This change is assumed to indicate an increase in potential habitat for the **southwestern willow flycatcher**.

Seasonally Adjusted Steady Flow Alternative

This alternative provides for an annual spring peak of 18,000 cfs to reinforce **humpback chub** spawning. Access to tributaries would be enhanced in the spring. Releases of 9,000 cfs in August and September would support development of backwater habitats. Habitats for early life stages of humpback chub would stabilize and warm somewhat during the steady, lower flow period (July through September), resulting in increased growth and survival of young-of-year humpback chub. Less movement and, consequently, reduced energy expenditure would be anticipated for the juvenile humpback chub during steady flows.

Food resources such as algae, zooplankton, and invertebrates might develop during each 3-month flow pattern if the stage changes are not too extreme from one period to the next. The response to this quarterly change is unknown but might be more beneficial than monthly changes in river stage.

Maintenance of a sediment balance that allows development of backwaters would be predicted to occur during 86 percent of the years (50-year sediment supply) in the reach important to humpback chub (RM 36 to RM 77). The higher spring flows should contribute to redistributing sediment and to flushing out backwater habitats.

Minimum flows of up to 8,000 cfs year-round would mean increased tributary access and large benefits to *Cladophora* and the aquatic food base. These would be assumed benefits to **bald eagles** and **belted kingfishers** through linkages to trout and the aquatic food base. Increased low flows represent an additional 7,000 cfs of permanent inundation—a 3.4- (at Lees Ferry) to 5.3-foot (near the dam) increase in stage and up to a 20.5-foot increase in wetted perimeter over no action.

Riparian vegetation would increase over no action conditions under this alternative. The area of beach available for expansion of woody plants would range from 0 to 36 feet, or an increase of 0 to 58 percent over no action (see chapter IV, VEGETATION). This change is assumed to indicate an increase in potential habitat for the **southwestern willow flycatcher**.

As under the Moderate and Modified Low Fluctuating Flow Alternatives, habitat maintenance flows would re-form and prepare backwaters for later use by larval and young-of-year native fish. However, flows under this alternative would inundate backwaters until August and September even during low water years. This inundation would reduce the assumed benefits derived from providing habitat needed in June through September. Nearshore habitats and the few backwaters available in July when flows are 12,500 cfs would not be subject to daily inundation.

Terrestrial species would experience the same effects (or lack of effects) discussed under the Moderate Fluctuating Flow Alternative.

In summary, under the Seasonally Adjusted Steady Flow Alternative:

- Tributary access, important for native fish and trout reproduction, would increase.
- Aquatic food base, important to bald eagles and belted kingfishers, would increase.
- Backwaters and nearshore habitats would experience less flow fluctuations, thus improving conditions for native fish.
- Woody plants that may be potential habitat for willow flycatchers would increase.

Therefore, habitat conditions would increase for all special status species over no action. Because this alternative would provide flow conditions closer to predam conditions than any other alternative, it is believed to be the most beneficial alternative for native fish. However, as under all alternatives, native fish reproduction in the mainstem would be prevented by cold water temperatures.

Year-Round Steady Flow Alternative

Access to tributaries for spawning fish would be enhanced, and ponding of tributary confluences—which benefits larval fish—would be constant throughout the year. This ponding might benefit **humpback chub**, but might benefit non-native species as well. The number of backwater habitats would decrease due to the high mean flows. Nearshore and backwater habitats would be stable throughout the year as hydrologic conditions allow.

Maintenance of net sediment balance for the reach important to humpback chub would be predicted to occur every year (50-year sediment supply), supplying the most sediment for that reach of any alternative. Beach/habitat-building flows may be necessary to create backwaters or other habitats.

Minimum flows of 11,400 cfs year-round would mean increased tributary access and large benefits to *Cladophora* and the aquatic food base. These also would be assumed benefits to **bald eagles** and **belted kingfishers**. Increased low flows represent an additional 10,400 cfs of permanent inundation—a 4.3- (at Lees Ferry) to 6.9-foot (near the dam) increase in stage and up to a 25.9-foot increase in wetted perimeter over no action.

Riparian vegetation would increase over no action conditions under this alternative. The area of beach available for expansion of woody plants would average 36 to 57 feet, or an increase of 63 to 94 percent over no action. This change would indicate an increase in potential habitat for the **southwestern willow flycatcher**.

CULTURAL RESOURCES

Issue:

How do flows 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** directly, indirectly, or potentially affected

Cultural resources in the Colorado River corridor are numerous, with 475 archeological sites and 489 isolated occurrences documented between Glen Canyon Dam and Separation Canyon. Isolated occurrences are findings of artifacts or other remains located apart from an archeological site. Because it is difficult to determine the significance of an artifact in an isolated location, these isolated occurrences are noted but not used in impact analysis and will not be discussed further.

In addition to those resources identified as archeological sites, numerous resources significant to Native Americans occur within the river corridor. These resources, which are culturally important because they represent areas of spiritual significance and/or traditional use, are called traditional cultural properties in this document. Though there is some overlap between categories, traditional cultural properties are discussed separately from properties identified as archeological sites.

Of the archeological sites located during the survey, 336 either have been affected by the existence and operation of Glen Canyon Dam or have the potential to be affected by floodflows that could be released from the dam. The remaining 139 sites are unaffected by the dam and have been excluded from further discussion. The specific sites identified as potentially impacted are all locations which contain physical manifestations and are recorded as archeological sites. Some archeological sites are also important as traditional cultural properties. Impacts to archeological sites, including those with traditional cultural significance, are discussed for each alternative.

Determination of eligibility for the *National Register of Historic Places* (National Register) was made by the Arizona State Historic Preservation Officer for the 336 sites potentially impacted by dam operations (attachment 5). Of these identified sites, 313 have been determined eligible for inclusion on the register, 14 are ineligible, and 9 will require testing. One of the sites identified as ineligible is being reevaluated. A number of sites are ineligible because they have lost integrity due to past impacts from dam operations. Other ineligible sites are relatively recent historic remains related to Reclamation's exploratory activities at the Marble Canyon and Bridge Canyon damsites. These sites are less than 50 years old, which makes them ineligible for inclusion on the National Register under Federal regulations (36 Code of Federal Regulations (CFR) 60.4). However, all 336 sites were included in this analysis because these historic resources will become eligible for the National Register within the next few years.

Criteria for National Register eligibility include those used for evaluating the significance of archeological properties under 36 CFR 60.4 and the guidelines for evaluating traditional cultural properties (Parker and King, n.d.). Specific details on individual site impacts are found in a technical archeological survey report (Balsom et al., 1991).

Numerous locations within the project area contain no archeological remains but are nonetheless tangible historic sites with cultural significance because of their use in Native American practices and beliefs. Virtually all prehistoric sites are affiliated with contemporary Indian Tribes, often more than one group due to multiple traditions or multiple uses of many sites found along the Colorado River. These traditional cultural properties are considered eligible for the National Register if they are rooted in the living community's history and important in maintaining the community's cultural identity.

Traditional cultural properties have been divided into two categories for this EIS:

1. Sites and locations including, but not limited to, plant gathering areas, landforms, springs, prayer offering locations (sacred sites), archeological sites, ancestral human remains, and the Colorado River.
2. Traditional resources including, but not limited to, certain minerals, sand deposits, and biological resources—such as animals and plants—traditionally used or referenced in ceremonies or used in preparing ceremonial implements.

Summary of Impacts: Cultural Resources

Impact analyses of cultural resources under alternative dam operations are based on the present understanding of changes in these resources known to have occurred as a result of Glen Canyon Dam. Some impacts are direct while others are indirect. Predicted influences of alternatives on traditional properties are based on information provided by ethnographic research and knowledge shared by Indian Tribes known to have ancestral involvement with Grand Canyon. Evaluation of isolated occurrences along the river corridor is ongoing and will be considered, as impacts are identified by individual tribes. Anticipated impacts to certain other cultural resources are linked to impacts on riparian vegetation. A summary of impacts on cultural resources resulting from all alternatives is shown in table IV-13. Impacts on cultural resources are irretrievable and generally regional or national in scope.

With the closure of Glen Canyon Dam in 1963, the pattern of deposition, erosion, and flooding on the Colorado River through Glen and Grand Canyons was changed forever. As a result, general loss of river-deposited terraces has occurred. Archeological sites once protected by sandbars and terraces have become increasingly exposed to erosion by the river and rainfall-induced terrace erosion.

The postdam river can't rebuild high terraces, resulting in more archeological site erosion than occurred during the predam environment (see discussion of high terraces in chapter III, SEDIMENT). The 1983-86 floodflows were known to cause direct erosion of terraces. Extreme rainfall conditions during 1978-85 led to accelerated erosion of archeological sites. Because the dam traps sediment and reduces floods, little or no sediment is deposited at the mouths of small ephemeral tributary streams, which makes the situation worse. Only low elevation sediment deposits can be replenished in the postdam environment. Large sediment-laden floods may rebuild the bases of high terraces at most locations but erode terraces at other locations.

The initial impacts to archeological sites began with the construction of Glen Canyon Dam and the resulting change in the amount and distribution of sediment. These sites depend on the terraces that have formed along the river corridor. Without a mechanism for sediment augmentation and redeposition to predam terrace levels, all alternative operations would impact cultural resources. None of the action alternatives considered in this EIS could alter the basic change in postdam sediment input to the system; thus, it is expected that dam-related impacts to archeological sites would continue regardless of alternative flow patterns. These impacts are permanent, the damage irretrievable. However, the rate at which impacts would occur could be affected by alternative operations, principally through flood frequency reduction measures.

Table IV-13.—Summary of anticipated impacts on CULTURAL RESOURCES by alternative

CULTURAL RESOURCES	No Action	Maximum Powerplant Capacity	High Fluctuating Flow	Moderate Fluctuating Flow	Modified Low Fluctuating Flow	Interim Low Fluctuating Flow	Existing Monthly Volume Steady Flow	Seasonally Adjusted Steady Flow	Year-Round Steady Flow
Archeological sites	Major (336)	Major (336)	Potential to become major (263)	Moderate (less than 157)	Moderate (less than 157)	Moderate (less than 157)	Moderate (less than 157)	Moderate (less than 157)	Moderate (less than 157)
Traditional cultural properties									
Native American traditional use areas	Major	Same as no action	Same as no action	Same as no action	Same as no action	Same as no action	Same as no action	Same as no action	Same as no action
Native American sacred sites\ resources	Major	Same as no action	Same as no action	Same as no action	Same as no action	Same as no action	Same as no action	Same as no action	Same as no action

Note: Number of sites potentially impacted are in parentheses.

Moderate: Readily apparent impacts attributable to current operations; determination of "no adverse effect" or "adverse effect" within 36CFR Part 800 likely.

Potential to become major: Potentially severe adverse impact from direct or indirect effects of flows related to operations; determination of "no adverse effect" or "adverse effect" within 36 CFR Part 800 likely.

Major: Severe adverse impacts from direct or indirect effects of flows related to operations as defined by 36CFR Part 800; determination of "adverse effect" with likely mitigation involving complete data recovery.

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Major: Severe adverse impacts from direct or indirect effects of flows related to operations as defined by 36CFR Part 800; determination of "adverse effect" with likely mitigation involving complete data recovery.

Many of the traditional cultural resources (especially riparian plant and animal species) also depend on sandbars and terraces along the river. The alternatives that allow for maximum growth and protection of the riparian habitat also would favor protection of these traditional resources.

Postdam changes in the riparian ecosystem within Grand Canyon have favored growth of NHWZ vegetation, while OHWZ vegetation is thought to be declining (chapter III, VEGETATION). The net effect of these changes in riparian vegetation is still in a dynamic state; however, some of the traditional resources (willows, giant reeds, yellow warblers, yellow-throats, and other plants and riparian birds) have clearly increased since construction of the dam. Although none of the action alternatives would influence OHWZ vegetation, the extent of the NHWZ—and thus the abundance of some traditional resources—would be affected by alternative discharge patterns.

It is important to note that the alternatives that restrict maximum flows to less than powerplant capacity (33,200 cfs) would allow an increase in NHWZ vegetation during low water years. During moderate and high water years, water releases could increase to a maximum of 33,200 cfs, thus limiting the area of sediment deposits available for vegetation growth.

The most visible traditional cultural property located within the river corridor, the Hopi Salt Mines and associated sediment deposits, would be better protected by alternatives that allow sediment accumulation on the sandbar at the base of the mines.

Generally, alternatives that have the capability to maintain the sediment balance and allow for sediment distribution along the river corridor would enhance long-term preservation of cultural resources. Although sediment transport is variable and depends on flow regimen, alternatives that would most likely produce a net positive sand balance in the system—while maintaining a high base level of sediment deposition—would be most favorable. The alternatives listed below would allow for a net positive sediment balance in the system and the possibility of sediment redeposition in areas that would protect cultural resources:

- Moderate, Modified Low, and Interim Low Fluctuating Flow Alternatives
- All steady flow alternatives

Sediment deposition is a critical factor in preserving terraces and related deposits that contain cultural resources. This is particularly true in the areas between Glen Canyon Dam and the LCR, where predam terraces are often in direct contact with the river. Although impacts to some sites would still occur due to the existence of the dam, it is likely that the impacts would be less than under no action.

Of the elements common to all restricted fluctuating flow and steady flow alternatives, the most important to cultural resources is flood frequency reduction. The flood releases during 1983-86 caused direct erosion of approximately 33 archeological sites and scoured or buried a large portion of the riparian vegetation in the NHWZ. Another uncontrolled flood of that magnitude and duration (4 plus years) could severely damage or destroy certain archeological sites—principally in Glen and Marble Canyons—and temporarily destroy riparian vegetation. Adopting flood frequency reduction measures would reduce the risk of uncontrolled flooding, thereby helping to preserve the river's physical cultural history.

Reduced flood frequency is included in all of the alternatives except no action and maximum powerplant capacity. It is assumed that with flood control, flows greater than 45,000 cfs would not occur more often than once in 100 years on average, except for beach/habitat-building flows.

The habitat maintenance and beach/habitat-building flows described in chapter II might benefit some of the cultural resources in the system. Adding sediment at the mouths of tributaries and creating sandbars at slightly higher elevations is a systemwide approach to rebuilding and stabilizing the high terraces upon which the sites depend. Although more research is needed on the success of these flows, creation of stable sandbars—even at lower levels—could result in a more stable situation for predam terraces.

Endangered fish research flows would be initially included in the Modified Low Fluctuating Flow Alternative during minimum release years. However, these flows are not expected to result in any additional impacts on cultural resources.

The concept of adaptive management has implications for cultural resources. National Historic Preservation Act requirements recommend a long-term monitoring program (through a programmatic agreement and historic preservation plan) to assess changing conditions of cultural resources. Long-term monitoring is now required under the Grand Canyon Protection Act of 1992. These assessments of site integrity and stability offer mechanisms for remedial actions which include site-specific mitigation along with management alternatives which could affect the entire system. The actions described in the programmatic agreement and accompanying monitoring plans are common to all alternatives (attachment 5).

Unrestricted Fluctuating Flows

No Action Alternative

Archeological Sites. Under no action conditions, continued degradation and eventual loss of significant prehistoric and historic archeological sites would occur. It should be noted that all archeological resources are nonrenewable, and damage to them is both irretrievable and irreversible. Impacts to these sites are categorized as follows:

- Direct impacts = 33 sites
- Indirect impacts = 124 sites
- Potential impacts = 179 sites

The potential for degradation of all 336 archeological sites would continue due to the loss of sediment in the system, arroyo-cutting through predam river-deposited terraces, and the risk of uncontrolled flooding. Sediment erosion and arroyo-cutting are linked to archeological site erosion. Impacts from the dam and its operations have occurred since 1963, with direct and indirect damage documented for 157 sites. Continuation of dam operations under the No Action Alternative could lead to the eventual loss of all 336 sites identified within the river corridor.

Postdam operations have had deteriorating effects on a National Register property—the Charles H. Spencer paddle wheel steamboat—due to exposure. The fluctuating flows cause constant wetting and drying of the steamboat that has led to its deterioration. Low flows have allowed additional damage to the steamboat by visitors who use parts of the steamboat (the boiler) for recreational purposes (fishing).

The 1983-86 clear-water floods were detrimental to some archeological sites. The risk of flooding remains unchanged under this alternative, and all 336 sites have the potential to be damaged or destroyed. Site-specific mitigation is possible for some sites within the river corridor. Specifics of mitigation are discussed in the documentation found in attachment 5.

Archeological Sites That Are Traditional Cultural Properties.—In addition to the physical impacts on archeological sites noted above, many of these sites also are considered to be traditional cultural properties significant to contemporary Indian Tribes people (table IV-14). Impacts on these sites are considered to be major in intensity, national in scope, and irretrievable.

Native American Traditional Cultural Properties. The river corridor has been used traditionally over hundreds or thousands of years by the native peoples of the region. The Colorado River, its tributaries, the canyons through which it flows, the canyon rims, and the mountains and plateaus that surround them form a sacred landscape that is culturally significant to the Indian Tribes with ties to Grand Canyon. Within this landscape are specific places, ranging from spiritual shrines to mineral collection areas, considered important for a variety of reasons 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.

Table IV-14.—Number of impacted archeological sites also considered traditional cultural properties under the No Action, Maximum Powerplant Capacity, and High Fluctuating Flow Alternatives

Type of impacts	Havasupai	Hopi	Hualapai	Navajo	Paiute	Zuni
Direct	2	9	2	4	1	*
Indirect	28	71	28	2	32	*
Potential	45	76	45	1	27	*

* To be determined.

A number of specific traditional cultural properties have been identified for this EIS; however, there may be additional areas whose locations have not been revealed. In addition to the specific sacred sites or locations, other natural resources of significance are found in the Colorado River corridor. Although these resources may be linked to specific locations, some are place-independent or encompass numerous locations. They also may have spiritual meanings. Most natural resources are considered sacred by Indian Tribes, and some resources are considered more sacred than others.

In general, no action conditions have fostered the growth (over predam conditions) of many riparian plants and animals as well as many species of birds of prey. This growth is primarily due to the lack of annual scouring floods and the increase in the NHWZ vegetative community. Under no action, however, the 1983-86 floods resulted in removal of approximately 40 percent of NHWZ vegetation that had established since closure of the dam (see chapter IV, VEGETATION).

Havasupai.—Many traditional cultural properties are associated with the Havasupai Tribe. Locations that contain archeological remains have been discussed above. In addition to these places, traditional cultural properties and resources also have been identified. Under the No Action Alternative, degradation would continue to the archeological sites identified as ancestral for the Havasupai. In addition, degradation of the entire ecosystem would be allowed to continue, seriously impacting Havasupai uses of the area.

Hopi.—The entire Grand Canyon and its immediate surroundings are of universal importance to the Hopi people. Specific places and concepts linked to Grand Canyon are referenced in daily prayers and play a profound role in Hopi ceremonial activities. The very presence of Glen Canyon Dam and its effect on the environment have a detrimental influence on Hopi lifeways. It is Hopi belief that if the natural and cultural elements of the canyon are being damaged by dam operations, daily prayers also are damaged and less effective. Hopis believe that natural erosion is an integral process in the Grand Canyon environment, but this is distinguished from the erosion caused by dam operations. Hopis believe that Glen Canyon Dam should be operated to minimize human-made erosion.

Within the canyon, both natural and cultural features are considered important. All springs are considered sacred to the Hopi people. Also sacred are the Hopi Salt Mines and the sand at its base. All biological resources are considered important, especially birds with yellow feathers, endangered and candidate species, aquatic organisms, and vegetation found in marsh and riparian habitats—especially reeds, willows, and cattails.

Under the No Action Alternative, continued degradation of the canyon's resources of Hopi concern would occur. Although considered a rare event, the situation that resulted in the floods of 1983-86 would be allowed to continue. Damage to archeological sites would continue, as previously discussed. Riparian habitat for the yellow birds would decline in quality and quantity. Ecological stability would not occur. Marsh habitat for reeds and cattails would continue to degrade. Although during normal operations the immediate area around the Hopi Salt Mines would not be affected, the sand at the base eventually would be lost.

Some endangered species may be impacted by no action. For example, opportunities for humpback chub to recover from jeopardy would not occur, and existing chub populations may decline further; wintering bald eagles at Nankoweap Creek may decline due to lack of food resources (inability for trout to access tributaries); willow flycatcher populations may continue to decline due to lack of habitat.

The Hopi people believe that during their migration, their ancestors left behind archeological sites, potshards, rock art, and other archeological materials to serve as markers that the Hopi people had fulfilled their pact with *Ma' saw.* Thus, the archeological record serves to mark the cultural claim of the Hopi people to the landscape. The erosion of archeological sites in Grand Canyon would diminish the cultural ability of the Hopi people to interpret their past as evidenced by these markers. Under the No Action Alterative, the erosion that would damage archeological sites and sacred ancestral graves remains a threat. The No Action Alternative would be more damaging to resources of Hopi concern than any other alternative except the Maximum Powerplant Capacity Alternative.

Hualapai.—Many traditional cultural properties are associated with the Hualapai Tribe. Those locations that contain archeological remains have been discussed above. Traditional cultural properties not associated with archeological remains also have been identified and are discussed below.

Resources found in the natural environment are considered traditional cultural properties by the Hualapai people. The deserts, plateaus, mountains, and valleys are considered important, as well as the botanical resources and wildlife. Plants have uses both for horticultural and medicinal purposes. Specific locations within the canyon have significance as places for religious or ceremonial activities.

Specific plants important to the Hualapai people include cattails, willows, arrowweed, mesquite, catclaw, agave, and yucca. Bighorn sheep, deer, elk, and a variety of other mammals are resources traditionally used by the Hualapai. Numerous side canyon locations, along with mineral collection areas and springs, are sacred places to the Hualapai. Springs, such as Honga, and collection areas for minerals, such as hematite, also are sacred places.

Under the No Action Alternative, degradation of the river corridor would continue and result in the continued loss of archeological places identified as ancestral to the Hualapai, along with the continued loss of resources considered traditional cultural properties. All resources—natural, cultural, and spiritual—would be impacted by this alternative.

Navajo.—Navajo residents of Grand Canyon area have identified many separate localities that represent traditional cultural properties. Those that contain archeological remains were noted in table IV-15. In addition to archeological sites and the larger landscape of which they are a part, more specific places of traditional significance also have been identified. Twelve such places are within the area of potential impact, and many more have been identified immediately outside the impact area. These places include various kinds of trails or routes into the canyon, the salt mines, prayer offering locations, river crossings,

Table IV-15.—Number of impacted archeological sites also considered traditional cultural properties under the Moderate, Modified Low, and Interim Low Fluctuating Flow Alternatives and under all steady flow alternatives

Type of impacts	Havasupai	Hopi	Hualapai	Navajo	Paiute	Zuni
Direct	2	9	2	4	*	*
Indirect	28	71	28	1	*	*
Potential	30	55	30	—	*	*

* To be determined.

places associated with stories of holy beings or historically significant figures, plants used for medicinal and subsistence purposes, minerals used for secular or sacred purposes, winter camps, cornfields, livestock grazing areas, places where people hid from enemies, areas where people lived during drought years, and places in side canyons where water may be collected.

The terraces and beaches of the Colorado River historically have been, and continue to be, the foundations of the Navajo heritage. Erosion of the terraces and beaches permanently removes the physical manifestations of Navajo history in Grand Canyon. As places disappear, the ability to pass on the stories associated with them also erodes. Loss of oral tradition cannot be mitigated.

Specific plants and animals are important to the Navajo people. Plant life of importance includes beargrass, agave, mormon tea, mullen, cholla and prickly pear cactus, snakeweed, datura, filaree, four o'clocks, dogweed, narrow leaf, and banana yucca. Important wildlife (and habitat) include bighorn sheep, deer, turkey, coyote, beaver, fox, and mountain lion. Birds such as red-tailed hawks, owls, eagles, and falcons also are considered important to the Navajo people.

The No Action Alternative is the most damaging to resources of concern to Navajo people of all alternatives except the Maximum Powerplant Capacity Alternative.

Southern Paiute.—Many traditional cultural properties are associated with the Southern Paiute (Kaibab, Shivwits, and San Juan). Those locations that contain archeological remains are noted in table IV-14. have been discussed above. In addition to those places, traditional cultural places and resources of importance also have been identified.

Under the No Action Alternative, degradation of archeological places identified as ancestral for the Southern Paiute would continue. In addition, degradation of the entire ecosystem would be allowed to continue, seriously impacting Southern Paiute traditional uses of the area.

Zuni.—The Zuni Tribe has many ties to the canyon, and many ancestral archeological sites—as well as other locations and resources of traditional and cultural importance—are known to be located along the Colorado River and the LCR. Under the No Action Alternative, serious degradation of ancestral archeological sites, traditional cultural properties, and other culturally important resources would occur. The Zuni Tribe is in the process of identifying cultural resources of importance to the tribe within the study area. When these studies are completed, the Zuni Tribe will be able to more fully assess impacts to the resources and traditional and cultural values.

Maximum Powerplant Capacity Alternative

Under this alternative, degradation of **archeological sites** and **traditional cultural properties** would be the same or worse than under no action. Loss of sediment and channel margin deposits would continue. More frequent high flows of up to 33,200 cfs would accelerate the loss of sediment from the system, hastening the loss of cultural resources. Arroyo-cutting through high terraces, which is linked to archeological site erosion, would continue.

Impacts to all 336 archeological sites identified within the river corridor would be likely to occur. Impacts to traditional cultural properties of all tribes also would continue under this alternative (table IV-13). For example, impacts to the Hopi Salt Mines would continue due to the lack of flood frequency reduction measures. With increased high flows and wider fluctuations, it is possible that the sand at the base of the mines would be eroded away—a serious impact to the Hopi people. Similar impacts would occur to other resources identified as traditional cultural properties for all the tribes. Impacts on natural resources are discussed in those sections of this document (see chapter IV, FISH, VEGETATION, WILDLIFE AND HABITAT, and ENDANGERED AND OTHER SPECIAL STATUS SPECIES).

With the increased range of flows under this alternative and no reduction in flood frequency, there would be a high probability of net loss of sediment in the system. This loss would likely result in damage to traditional cultural properties and resources, both natural and cultural, and would create conditions similar or more adverse than those under the No Action Alternative.

Restricted Fluctuating Flows

Degradation of **archeological sites** and **traditional cultural properties** would decrease from no action primarily due to flood frequency reduction measures. The probability of net loss of sediment would be less than under the No Action or Maximum Powerplant Capacity Alternatives. Arroyo-cutting of high terraces, which is linked to archeological site erosion, would continue. Flood control measures included in all restricted fluctuating and steady flow alternatives would provide increased protection of these resources.

Physical cultural resources within the river corridor are linked to sediment. Flows that cause a net decrease in stored sediment also will hasten deterioration of the cultural resources dependent on it. Since Glen Canyon Dam blocks the downstream passage of sediment, typical maximum flows less than 20,000 to 22,000 cfs appear to provide the best opportunity for a net positive balance of sediment in the system. Minimum flows of 8,000 cfs or more would provide the best protection for the Charles H. Spencer steamboat located upstream from Lees Ferry.

Site-specific mitigation would be required for all sites considered to be directly, indirectly, or potentially impacted by these alternatives. Specifics of mitigation actions are included in the section 106 compliance, found in attachment 5.

Existing impacts to traditional cultural properties would be reduced under the restricted fluctuating flow alternatives because of the flood frequency reduction measures added to these alternatives. These are measures which would lengthen the time between scouring floods (from an average 1 in 40 years to 1 in 100 years), resulting in increased growth and stability of NHWZ riparian habitat.

High Fluctuating Flow Alternative

Under this alternative, degradation of **archeological sites** would be less than under no action because of the flood frequency reduction measures discussed above. However, high fluctuating flows could continue to cause net loss of sediment, similar to the No Action and Maximum Powerplant Capacity Alternatives. Maximum hourly flows would be greater than 21,000 cfs 62 percent of the time and greater than 25,000 cfs 47 percent of the time. The relatively high frequency of these flows may not allow sediment to accumulate in the river channel. Infrequent beach/habitat-building flows between 41,500 and 45,000 cfs would help maintain sandbars, which protect high terraces and archeological sites. Arroyo-cutting of high terraces, which is linked to archeological site erosion, would continue. Because of the reduced risk of flooding, impacts are likely to occur at 263 sites identified as having direct, indirect, or potential impacts. Sites not located on river sediment (73) would not be impacted.

Impacts to **traditional cultural properties** would be less than under no action due to flood frequency reduction measures.

Moderate Fluctuating Flow Alternative

Degradation of **archeological sites** would continue under this alternative but would be lessened due to reduced probability of net sediment loss and the adoption of flood control measures. Although impacts on these resources would occur, fewer sites would be potentially impacted under this alternative as compared to no action. Maximum hourly flows would be greater than 21,000 cfs 18 percent of the time and greater than 25,000 cfs 6 percent of the time. This would likely allow sediment to accumulate in the river during most years. Habitat maintenance and beach/habitat-building flows would help maintain sandbars, which protect high terraces and archeological sites. Impacts on those sites (33) that have been directly impacted by postdam operations would continue; however, the likelihood of additional effects on directly and indirectly impacted sites (124) would lessen.

Effects on potentially damaged sites (106) that lie within predam river deposits would continue, although the risk is less than under no action. Some of these archeological sites also have been identified as traditional cultural properties, as shown in table IV-15.

Traditional **cultural properties** within the river corridor would continue to be impacted under this alternative, although impacts would be less than under no action (table IV-14). However, with lower maximum releases, fewer impacts would occur to resources and places valued by the various Indian Tribes. Those biological (riparian habitat, wildlife) and mineral (Hopi Salt Mines and associated sand) resources that have been identified as important to Native Americans would be protected to a greater extent under the controlled flows of this alternative.

Modified Low Fluctuating Flow Alternative

Under this alternative, degradation of **archeological sites** would continue but would be lessened compared to no action due to reduced probability of net sediment loss and reduced flood frequency. Maximum hourly flows would be greater than 21,000 cfs 4 percent of the time and greater than 25,000 cfs 2 percent of the time. This would likely allow sediment to accumulate in the river during most years. Habitat maintenance and beach/habitat-building flows would help maintain sandbars, which protect high terraces and archeological sites. Impacts on those sites directly impacted by postdam operations would continue; however, the likelihood of additional impacts on those directly and indirectly impacted sites would lessen. Effects on potentially impacted sites that lie within predam river deposits would continue.

Impacts on **traditional cultural properties** also would be less under this alternative (table IV-14). However, impacts on archeological sites considered to be traditional cultural properties would continue, along with impacts on resources and places of traditional use.

Endangered fish research flows are not expected to result in any additional impacts on cultural resources.

Interim Low Fluctuating Flow Alternative

Under this alternative, degradation of **archeological sites** would continue but would be lessened compared to no action due to reduced probability of net sediment loss and reduced flood frequency. Maximum hourly flows would be greater than 21,000 cfs 4 percent of the time and greater than 25,000 cfs 2 percent of the time. This would likely allow sediment to accumulate in the river during most years. Beach/habitat-building flows between 30,000 and 45,000 cfs would help maintain sandbars, which protect high terraces and archeological sites. Impacts on those sites directly impacted by postdam operations would continue; however, the likelihood of additional impacts to those directly and indirectly impacted sites would lessen. Effects on potentially impacted sites that lie within predam river deposits would continue.

Impacts on **traditional cultural properties** also would be less under this alternative (table IV-14). However, impacts to archeological sites considered to be traditional cultural properties would continue, along with impacts on resources and places of traditional use.

Steady Flows

Impacts on cultural resources would vary under the steady flow alternatives. Degradation of **archeological sites** and **traditional cultural properties** would decrease from no action primarily due to flood frequency reduction measures (table IV-14). The probability of net loss of sediment would be less than under the No Action or Maximum Powerplant Capacity Alternatives. Arroyo-cutting of high terraces, which is linked to archeological site erosion, would continue. Flood control measures would provide a potential measure of increased protection to these resources.

Physical cultural resources within the river corridor are linked to the sediment resource.

Flows that accelerate sediment erosion also would hasten the deterioration of cultural resources. Flows less than 20,000 to 22,000 cfs appear to provide the highest probabilities for a positive net sand balance in the system. Minimum flows greater than 8,000 cfs would provide the best protection for the Charles H. Spencer steamboat, along with providing a relatively stable sediment base level.

Those biological (riparian habitat, wildlife) and mineral (Hopi Salt Mines and associated sand) resources which have been identified as important to Indian Tribes would be protected to a greater extent under the steady flows of these alternatives than under no action.

Site-specific mitigation would be required for all sites considered directly, indirectly, or potentially impacted by these alternatives. Specifics of mitigation actions are included in the section 106 compliance, found in attachment 5.

Existing Monthly Volume Steady Flow Alternative

Degradation of **archeological sites** would continue under this alternative but would be less than under no action due to the higher probabilities of a positive sand balance in the system. Flows would be expected to exceed 20,000 cfs 7 to 17 percent of the time. This would likely allow sediment to accumulate in the river during most years. Beach/habitat-building flows between 26,300 and 45,000 cfs would help maintain sandbars, which protect high terraces and archeological sites. Effects on those sites that have been directly impacted by postdam operations would continue; however, the likelihood of additional impacts on those sites and indirectly impacted sites would lessen. Effects on potentially impacted sites that lie within predam river deposits would continue.

Impacts on **traditional cultural properties** generally would be less under this alternative because sediment loss would be slowed. However, operations under this alternative would still impact the Hopi Salt Mines. Impacts on archeological sites would continue and, as these sites are also considered traditional cultural properties, impacts on traditional cultural properties would continue.

Seasonally Adjusted Steady Flow Alternative

Under this alternative, degradation of **archeological sites** would continue but would be less than under no action due to the higher probabilities of a positive sand balance in the system. Effects on those sites which have been directly impacted by postdam operations would continue; however, the likelihood of additional impacts on those sites and indirectly impacted sites would lessen. Effects on potentially impacted sites that lie within predam river deposits would continue. Flows would be expected to exceed 20,000 cfs 5 to 27 percent of the time. This would likely allow sediment to accumulate in the river during most years. Habitat maintenance and beach/habitat-building flows would help maintain sandbars, which protect high terraces and archeological sites.

Impacts on **traditional cultural properties** would be the same as those described for the Existing Monthly Volume Steady Flow Alternative.

Year-Round Steady Flow Alternative

Degradation of **archeological sites** would continue under year-round steady flows but would be less than under no action due to the higher probabilities of net positive sand balance in the system. Effects on those sites directly impacted by postdam operations would continue; however, the likelihood of additional impacts on those sites and indirectly impacted sites would lessen. Effects on potentially impacted sites that lie within predam river deposits would continue. Flows would be expected to exceed 20,000 cfs 8 to 12 percent of the time, allowing sediment to accumulate in the river during most years.

Beach/habitat-building flows between 21,400 and 45,000 cfs would help maintain sandbars, which protect high terraces and archeological sites. The probability of a net positive sand balance would be very high. Although sediment deposition would not be substantial enough to increase the stability of the sediment deposits, erosion of terraces in direct contact with the river would be reduced.

Impacts on **traditional cultural properties** would be the same as those described for the Existing Monthly Volume Steady Flow Alternative.

AIR QUALITY

Issue:

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

Indicators:

Sulfates in **Grand Canyon air**
Tons of sulfur dioxide (SO_2) and nitrogen oxides (NO_x) in **regional air**

Impacts on air quality in the immediate Grand Canyon vicinity and across the region served with Salt Lake City Area (SLCA) power were evaluated for each alternative. Although hydroelectric power production at Glen Canyon Dam has no direct influence on air quality, a change in its operations would affect the electrical power system of which it is a part. Glen Canyon Dam historically has been used to produce peaking power. If it were used as a baseload or base-assist facility instead, another source of peaking power would be required to generate the amount of peaking power that could not be compensated for through conservation or renewable energy technologies. If the alternative source of power used fossil fuel, there would be a net change in system emissions, either in the region or somewhere in the SLCA marketing area. Fossil fuels contain hydrocarbons, whose combustion can result in emissions of such atmospheric pollutants as sulfur dioxide and nitrogen oxides.

Natural gas combustion turbines are a common type of facility used to produce peaking power. Like hydroelectric generators, gas combustion turbines can be used to follow load during peak periods of demand. Natural gas is a hydrocarbon fuel, but is relatively clean compared to coal. Although it might be necessary to use gas turbines to replace peaking power if dam operations are changed, it is also likely that Glen Canyon Powerplant would be used to replace power production at baseload or base-assist facilities, many of which burn coal. It is also possible that a change in operations could influence the schedule for adding new baseload facilities to the power system (see chapter IV, HYDROPOWER). Emissions from coal combustion usually have components of SO_2 and NO_x in greater amounts than emissions from natural gas.

Analysis Methods

This EIS considered SO_2 and NO_x emissions and factors such as the Clean Air Act provisions mandating a national ceiling on such emissions. Information on other substances—such as carbon monoxide and particulates—was not available for this EIS. However, numbers for SO_2 and NO_x can be considered representative of changes in carbon monoxide and particulate concentrations.

The two computer models used to assess hydropower impacts also were used to assess power system impacts (Roluti et al., written communication, 1992). However, these models do not specify the location and concentration of atmospheric pollutants. Emissions could have an influence on the air quality in Grand Canyon and the other national parks on the Colorado Plateau, all of which are class I areas (chapter III, AIR QUALITY). However, the source of emissions would not necessarily be in the immediate vicinity; it could be elsewhere in the load control area. If there were not enough peaking power capacity within the region and it became necessary to construct a new facility, it would be necessary to conduct a new source review. However, in this analysis it is not as important to know the source as it is to understand the relative tradeoffs of different alternatives and their influence, in terms of emissions and their relative influence on air quality.

The first 5 years of operation under each alternative and how that operation would influence air quality are defined as short-term impacts. Since modeling results did not provide emissions estimates for a 5-year period, this analysis looks at what short-term system expansion might be needed and how that expansion would influence, in qualified terms, system emissions. The geographic area of potential impacts would be the same as for hydropower—the SLCA/IP service area, which includes all or part of Wyoming, Utah, Colorado, Arizona, Nevada, and New Mexico.

For the long-term period of analysis, emissions representing a 50-year period and across the regional power grid area are evaluated. This emissions analysis includes assumptions for power system expansion plans. Emissions would vary by alternative because each would require a different power system expansion plan.

Summary of Impacts: Air Quality

Glen Canyon Dam is in the same power system as the Navajo Generation Station, which was identified as a source of **Grand Canyon** air **quality** problems and is scheduled to be modified to reduce emissions, beginning in 1995. Navajo Generating Station is independent of Glen Canyon Dam operations, and its modifications will be made regardless of which EIS alternative is implemented. Grand Canyon air quality would likely improve due to the modifications at Navajo Generating Station no matter which alternative is selected.

Under most of the alternatives, increased emissions of SO_2 and NO_X would affect **regional** air **quality** compared to no action conditions because more baseload capacity would need to be added sooner. However, under all alternatives, net changes in emissions would be less than plus or minus 1 percent compared to no action. Table IV-16 presents impacts on air quality that would likely result from each alternative. The amount of peaking power that would need to be replaced varies under each alternative.

The endangered fish research flows initially included in the Modified Low Fluctuating Flow Alternative are not expected to result in any additional impacts on air quality.

Unrestricted Fluctuating Flows

No Action Alternative

Glen Canyon Powerplant is used as a peaking power facility, but it is part of a regional power system that is made up of both hydropower and fossil fuel plants. Power production at the dam varies annually based on the volume of water available to pass through the turbines. It is anticipated that demand for power from the system will increase, but most short-term increases in demand can be absorbed by greater energy efficiency. It is also anticipated that, by as early as 1995, gas combustion turbines will be added to the power system to replace older and inefficient facilities. Since natural gas is a cleaner fuel than coal, these additions probably will reduce system emissions over the short term.

In the long term, the need for additional baseload coal-fired capacity is anticipated. The emissions of the power system for the entire period would be approximately 2 million tons of SO_2 and 2 million tons of NO_X.

Maximum Powerplant Capacity Alternative

Power production under the Maximum Powerplant Capacity Alternative would be similar to that under the No Action Alternative. Changes in SO_2 emissions would range from a decrease of 0.9 thousand ton to no change from no action, while changes in NO_X emissions could range from a decrease of 1.2 thousand tons to no change from no action.

Restricted Fluctuating Flows

Emissions would vary by alternative. In the short term, facility emissions would be similar to those under the No Action Alternative.

Table IV-16.—Summary of anticipated impacts on AIR QUALITY during the 50-year period of analysis by alternative

AIR QUALITY	No Action	Maximum Powerplant Capacity	High Fluctuating Flow	Moderate Fluctuating Flow	Modified Low Fluctuating Flow	Interim Low Fluctuating Flow	Existing Monthly Volume Steady Flow	Seasonally Adjusted Steady Flow	Year-Round Steady Flow
Grand Canyon air quality									
Sulfates resulting from SO_2 emissions at Navajo Generating Station	Reduced to EPA-mandated levels by 1999	Same as no action	Same as no action	Same as no action	Same as no action	Same as no action	Same as no action	Same as no action	Same as no action
Regional air quality[1]									
SO_2 total emissions (thousand tons)	1,960	-.9 to 0	+1.4 to +2.8	+9.3 to +13.9	+11.6 to +13.8	+11.6 to +13.8	+10.7 to +15.1	-14.1 to +8.9	+1.6 to +15.4
NO_x total emissions (thousand tons)	1,954	-1.2 to 0	+.4 to +2.2	+3.8 to +9.3	+5.7 to +9.4	+5.7 to +9.4	+11.6 to +16.0	-5.7 to +13.2	-.3 to +12.0

[1] Under all alternatives, changes in SO_2 and NO_x emissions would be less than plus or minus 1 percent compared to no action.

Modeling results for the High Fluctuating Flow Alternative suggest that it would result in fewer emissions over the long term because there would be less use of existing baseload coal-fired capacity. Under the other restricted fluctuating flow alternatives, expansion plans would change to bring on additional baseload production sooner than under no action, resulting in increased emissions.

High Fluctuating Flow Alternative

Under this alternative, increases in SO_2 emissions would range from approximately 1.4 to 2.8 thousand tons. Increases in NO_X emissions would range from approximately 0.4 to 2.2 thousand tons. These changes would be due to less use of existing baseload coal-fired capacity to meet demand. The expansion plan for this alternative would be similar to that under no action.

Moderate Fluctuating Flow Alternative

Lost peaking power would be replaced in the short term through power purchases. Most increases in short-term demand would be absorbed through both increased energy efficiency and additional purchases, resulting in a potential reduction in emissions from baseload facilities.

In the long term, it might be necessary to speed up construction of combustion turbines to replace older facilities. These measures could result in reduced emissions early in the period, since some baseload production would be replaced by Glen Canyon Powerplant, and older combustion turbines would be replaced by more efficient ones. However, new coal-fired generation capacity would be brought online sooner than under the No Action Alternative. Increases of SO_2 emissions would range from 9.3 to 13.9 thousand tons, and increases in NO_X emissions would range from 3.8 to 9.3 thousand tons compared to no action.

Modified Low Fluctuating Flow Alternative

Short- and long-term impacts would be similar to those under the Moderate Fluctuating Flow Alternative. In the long term, SO_2 emission increases would range from 11.6 to 13.8 thousand tons, and NO_X emission increases would range from 5.7 to 9.4 thousand tons as compared to no action. Endangered fish research flows are not expected to result in any additional impacts on air quality.

Interim Low Fluctuating Flow Alternative

Under this alternative, increases in SO_2 and NO_X emissions would be the same as under the Modified Low Fluctuating Flow Alternative.

Steady Flows

More combustion turbine generation would be necessary in the short term for all steady flow alternatives as compared to no action and other fluctuating flow alternatives. This combustion turbine generation would be needed to replace lost marketable capacity, since Glen Canyon Powerplant would be used as a baseload facility. Replacing coal-fired and less efficient combustion turbines would reduce emissions in the short term.

In the long term, the phased addition of new coal-fired, baseload facilities would take place sooner than under no action and other fluctuating flow alternatives. Over the 20-year period, emissions would increase under all steady flow alternatives as compared to no action conditions.

Existing Monthly Volume Steady Flow Alternative

In the long term, SO_2 emission increases would range from 10.7 to 15.1 thousand tons as compared to the No Action Alternative. NO_X emission increases would range from 11.6 to 16.0 thousand tons compared to no action.

Seasonally Adjusted Steady Flow Alternative

In the long term, SO_2 emission changes would range from a decrease of 14.1 thousand tons to an increase of 18.9 thousand tons as compared to the No Action Alternative. NO_X emission changes would range from a decrease of 5.7 thousand tons to an increase of 13.2 thousand tons.

Year-Round Steady Flow Alternative

In the long term, SO_2 emission increases would range from 1.6 to 15.4 thousand tons compared to the No Action Alternative. NO_X emission changes would range from a decrease of 0.3 thousand tons to an increase of 12.0 thousand tons.

RECREATION

Issue:

How do flows 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

Discharge from Glen Canyon Dam affects recreation through its influence on flow-sensitive attributes or through changes in the recreation environment. Impacts on recreation would range from regional to international in scope.

Analysis Methods

Recreation would be impacted immediately by changing discharge, and impacts would occur over both the short and long term. Water years 1989, 1987, and 1984 are used for analyzing impacts under low, medium, and high annual water release conditions. For fluctuating flow alternatives, the magnitude of impacts associated with daily fluctuations for low, moderate, and high release years are compared using certain representative days in those years (figure II-7). Typical conditions, rather than exceptional ones, are evaluated under each alternative. Impacts may be similar for most alternatives during high water years, while quite different during low and moderate water years.

Impacts on the recreation environment, the resource upon which the activity is focused or dependent, are long term (20 to 50 years). Analyses of impacts on resources upon which recreation depends are discussed elsewhere in this chapter (primarily SEDIMENT, FISH, and VEGETATION) and will be only referenced in this section.

Summary of Impacts: Recreation

The impacts of the alternatives on recreation activities are summarized in table IV-17. Numerical values are listed where possible; otherwise, qualitative assessments are made. Impact assessments for many activities are based on rankings of alternative operational scenarios in a study of visitor preferences by Bishop et al. (1987). Each alternative was ranked as more or less favorable for recreation overall and for each indicator activity. As discussed in chapter III, indicator activities are fishing, day rafting, white-water boating, and lake facilities and activities.

Effects of habitat maintenance flows are discussed under the three alternatives that include them.

Initially, endangered fish research flows would be included in the Modified Low Fluctuating Flow Alternative during minimum release years. The extent to which steady flows would be permanently incorporated would depend on evaluation of the research results. Because these 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 table of impacts. Endangered fish research flows (when they occur) would have impacts on recreation that fall within the range of impacts between the Modified Low Fluctuating and Seasonally Adjusted Steady Flow Alternatives.

Based on preferences determined by the Bishop et al. study, net economic values also were estimated for each alternative. Net economic benefits are discussed under "Economics of Recreational Use" at the end of this section.

Table IV-17.—Summary of anticipated impacts on RECREATION by alternative

RECREATION	No Action	Maximum Powerplant Capacity	High Fluctuating Flow	Moderate Fluctuating Flow	Modified Low Fluctuating Flow[1]	Interim Low Fluctuating Flow	Existing Monthly Volume Steady Flow	Seasonally Adjusted Steady Flow	Year-Round Steady Flow
Fishing									
Trip quality (fishing success)	Influenced by daily fluctuations	Same as no action	Same as no action	Minor increase	Potential to become major increase	Potential to become major increase	Potential to become major increase	Moderate increase	Major increase
Glen Canyon blue ribbon trout fishery quality	Influenced by low flows and fluctuations	Negligible decrease	Negligible increase	Minor increase	Minor increase	Minor increase	Minor increase	Minor increase	Minor increase
Angler safety	Potential danger	Same as no action	Same as no action	Moderate improvement	Moderate improvement	Moderate improvement	Major improvement	Major improvement	Major improvement
Day rafting									
Navigation past 3-Mile Bar	Difficult at low flows	Same as no action	Negligible improvement	Major improvement	Major improvement	Major improvement	Major improvement	Major improvement	Major improvement
White-water boating									
Trip quality	Influenced by daily fluctuations and low flows	Same as no action	Same as no action	Moderate increase	Potential to become major increase	Potential to become major increase	Major increase	Major increase	Major increase
Wilderness values	Influenced by daily fluctuations	Same as no action	Minor increase	Moderate increase	Moderate to potential to become major increase	Moderate to potential to become major increase	Major increase	Major increase	Major increase
Safety and handicapped accessibility	High risk at very high and very low flows	Same as no action	Negligible improvement	Minor improvement	Minor improvement	Minor improvement	Moderate improvement	Potential to become major improvement	Major 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	Minor increase	Minor increase	Major increase	Potential to become major increase	Major increase
Lake activities and facilities									
Lake Powell facilities average seasonal adjustment cost ($)	21,600	21,600	21,600	21,600	21,600	21,600	21,600	14,400	21,600
Upper Lake Mead navigability	Primarily influenced by lake elevation	Negligible effect	Minor effect	Minor effect	Minor effect	Moderate effect	Moderate effect	Moderate effect	Minor to moderate effect
Economics									
Equivalent annual net benefit (1991 $ million)	0	0	0	+0.40	+3.74	+3.94	+3.94	+4.76	+2.93

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[1] Impacts of endangered fish research flows (during years when they occur) would be within the range of impacts described for the Modified Low Fluctuating (without these research flows) and Seasonally Adjusted Steady Flow Alternatives.

Fishing

Fishing trip quality for most anglers in the Glen Canyon reach is highest during moderate, steady discharges because they believe such discharges improve several attributes of fishing trips.

Anglers using the Glen Canyon trout fishery place a high value on catching large fish (chapter III, RECREATION). It is believed that under the fluctuating flow alternatives, including no action, trout would be less likely to reproduce and survive until they reach trophy size. Under the Moderate, Modified Low, and Interim Low Fluctuating Flow Alternatives, the potential for catching large fish would increase, and therefore fishing trip quality also would have the potential to increase. The steady flow alternatives are believed to have the greatest potential for benefiting aquatic productivity, which could result in trophy-sized fish.

Rapid stage change puts wading anglers in Glen Canyon at risk of inundation. If their waders are filled with water, it becomes difficult for them to wade or swim toward shore. In the alternatives without ramp rate restrictions, stage can increase within 20 minutes by 0.62 foot at Lees Ferry and by 0.88 foot at the dam (the latter is more representative of the reach). This risk would be reduced under the alternatives with ramp rate restrictions and would be eliminated in the steady flow alternatives, as shown in table IV-18. During high water volume years, fluctuations would be at a minimum under all alternatives. High water velocity may present hazards to wading anglers, but they also would be able to assess risk before putting themselves in a hazardous position.

There are 18 camping beach sites potentially available in Glen Canyon; only 6 of these are formally designated campsites. Six others are available only at discharges of less than 15,000 cfs. These sites would be available in the Moderate, Modified Low, and Interim Low Fluctuating Flow Alternatives during winter months of low discharge years.

Downstream in the Grand Canyon wild fishery, angler safety is not believed to be a major issue, primarily because most fishing activities take place from boats or shore. Historically, trout spawning success has been adequate to maintain the downstream trout fisheries without depending on stocking or restrictive management of fishing activities. Trout population success would likely continue under all alternatives. This issue is discussed in this chapter under FISH and will not be tracked further in this section.

Day Rafting

Boaters in the Glen Canyon reach, most of whom are anglers, have difficulty navigating 3-Mile Bar

Table IV-18.—Stage change in the Glen Canyon reach by alternative

Alternative	Stage change per day at Lees Ferry (feet)	Maximum 20-minute stage change at Lees Ferry (feet)	Maximum 20-minute stage change at Glen Canyon Dam (feet)
No action	4.5	0.62	0.88
Maximum powerplant capacity	4.5	0.62	0.88
High fluctuating flow	4	0.62	0.88
Moderate fluctuating flow	2.5	0.24	0.50
Modified low fluctuating flow	1.5	0.10	0.30
Interim low fluctuating flow	1.5	0.10	0.30
Existing monthly volume steady flow	0	0	0
Seasonally adjusted steady flow	0	0	0
Year-round steady flow	0	0	0

when discharge is 3,000 cfs or less (U.S. Department of the Interior, 1990). Most boaters are unable to move up or downstream, and some of those attempting to navigate the channel hit rocks and sustain boat and motor damage. Difficulties typically occur during morning hours, a popular fishing time.

Boaters would have navigation problems under the No Action, Maximum Powerplant Capacity, and High Fluctuating Flow Alternatives. The other fluctuating flow alternatives, which have minimum flows of 5,000 cfs, would eliminate navigation and safety impacts for most day rafters and other boaters. Steady flow alternatives should make 3-Mile Bar passable to all boaters.

Day rafters in Glen Canyon benefit slightly by launching at the dam rather than at Lees Ferry. However, there is no significant preference by users as to the origin of their trip (Bishop et al., 1987), so impacts would be negligible. All alternatives are thought to have similar influences on day rafting, and habitat maintenance flows are unlikely to have any impact on the quality of day rafting below Glen Canyon Dam. Since this is not a significant issue, it will not be tracked further.

White-Water Boating

White-water boaters prefer moderate fluctuations and steady flows because of their influence on important trip attributes, including itinerary, character of rapids, wilderness values, and boat management at camp. White-water boaters were asked to rank several operational scenarios in the Bishop et al. study (1987). Of the EIS alternatives, the steady flow alternatives would be most similar to the preferred scenarios. Fluctuating flow alternatives with daily range and ramp restrictions and 5,000-cfs minimum flows would be more tolerable than those without.

Wilderness values are influenced by daily fluctuating flows. When the river undergoes wide daily fluctuations, most river-runners are aware of these fluctuations and feel they make the trip seem less like a natural setting (Bishop et al., 1987). Fewer river-runners would be aware of the daily fluctuations under alternatives with more restricted daily ranges. Noticeable fluctuations would decrease with distance below the dam because of wave transformation (see chapter III, WATER). Under the steady flow alternatives, more river-runners would feel that the river provided a more natural setting than fluctuating flows, thus improving wilderness values.

An index of white-water accident risk, developed by Brown and Hahn (1987), was used to compare safety of alternatives. Specific assessments were made for private and commercial groups. The No Action and Maximum Powerplant Capacity Alternatives have the highest overall risk index because they would have more time at low flows, when accident potential is great for commercial motor and small oar-powered craft. The probability of people going overboard is highest at discharges that exceed powerplant capacity (Brown and Hahn, 1987). Risk would be reduced most under the steady flow alternatives, while the restricted fluctuating flow alternatives would reduce risk half as much.

Handicapped accessibility was raised as an issue in scoping and is a concern for NPS, which issues preferential permits for trips with handicapped individuals. Low flows (less than 5,000 cfs) increase the potential for having to walk handicapped individuals around a rapid, while extremely high flows increase the potential for a passenger and rescuer going overboard. Effects on accessibility under each alternative follow the same pattern as accident risk, above.

The number, size, and character of camping beaches in Grand Canyon have a direct effect on the total recreational capacity of the river corridor and the experience for white-water recreationists. The absolute limits on numbers of people are determined by the reaches in which campable beaches are critically limited. Under the fluctuating flow alternatives, distribution of sites within powerplant capacity would be 0.7 site per mile in critical (narrow) reaches and 1.1 sites per mile in noncritical (wide) reaches. Steady flow alternatives would have 0.9 site per mile in critical reaches and 1.1 in noncritical reaches.

The size of a particular camping beach would be highly variable depending on flow, as determined by the maximum daily discharge. In most years, campable area would average 7,720 square feet or less under the No Action, Maximum Powerplant Capacity, and High Fluctuating Flow Alternatives; more than 7,720 square feet under the restricted fluctuating flow alternatives; and up to 9,200 square feet under the steady flow alternatives. Fluctuating flows would influence mooring quality, causing boat management problems and stranding. Under the fluctuating flow alternatives, mooring would be fair to good at 64 percent of camping beaches compared to 92 percent fair to good under the steady flow alternatives.

The reach below Diamond Creek (RM 225 to RM 260) is extremely critical; 11 beaches currently are available—a site distribution ratio of only 0.3 beach per mile. Studies relating campsite availability to various discharges are not being performed on this part of the river. Because a negligible amount of the campable areas would be available below the high water line and fluctuations would attenuate downstream, it can be assumed that any difference in campsite availability due to discharge levels would be minor to negligible. In general, however, the availability and carrying capacity of camping beaches below Diamond Creek would be assumed to follow the same response trends under fluctuating and steady flow alternatives as beaches in other Grand Canyon reaches, and they will not be treated further in this analysis.

Camping area losses due to erosion and/or vegetation overgrowth have been recorded (Ross, written communication, 1992). To what degree this is attributable to dam operations is being studied by the Hualapai Tribe. A comparison of campable area under the various alternatives is shown in table IV-19.

It would be difficult to project the number of camping beaches that would exist under each alternative over the long term. However, sediment storage and active sandbar height were used to indicate the relative potential for maintaining and rebuilding camping beaches over the long term. After the high flows of 1983, more beaches were present than had been in 1975 (figure III-36). Most of the increase probably is evidence of beach-building, meaning many sites are resilient and can be maintained through either habitat maintenance or beach/habitat-building flows. However, some beaches would be lost under all alternatives, due to site characteristics and the presence of the dam.

Floodflows would be more frequent under the No Action and Maximum Powerplant Capacity Alternatives, which could reduce the number of beaches, especially in critical reaches. Under the other alternatives, floods would be reduced owing to the addition of flood frequency reduction measures. Under alternatives that maintain a sediment balance, beaches would be restored to varying degrees (see chapter IV, SEDIMENT).

Table IV-19.—Comparison of campable area by alternative

Alternative	Campable area (square feet)	Number of sites per mile	
		Noncritical reaches	Critical reaches
No action	7,720	1.1	0.7
Maximum powerplant capacity	7,720	1.1	0.7
High fluctuating flow	7,720	1.1	0.7
Moderate fluctuating flow	7,720	1.1	0.7
Modified low fluctuating flow	>7,720	1.1	0.7
Interim low fluctuating flow	>7,720	1.1	0.7
Existing monthly volume steady flow	9,200	+.15	+.2
Seasonally adjusted steady flow	7,720 to 8,200	Same to +.15	Same to +.2
Year-round steady flow	9,199	+.15	+.2

Vegetation encroachment likely would occur at camping beaches. However, visitor use would limit permanent expansion at popular sites under all alternatives. On less popular beaches, vegetation encroachment eventually would make the site difficult to use. If dam operations could be used to limit vegetation encroachment, consistent with ecosystem objectives, habitat maintenance and beach/habitat-building flows likely would be scheduled to do so. However, ecosystem needs are a more important consideration than camping beaches, especially since clearing vegetation is an option, and much of the encroaching vegetation is non-native. Vegetation patterns would vary by alternative and are discussed under VEGETATION, earlier in this chapter.

Lake Activities and Facilities

Lake Powell level depends on annual inflow and water deliveries. The costs to adjust facilities such as marinas, docks, and launch ramps to the lake level are approximately $1,275 per 1-foot change, $33,460 per 25-foot change, and $2 million per single adjustment of 50 or more feet (Combrink and Collins, 1992). Capacities for boating and camping depend on space, which increases with reservoir elevation. Annual fluctuations are much greater than the seasonal fluctuations that occur throughout the year (approximately 18.5 feet under no action in the 50-year analysis); thus, costs of making annual adjustments would be much greater than those for seasonal adjustments. The variability among years would be much greater than the seasonal variability among the alternatives (approximately 6 feet difference among the alternatives). Under all alternatives, the cost of seasonal adjustments most likely would be incremental and generally would not exceed $33,460. Between-year variability for all alternatives could result in adjustments that cost as much as $2 million.

Navigability of the Colorado River where it interfaces with upper Lake Mead is influenced by several factors, including reservoir level, riverflow, and the recent pattern of release and its influence on sedimentation processes. Because release patterns would vary among all alternatives, effects would vary also and are discussed under each alternative. Habitat maintenance flows are expected to have little or no effect on access through the Colorado River delta under any alternative.

Unrestricted Fluctuating Flows

No Action Alternative

Fishing. Most anglers prefer moderate, steady flows (chapter III, RECREATION). However, during low water release years, the historical water release pattern under no action has been widely fluctuating flows (chapter III, WATER). This pattern is preferred over some scenarios, such as very high (greater than 40,000 cfs) or very low (less than 3,000 cfs) steady flows.

During moderate water release years, the reduced range of fluctuations would be seen as an improvement but not a significant one. During high water years, the range of fluctuations would be reduced because of the high volume of water released. However, such high steady discharge would not be preferred because of its negative impact on fishing success.

The effects of no action on the fishery itself parallel the effects on trout described in the FISH section of this chapter. Anglers prefer wild fish over stocked fish, but it would be necessary to continue trout stocking under no action because of stranding and spawning bed exposure resulting from fluctuating flows. Dam operations limit the extent of aquatic food base, thus limiting the trout population that can be supported by the system. Fishery managers have therefore had to limit the trout population and, in turn, restrict harvest either by reducing the creel limit or limiting angler access to the fishery. This policy may be detrimental for anglers who prefer larger bag limits but would likely continue under no action. Fishing is an activity of regional importance.

In the Glen Canyon reach, 18 camping sites potentially are available, but only 12 normally are available. The other 6 are low water sites that are available only when flows are at or below 15,000 cfs. Maximum daily flow would be less than 15,000 cfs 12 percent of the time.

At Lees Ferry, where most angler wading occurs, there can be more than a 4-foot stage change during the day in low water years and even more at the dam. The representative stage change over 20 minutes typically is around 0.62 foot at Lees Ferry and 0.88 foot near the dam (more representative of most of the reach). A rapid change of this magnitude would place wading anglers at risk of inundation.

Day Rafting. During periods of 3,000-cfs flows or less, few (unquantified) boaters can successfully navigate 3-Mile Bar (U.S. Department of the Interior, 1990). Because few anglers would be able to move upstream during hours they prefer, impacts are of major concern. Some of those attempting to navigate the channel hit rocks and sustain boat and motor damage. Under no action, the low end of the daily range commonly reaches 3,000 cfs for the period between Easter and Labor Day and 1,000 cfs between Labor Day and Easter. During low water years, 1,000-cfs flows occur often.

In moderate water years, 1,000-cfs flows are less frequent; however, 3,000-cfs flows may continue to occur, especially during the spring months. Typical summer releases would be around 5,000 cfs, higher than in low water years, with the proportion of successful boat passages increasing to 75 percent during periods of minimum discharge. During high water years, the potential would diminish for both a wide range of fluctuations and extremely low flows. Boats with 10horsepower or smaller motors would have problems getting upstream during high water years.

White-Water Boating. The impacts on white-water recreation, discussed below, typically are short term and of national and international importance.

River Trip Attributes.—Many white-water boating guides and trip leaders have expressed highest preference for either a narrow range of daily fluctuations or steady flows and lowest preference for operations similar to no action. The No Action, Maximum Powerplant Capacity, and High Fluctuating Flow Alternatives rank lowest among alternatives.

Under no action, there are numerous impacts on white-water boating trip attributes. A majority of river-runners feel that flow fluctuations during low water release years make the river seem less natural. During low flow periods, problems with stranding, navigation, and passenger enjoyment may occur (chapter III, RECREATION). During high flow periods, travel time improves as does navigability at some rapids.

During high water years, steady flows would be closer to the preferences of most boaters, although optimum conditions occur under flows of 22,000 to around 31,000 cfs. During high water years, there is more possibility that passengers on oar-powered trips would have to walk around one of the major rapids. Campsites would become smaller, and the likelihood of camping with or near another group would be increased.

Wilderness Values.—Under no action, the range of fluctuations occurring under all but the highest water volume months (and years) would be noticed by up to 87 percent of all river-runners. Of these, 75 percent of private and 50 percent of commercial passengers feel fluctuating flows make a river trip setting seem less natural. The magnitude of the impact would likely be greatest during low water years when the range of fluctuations is greatest. It is likely that the river seems most natural during high water years, due to the lack of daily fluctuations.

White-Water Safety (Accident Occurrence).—The No Action Alternative has the highest potential of all the alternatives except the Maximum Powerplant Capacity Alternative for accident occurrence. This is due to the length of extremely low and extremely high discharge periods and would be especially true during low water years. During periods of low flow (less than 5,000 cfs), the relative risk index of having an accident would be greatest for commercial motor and small oar-powered craft (Brown and Hahn, 1987; Jalbert, 1992). During the high flow periods of the day, risk would decrease for all boat types.

During high water volume years, floodflows may occur. The probability of having an accident while running a rapid during floodflows is highest for all trips, but especially for small, oar-powered craft. No action would have the greatest overall relative level of risk.

Handicapped Accessibility.—Under no action, passengers potentially would have to walk around rapids during low water periods, a situation that could impact physically challenged persons. Having to walk around rapids occurs most with motor rigs and smaller oar-powered craft. During high flow periods, this problem decreases for all boat types; however, the risk of people going overboard is increased.

Floodflows increase the potential of handicapped individuals having to walk around some rapids. The overall risk of capsizing a boat is also greatest. These risk patterns are similar to those experienced by the general population, but the effects are potentially greater.

Camping Beaches.—Even though size of a particular camping beach may be highly variable owing to fluctuating flows, the amount of campable area under no action can be determined largely by the maximum discharge within the daily period. In other words, a new beach exposed during the low flow period does not provide additional camping area because it could still be inundated during the high flow period.

On typical days in low and moderate water release years, the maximum daily release would be in the range of 25,000 to 30,000 cfs. The average campsite area above this discharge would be less than 7,720 square feet (the average for 25,000 cfs), with large, medium, and small sites averaging less than 11,720; 4,950; and 2,390 square feet, respectively. During high water release years, usable campsite area would be further reduced; campable area during flows above powerplant capacity has not been quantified.

The absolute limits on the Grand Canyon's recreational carrying capacity are determined by camping beach distribution in critical (narrow) reaches. Some sites are usable at all discharges within powerplant capacity—approximately 0.7 site per mile in critical reaches and 1.1 sites per mile in noncritical reaches. Additional low water sites—approximately 0.2 per mile in critical reaches and 0.15 in noncritical reaches—are not usable under no action due to range of fluctuations.

In the long term, it is expected that the number of beaches would decline to a new equilibrium value, especially in critical reaches, due to the low probability of storing sand in the system (table IV-8). This decline in camping beach numbers would reduce the canyon's carrying capacity so that the numbers of parties that could be accommodated would progressively decrease. Under no action, there would not be enough sand stored in the system to rebuild sandbars and camping beaches.

During low and moderate water years, mooring quality is poor at 36 percent of the camping beaches due to fluctuating flows and the resulting influence on boat management and stranding.

Lake Activities and Facilities. Changes in dam operations could affect lake levels—and therefore facilities and recreation activities—at both Lakes Powell and Mead.

Lake Powell Facilities.—Lake elevation may rise or decline with water deliveries, requiring adjustment of lake facilities such as marinas, docks, and launch ramps. Under no action, the median amount of seasonal change in lake elevation (50-year analysis) is approximately 18.5 feet, with minimum elevation occurring during March and maximum elevation occurring during July. Between-year variability in lake elevation is greater than seasonal variability. During successive years of high water inflow from the Upper Basin, Lake Powell can be maintained at a high level. During these periods, annual adjustment costs are low, but operators of lake facilities incur approximately $1,275 of seasonal expense for every foot of adjustment necessary.

During periods of moderate water inflow, Lake Powell elevation may drop. The approximate cost of seasonal adjustments remains the same, but the one-time cost of making an annual adjustment for lake fluctuations exceeding 25 feet is approximately $33,460. When the lake level declines more than 25 to 30 feet, capital costs increase. For every 50-foot drop in lake elevation, the capital investment is estimated to be $2 million; these between-year costs are more likely to occur during successive low water years.

Lake Powell Boating.—As the density of boats on the lake increases, so does the potential for collisions and other recreational accidents. Safe boating capacity increases as surface area increases and declines with lake elevation. At 3700-foot elevation, which would result under successive high water years, the lake has a safe boating density of approximately 17,932 boats. In moderate water years, if lake elevation dropped to around 3680 feet, safe boating density would decrease to 16,387 boats. If the reservoir level reaches 3660 feet, as it might following several low water years, safe boating density could decrease to 14,920 boats.

Lake Powell Camping.—The number of campsites the shoreline can accommodate decreases as lake elevation declines. (Boaters generally camp at the lakeshore, near their boats.) Recreational use levels ultimately would be limited by suitable campsites. Potential campsite capacity for Lake Powell at full pool would be approximately 7,360 campsites. At a 3680-foot elevation, potential campsite capacity may decrease to approximately 7,134 sites. Shoreline campsite capacity would decrease to approximately 7,105 sites at 3660-foot elevation and 6,586 sites at 3620-foot elevation.

Navigability of Upper Lake Mead/Colorado River.—High lake elevations and sediment deposition during 1983-86 caused Lake Mead to submerge all rapids through Lower Granite Gorge downstream from RM 235 (see chapter III, SEDIMENT). In 1987, Lake Mead began to recede, and a shallow river channel formed. The Colorado River delta now restricts passage into or out of the Lower Gorge within Grand Canyon. The channel also is choked by new sediment being dropped along the low velocity river that runs through the area. Marsh habitat has spread on the delta along the channel banks. The extent and magnitude of these navigation problems have not been thoroughly investigated; however, it is known from observations that the number of take-outs at South Cove (further downlake) increases during successive low water years because navigation is difficult in Pierce basin.

During low and moderate water years, when fluctuating flows are prevalent, navigation is most difficult because the configuration of the river channel can change daily. During the low water portion of the day, navigation can be difficult where the river interfaces with flat lake water because the river channel can be shallow and sandbars sometimes are exposed. Conditions for navigation are best during high water years, when lake levels are high. Impacts are unquantified.

Maximum Powerplant Capacity Alternative

The influences of this alternative on recreational resources would be essentially the same as those that occur under no action. Recreation variables influenced under no action would likely be influenced to an even greater extent under this alternative. However, the relative difference is not supported by research; therefore, impacts of this alternative will be characterized as the same as no action.

Restricted Fluctuating Flows

Impacts to recreation under the High, Moderate, Modified Low, and Interim Low Fluctuating Flow Alternatives are described in this section. An overview of common impacts from these alternatives is presented first; specific details follow under the individual alternatives.

Under the restricted fluctuating flow alternatives, impacts on **fishing** would vary, but all would potentially reduce dependence on stocking. Because of the reduced range of fluctuations, all restricted fluctuating flow alternatives would reduce angler safety problems compared to no action, but the amounts would vary by alternative. In the Glen Canyon reach, the same number of campsites probably would exist in July and August under all restricted fluctuating flow alternatives as under no action. During low volume months, six additional sites would be usable, except under the High Fluctuating Flow Alternative.

Up to 75 percent of all **day rafting** boats should be able to navigate the 3-Mile Bar under all restricted fluctuating flow alternatives except the High Fluctuating Flow Alternative, which would be similar to no action.

The Moderate, Modified Low, and Interim Low Fluctuating Flow Alternatives would have improved impacts on **white-water boating** trip attributes and would be closer to preference than no action. The High Fluctuating Flow Alternative would have impacts on river trip attributes comparable to no action. River-runners would be aware of fluctuations under all alternatives. There likely would be a difference in the magnitude of such impacts compared to no action, but this difference has not been quantified.

The relative risk of accident occurrence would vary among the four restricted fluctuating flow alternatives from 4 to 10 percent less than under no action. The High Fluctuating Flow Alternative would be similar to no action, while the others would reduce the amount of time at low flow risk. There would be no differences among alternatives during floodflows.

Effects on handicapped accessibility would vary among the restricted fluctuating flow alternatives. Low flow risk would be greatest during low water release years under the High Fluctuating Flow Alternative.

Under all restricted fluctuating flow alternatives except high fluctuating flows, there would be numerous months when maximum discharge would not exceed 15,000 cfs and when beach availability and distribution in Grand Canyon would increase—up to 0.9 site per mile in critical reaches and 1.28 sites per mile in noncritical reaches. However, boaters using these sites would be at risk of being inundated in the event of emergency exception criteria (chapter II, "Common Elements").

The availability and distribution of beaches in Grand Canyon over the short term would be comparable to no action. Under restricted fluctuating flows, camping beaches would be dynamic but more stable than under the No Action and Maximum Powerplant Capacity Alternatives. Beach height would be lower, but the amount of riverbed sand available for deposition would increase over time (table IV-8). Sandbar heights and active widths would be greater than under steady flow alternatives, and the bar heights under Moderate and Modified Low Fluctuating Flow Alternatives would be maintained due to the habitat maintenance flows. The potential for rebuilding and maintaining camping beaches is greater than under no action, although site loss would continue in some places.

Enough sediment would be available under all restricted fluctuating flow alternatives to contribute toward maintaining and rebuilding camping beaches with beach/habitat-building flows. Reduced flood frequency would likely maintain beaches in critical reaches, because there would be fewer floods of a magnitude to top debris fans. Managed, low magnitude beach/habitat-building flows would help maintain beach distribution under all alternatives; longevity of benefits would vary by alternative.

Mooring quality would be essentially the same as under no action—poor at 40 percent of the camping beaches—although the severity of boat stranding and mooring difficulties would decrease as the range of fluctuations decreased. Stage change would be much reduced in the summer months under the Modified Low and Interim Low Fluctuating Flow Alternatives.

Concerning **lake activities and facilities**, Lake Powell's annual water storage and surface area would be the same as under no action. As a result, the costs of making facility adjustments under most alternatives would be the same as those incurred under no action. Safe boating capacity and recreation use levels, as determined by the number of suitable campsites, also would be the same as no action under all fluctuating flow alternatives.

Navigability of upper Lake Mead under all restricted fluctuating flow alternatives would be improved compared to no action.

High Fluctuating Flow Alternative

Regarding **fishing** trip attributes, the High Fluctuating Flow Alternative would have impacts similar to no action, although the reduced ranges in daily flows would result in improvements. Management of the fishery in Glen Canyon and in Grand Canyon would be similar to no action.

The overall (relative) risk of having a **white-water boating** accident would be 4 percent less than under no action. The risk for commercial users would be approximately the same as under no action, while the risk for private users would be 12 percent less.

Moderate Fluctuating Flow Alternative

Increased reliable minimum flows (5,000 cfs) during the trout spawning season would improve fishing by reducing trout stranding, increasing recruitment and aquatic productivity, and reducing reliance on trout stocking.

Habitat maintenance flows included in this alternative are likely to have short-term effects on angling quality in Glen Canyon. During the early stages of the habitat flow, there would be increased drift of macroinvertebrates and detritus. This would likely stimulate increased trout feeding and thereby improve fishing quality. During the latter days of the habitat maintenance flow period, drift would decline and continuing high releases might make fishing more difficult than at lower flows. The net effect on angling quality is unknown but likely to be minor due to the short duration of these events.

The daily stage change affecting wading anglers at Lees Ferry would be approximately 2 feet less than under no action. Representative 20-minute stage changes would be approximately 0.24 foot (61 percent less than no action) at Lees Ferry and 0.5 foot (43 percent less than no action) at the dam.

Habitat maintenance and beach/habitat-building flows also would have some effect on the safety of wading anglers. This effect generally would be limited to the transition period when flow is being increased from normal operations to the higher habitat maintenance flows. During this transition, increasing flows might catch unwary anglers in midstream. However, since Lees Ferry is the sole access point for this reach, this potential safety problem could be easily mitigated by notifying anglers in advance of this impending flow change. Once target flows are reached, the risk of angler inundation due to fluctuations would be eliminated. Higher velocity flows would present some increase in risk to wading anglers, but most individuals can recognize this risk and avoid placing themselves in a dangerous situation.

Approximately 75 percent of all **day rafting** parties would be able to negotiate 3-Mile Bar at minimum discharge (5,000 cfs), compared to only a few at 3,000 cfs (U.S. Department of the Interior, 1990). Some boat and motor damage would likely occur.

High, steady habitat maintenance flows would make boating access over 3-Mile Bar easier but might make upstream passage more difficult for boats with smaller engines. Additional caution on the part of boaters might be required to avoid being stranded at mooring sites as the water level recedes.

Discharge levels would improve **white-water boating** trip attributes in terms of guide and trip leader preferences. Fewer white-water boaters (69 percent, or 18 percent less than under no action) would be aware of fluctuating flows because of increased restrictions.

Effects of habitat maintenance flows on white-water boating would be negligible because they would be scheduled before the peak rafting season. Individuals taking trips during the period when habitat maintenance flows begin undoubtedly would notice the transitions between normal operations and maintenance flows. The changes in river stage would be similar to naturally occurring tributary flood events except that they would not include large sediment inflows. Some individuals might perceive high flows without sediment as artificial, which could impact their wilderness experience.

Conversely, habitat maintenance flows would contribute to maintenance of the natural environment, including sandbars and beaches. This might improve the wilderness character of trips for the majority of individuals.

The overall risk of having a white-water accident would be 10 percent less than under the No Action Alternative. The risk index for commercial users would be 7 percent less than under no action, for private users risk would be 16 percent less. The potential for having to walk around a rapid would be diminished for all trip types. The risk of people going overboard in a rapid would remain during high flow periods.

During habitat maintenance flows, the probability that some passengers may opt or be required to walk around major rapids would be somewhat increased. This could be a problem for handicapped individuals boating during this period. High flows also could increase the risk of white-water boating accidents. However, these flows would be scheduled for only 1 to 2 weeks during low-use periods. For these reasons, the influence of habitat maintenance flows on handicapped access and on white-water boating accidents likely would be negligible.

Average campable area would be greater than the average of 7,720 square feet available under no action. During habitat maintenance flows included in this alternative, changes in stage would require carefully locating camps and mooring sites.

Concerning **lake activities and facilities**, there would likely be improved navigability in the river and at the interface with Lake Mead, but difficulties would remain due to fluctuations in river stage. Sandbars would continue to be exposed during low flow periods, but conditions might be less variable because river velocity would be less variable.

In a year when habitat maintenance flows are scheduled, the level of Lake Powell would be about 1.5 feet above normal from October through March. During the 1 to 2 weeks of habitat maintenance flows in March/April, the level of Lake Powell would fall by approximately 3 feet, resulting in facility adjustment charges of approximately $4,000. Following habitat maintenance flows, the lake would be approximately 1.5 feet below normal. Compared to a year without habitat maintenance flows, lake elevation would gradually increase from March through September.

Modified Low Fluctuating Flow Alternative

This alternative would have the greatest potential (along with interim low fluctuating flows) among the restricted fluctuating flow alternatives of enhancing **fishing** by reducing trout stocking in the Glen Canyon reach.

Habitat maintenance flows included in this alternative would likely have short-term effects on angling quality in Glen Canyon. During the early stages of the habitat flow, there would be increased drift of macroinvertebrates and detritus. This would likely stimulate increased trout feeding and thereby improve fishing quality. During the latter days of the habitat maintenance flow period, drift would decline and continuing high releases might make fishing more difficult than at lower flows. The net effect on angling quality is unknown but likely to be minor due to the short duration of these events.

In years when they occur, endangered fish research flows would have impacts on recreation that fall within the range of impacts between this alternative and the Seasonally Adjusted Steady Flow Alternative.

The stage change at Lees Ferry would be approximately 1.5 feet, or 3 feet less than under no action. Representative 20-minute stage changes typically would be in the range of 0.1 foot (83 percent less than no action) at Lees Ferry and 0.3 foot (66 percent less than no action) at the dam. As such, the risk of major impacts to anglers would be reduced.

Habitat maintenance and beach/habitat-building flows also would have some effect on the safety of wading anglers during the transition period when flow is being increased from normal operations to the higher flows. These effects would be the same as described under the Moderate Fluctuating Flow Alternative.

Campable area would have a slight, unquantified improvement over the Moderate Fluctuating Flow Alternative. During most months, the number of available camping areas would be the same as under no action. During days with maximum flows less than 15,000 cfs, the number of available beaches in Glen Canyon would increase by six.

High, steady habitat maintenance flows would make boating access over 3-Mile Bar easier but might make upstream passage more difficult for boats with smaller engines.

White-water boating trips would benefit because the minimum flow and range restriction would reduce effects on mooring/boat management and navigation of rapids. The range of fluctuations would be among those most preferred for both guides/trip leaders and passengers. Effects of habitat maintenance flows on white-water boating would be the same as those described under the Moderate Fluctuating Flow Alternative.

The overall risk of white-water rafters having an accident would be 10 percent less than under no action. The risk index for commercial users would be 7 percent less than under no action, while the index for private users would be 15 percent less. The effects of habitat maintenance flows on handicapped access and on white-water boating accidents likely would be negligible.

Campable area would be slightly improved over the Moderate Fluctuating Flow Alternative. During most months, the number of available camping areas would be the same as under no action. However, during those days when the maximum flow would be less than 15,000 cfs, the number of available beaches in Grand Canyon would increase by 0.2 site per mile in critical reaches and 0.15 site per mile in noncritical reaches. During habitat maintenance flows, changes in stage would require carefully locating camps and mooring sites.

Concerning **lake activities and facilities**, navigability of upper Lake Mead would improve over most other fluctuating flow alternatives, but difficulties would remain since stage would continue to change with the variable flow. Sandbars would continue to be exposed during low flow periods, but conditions would be among the least variable of any fluctuating flow alternative.

In a year when habitat maintenance flows are scheduled, the level of Lake Powell would be about 1.5 feet above normal from October through March. During the 1 to 2 weeks of habitat maintenance flows in March/April, the level of Lake Powell would fall by approximately 3 feet (resulting in facility adjustment charges of approximately $4,000). Following habitat maintenance flows, the lake would be approximately 1.5 feet below normal. Compared to a year without habitat maintenance flows, lake elevation would gradually increase from March through September.

Interim Low Fluctuating Flow Alternative

Except for the influence of habitat maintenance flows, impacts on recreation under the Interim Low Fluctuating Flow Alternative would be the same as under modified low fluctuating flow compared to no action.

Steady Flows

Impacts to recreation under the steady flow alternatives are described in this section. An overview of common impacts is presented first, followed by specific details about individual alternatives.

Releases during low and moderate water years would be comparable to anglers' most preferred fishing scenarios. The fishing environment and associated boating activities would be improved the most under these alternatives. As a result, these three alternatives have the highest preference ranking for fishing among alternatives, with the Year-Round Steady Flow Alternative being the most preferred, followed by the Existing Monthly Volume and Seasonally Adjusted Steady Flow Alternatives (see chapter IV, FISH).

Under all steady flow alternatives, risk of inundation would be removed for wading anglers.

Although some **day rafting** navigation problems might occur during low discharge months (data suggest that elimination of navigation problems would require 10,000 cfs), the frequency of navigation problems would be extremely low.

All three steady flow alternatives would lessen impacts on **white-water boating** trip attributes. Since there would be virtually no daily fluctuations, the risk of stranding moored boats would be eliminated. On the average, rapids would provide a bigger "roller coaster ride" and would thus be more exciting. There would be a low likelihood of passengers having to walk around rapids. Flows during all months of most years would not impede navigation; as a result, rafting parties would not frequently encounter each other. Except during extreme low flow months, the predictable nature of the flow should result in improvement over no action, reducing effects on itinerary.

As a result of these benefits to white-water recreation, steady flow alternatives have three of the highest four preference rankings among alternatives, with seasonally adjusted steady flows being the most preferred.

Since flows would be steady, the river would seem more like a natural setting under all steady flow alternatives as compared to no action. Approximately 38 percent of white-water boaters would be aware of minor stage changes, such as those between months and for power system emergencies. Because these events are rare, impacts would be considered negligible.

Risk of white-water boating accidents would range from 14 to 21 percent less than under no action, with the Year-Round Steady Flow Alternative being lowest.

Flows under the steady flow alternatives would be relatively moderate (except in high water volume years) compared to no action. Due to the lack of daily lows and peaks, both the need for handicapped passengers to walk around rapids and the risk of their going overboard would be reduced. Another benefit of these alternatives would be that handicapped individuals would not need to prepare for both low and high flows within one trip.

Steady flow alternatives would improve usable camping area, distribution, and mooring characteristics compared to no action and fluctuating flow alternatives. Benefits would vary by alternative. Sandbars generally would be less dynamic and more stable. Sandbar heights and active widths would be less under the Existing Monthly Volume and Year-Round Steady Flow Alternatives than under any other alternatives. Bar heights under the Seasonally Adjusted Steady Flow Alternative would be maintained due to habitat maintenance flows (table IV-8). The potential for rebuilding and maintaining camping beaches would be greater than under no action and would be similar to those under moderate and modified low fluctuating flows. The loss of sites would continue in some places.

Under the Existing Monthly Volume Steady Flow Alternative, the monthly delivery pattern, and therefore the impacts on **lake activities and facilities**, would be the same as under no action. The water release pattern would change under the Seasonally Adjusted and Year-Round Steady Flow Alternatives, but the consequential influences on lake facilities, boating capacity, and shoreline campsite capacity essentially would be the same.

The steady flow alternatives would affect navigability similarly to no action during successive low water years. Daily flows at the river/lake interface would improve navigation because steady flows would not alter the river channel as fluctuating flows would. Conditions would continue to be variable, depending on riverflow and velocity, lake level, and prevailing sediment conditions.

Existing Monthly Volume Steady Flow Alternative

This alternative would benefit **fishing** activities and success. Since trout stranding would be eliminated and potential for recruitment and aquatic productivity would be improved, trout stocking would be reduced.

In the Glen Canyon reach, there would be as many as 18 beaches available for camping and day use in low water years—an increase of 6 (50 percent) more than under no action. However, during peak discharge months impacts would be the same as under no action.

Steady flows would result in the near elimination of navigation and access problems for **day rafting** parties at 3-Mile Bar.

White-water boating trip attributes would improve to match preferences. Since daily flows would be steady, the river would seem more like a natural setting to river-runners. The overall risk for white-water boaters under this alternative would be approximately 14 percent less than under no action. The risk for commercial users would be 13 percent less than under no action, while the risk for private users would be 15 percent less.

In most years, additional camping area would be available in Grand Canyon compared to no action and the fluctuating flow alternatives. The average area for campsites would be greater than 9,200 square feet, an increase of more than 25 percent. Campable area for large, medium, and small sites would average, respectively, more than 13,980; 4,940; and 2,660 square feet larger than under no action (for 25,000 cfs discharge). During low discharge months, the area would increase for all beaches to 11,740 square feet, or an increase of more than 52 percent compared to no action. Large, medium, and small campsites would increase in average area to 17,660; 6,490; and 3,560 square feet, respectively.

On most days of the year, low water campsites would be usable, increasing distribution of camping beaches to 0.9 site per mile in critical reaches and 1.28 sites per mile in noncritical reaches, an increase of 0.2 (25 percent), and 0.15 (16 percent) site per mile, respectively, compared to no action. During months well above 15,000 cfs, the low water sites would be unusable.

Mooring quality would be good at 92 percent of camping beaches, compared to 64 percent under no action.

Concerning **lake activities and facilities**, navigability of upper Lake Mead would be the same as under no action during successive low water years. The steady nature of daily flows during all years would improve navigation at the river's interface with the lake.

Seasonally Adjusted Steady Flow Alternative

This alternative would improve **fishing** compared to the No Action Alternative, but has the lowest preference ranking for anglers among the steady flow alternatives.

Habitat maintenance flows included in this alternative are likely to have short-term effects on angling quality and the safety of wading anglers in Glen Canyon. These effects would be the same as those described under the Moderate Fluctuating Flow Alternative.

Habitat maintenance flows would make boating access over 3-Mile Bar easier but might make upstream passage more difficult for boats with smaller engines. Additional caution on the part of boaters might be required to avoid being stranded at mooring sites as the water level recedes.

The overall risk index for **white-water boating** would be 16 percent less than under no action. The index for commercial users would be 16 percent less than under no action, while the index for private users would be 17 percent less.

Effects of habitat maintenance flows on white-water boating would be negligible because they would be scheduled before the peak rafting season. Such effects are identical to those described under the Moderate Fluctuating Flow Alternative. The influence of habitat maintenance flows on handicapped access and on white-water boating accidents likely would be negligible.

All steady flow alternatives would increase usable camping area compared to no action and the fluctuating flow alternatives. During habitat maintenance flows included in this alternative, changes in stage would require carefully locating camps and mooring sites.

Concerning **lake activities and facilities**, the seasonal pattern of Lake Powell elevation would be influenced by the change in water releases (a median seasonal difference of 12.7 feet, which is approximately 6 feet less than under no action). However, the resulting effects on lake facilities, safe boating capacity, and shoreline campsite capacity essentially would be the same as under no action.

In a year when habitat maintenance flows are scheduled, the level of Lake Powell would be about 1.5 feet above normal from October through March. During the 1 to 2 weeks of habitat maintenance flows in March/April, the level of Lake Powell would fall by approximately 3 feet (resulting in facility adjustment charges of approximately $4,000). Following habitat maintenance flows, the lake would be approximately 1.5 feet below normal. Compared to a year without habitat maintenance flows, lake elevation would gradually increase from March through September.

Slightly higher deltas would impair navigability in upper Lake Mead.

Year-Round Steady Flow Alternative

Fishing attributes would improve because more reliable minimum flows (11,400 cfs) during the trout spawning season and steady flows throughout the year would result in near elimination of conditions that contribute to stranding and recruitment failure. The trout fishery would be less dependent on stocking than under any other alternative. Year-round steady flows would have the greatest potential for improved spawning, meaning a larger trout population. As a result, this alternative would have the highest preference ranking for anglers.

Since discharge during low water years is likely to be above 12,000 cfs, this alternative would nearly eliminate navigation and access problems for **day rafting** at 3-Mile Bar.

This alternative is the least preferred of the steady flow alternatives for **white-water rafters**, primarily because of the low volume of water that would be released during summer, the peak white-water season.

The overall risk index for white-water boaters under this alternative would be 21 percent less than under no action. The index for commercial users would be 20 percent less than under no action, while the index for private users would be 23 percent less.

Concerning **lake activities and facilities**, the pattern of discharge would result in lake elevations that would differ seasonally (median elevations in some months would be as much as 4 feet different than under no action). The median within-year range for Lake Powell's elevation would be approximately 18 feet for both the Year-Round Steady Flow and the No Action Alternatives.

Compared to other steady flow alternatives, navigation in upper Lake Mead might progressively diminish in quality during the course of the year because of a lack of variability and the possibility of some river sedimentation.

Economics of Recreational Use

Analysis Methods

Statistical models for angling and commercial and private white-water boating were developed by Bishop et al. (1987) and are reported in Boyle et al. (1988). These statistical models describe the relationship among the economic benefits of each recreation activity, the average flow during the month, and the occurrence of fluctuations exceeding 10,000 cfs during the month. For each type of recreation activity, the model calculates net economic benefits per trip and then aggregates benefits over the actual distribution of recreation trips recorded in 1991.

The statistical models predict the same economic benefits for several of the alternatives because some alternatives have identical inputs to the statistical models. For example, both the Interim Low Fluctuating Flow and Existing Monthly Volume Steady Flow Alternatives have the same average monthly flows. There would be no fluctuations under the Existing Monthly Volume Steady Flow Alternative and no fluctuations over 10,000 cfs under the Interim Low Fluctuating Flow Alternative. Consequently, the statistical models cannot distinguish between these two alternatives. Likewise, the No Action, Maximum Powerplant Capacity, and High Fluctuating Flow Alternatives all allow daily fluctuations exceeding 10,000 cfs and would have identical average releases. Consequently, the statistical models cannot distinguish among these alternatives.

The 50-year analysis is based on hydrology trace number 60, the same 20-year hydrology trace used in the hydropower impact analysis. The use of this 20-year sequence for analyzing recreation benefits required several steps. First, mean monthly flows were calculated using the monthly release volumes for each alternative. Second, it was determined whether or not fluctuations exceeding 10,000 cfs occurred during the month. The result of these two steps was a 20-year series of data for each alternative. Like the power system analysis, the 20th year was repeated for an additional 30 years to obtain a 50-year data series.

The resulting 50-year data series for each alternative was then used in the previously described models. This procedure yielded a 50-year series of net economic values for each alternative. Using the same methodology as the power economics study, the equivalent annual value of this 50-year series was calculated.[3] Next, the equivalent annual value for each alternative was subtracted from the No Action Alternative's equivalent annual value to obtain the change under each alternative.

The discussion for each alternative focuses primarily on water years 1989 (a low water year), 1987 (a moderate water year), and 1984 (a high water year). Monthly average flows in water year 1984 were extremely high—ranging from about 24,000 cfs to nearly 43,000 cfs. Under the Seasonally Adjusted and Year-Round Steady Flow Alternatives, monthly average flows would range from about 20,000 cfs to over 55,000 cfs. While analysis of the alternatives must include these extremes, water years 1985 and 1986 may represent more typical high flow years. Therefore, analysis of these additional water years has been provided for comparison.

Summary of Impacts on Recreation Economics

Recreation Use. The 1991 level of recreation use is shown in figure III-38 in chapter III. Current NPS regulations restrict the number of trips that can be taken, preventing any increase in white-water boating in Grand Canyon. Thus, it seems unlikely that the number of white-water boating trips will change in response to any of the alternatives. The long waiting list for private permits and the number of commercial passengers who cannot be accommodated due to these restrictions appear to ensure that visitation is unlikely to fall below present levels. For these reasons, white-water boating use is held constant at 1991 levels for this study.

Angling trips may vary with general economic conditions, fishing regulations, and the quality of the fishery. Studies have documented a relationship between angling quality and the number of trips taken. In these studies, angling quality has been measured by the species, number, and size of fish caught as well as by the presence of native fish in the catch. Some alternatives may result in changes in average catch, average fish size, and

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[3] The levelized or equivalent annual value of this series is the amount of money which, if received each year, would yield an amount equal to the present worth of the varying 50-year series of payments. The details of this calculation may be found in Shaner (1979).

composition of the fish stock. Presumably, any change in fishery quality would result in a change in the number of trips taken.

Biological models which could predict angling quality are unavailable, and economic models that could predict the number of trips based on angling quality have not been developed. As a result, the magnitude and direction of the biological response to each alternative cannot be assessed now, and it is not possible to predict a resulting change in fishing effort. In the absence of these data, angling recreation is assumed to be at 1991 levels for this study.

Net Economic Value. Release volumes and the magnitude and frequency of fluctuation differ under each alternative. When compared to the No Action Alternative, this variation results in differences in the net economic value of recreation across alternatives.

The estimates of net economic benefit are based on the statistical relationship between flow and recreation holding all other factors at the time of the study the same, thus creating a "snapshot" in time. Therefore, these benefit estimates do not account for any long-term impacts on the recreation environment that might affect value.

Tables IV-21 through IV-27—included with the discussion of individual alternatives— illustrate the representative annual net economic value of recreation by alternative and type of water release year. These individual tables convey the range of expected recreation economic impact for representative water years, but do not reflect the magnitude of the impacts over the long-term (50-year) period of analysis used in this study.

Table IV-20 illustrates the change in equivalent annual value under each alternative compared to no action for the 50-year period. The Seasonally Adjusted Steady Flow Alternative would result in the largest increase in equivalent annual value, $4.76 million, compared to no action. The Maximum Powerplant Capacity and High Fluctuating Flow Alternatives would not change the equivalent annual value of recreational benefits from no action.

Estimates presented in table IV-20 do not capture the long-term impacts of the alternatives on the recreation environment. To the extent that any of

Table IV-20.—Change in equivalent annual value of recreation for the 50-year planning period[1]

	Change in equivalent annual value compared to no action (1991 $ millions)				
Alternative	Anglers	Commercial white-water boating	Private white-water boating	White-water boating below Diamond Creek	Total
No action	0.0	0.0	0.0	0.0	0.0
Maximum powerplant capacity	0.0	0.0	0.0	0.0	0.0
High fluctuating flow	0.0	0.0	0.0	0.0	0.0
Moderate fluctuating flow	0.40	0.10	-0.10	0.0	0.40
Modified low fluctuating flow	0.90	2.60	0.20	0.04	3.74
Interim low fluctuating flow	1.00	2.70	0.20	0.04	3.94
Existing monthly volume steady flow	1.00	2.70	0.20	0.04	3.94
Seasonally adjusted steady flow	0.80	3.60	0.30	0.06	4.76
Year-round steady flow	1.00	1.70	0.20	0.03	2.93

[1] For consistency with power system analysis, the net ecomic benefits in each year were inflated by the projected gross national product price deflator for that year (Power Resources Committee, 1993) and were discounted using the Federal Discount Rate (8.5 percent). The equivalent annual value was then calculated using the same rate.

the proposed alternatives result in long-term impacts on the recreation environment, the estimates in table IV-20 may overstate or understate the true effects on net economic value.

Regional Economic Activity. Since the number of white-water boating trips is not expected to change and the number of angling trips taken is held constant for this analysis, there is no change in regional economic activity for any of the alternatives. Estimates of local economic activity for the No Action Alternative are reported in chapter III, table III-15. These estimates depend on the number of trips taken by nonresidents and their pattern of expenditures.

Recreation, Economics, and Indian Tribes. A number of commercial and private white-water boating trips launch from Diamond Creek on the Hualapai Reservation. Estimates of the net economic value of white-water boating below Diamond Creek are described in tables IV-21 through IV-27 for representative water years and in table IV-20 for the 50-year analysis.

White-water boating use below Diamond Creek, as measured by the number of trips taken, is expected to increase over time until use reaches capacity limits. The nature and timing of this increase is unknown; however, any change in the number of trips is expected to be unrelated to dam operations. Therefore, white-water boating use is held constant at 1991 use levels, and local economic activity would be identical across all alternatives.

Because no other Native American-owned or operated river-based businesses have been identified, no measurable economic impact would be expected under any of the proposed alternatives.

Unrestricted Fluctuating Flows

Under the unrestricted fluctuating flow alternatives, releases in low water years are characterized by low minimum flows with relatively high peak flows of short duration. As a result, flows fluctuate considerably within the constraints imposed by available storage. Flows generally would be below the optimal recreation level, and fluctuations would affect recreation benefits.

Minimum flows in a moderate release year generally would be higher than in low water years, although flow fluctuations would remain large. In a high water release year, minimum flows are higher than under low and moderate release conditions. In addition, because of the need to release a large volume of water, flow fluctuations are reduced.

No Action Alternative. Net economic benefits to white-water boaters and anglers under the No Action Alternative are presented in table IV-21.

Maximum Powerplant Capacity Alternative. Under this alternative, the net economic benefits of white-water boating and angling are the same as under no action (see table IV-21).

Table IV-21.—Net economic benefits of recreation under the No Action, Maximum Powerplant Capacity, and High Fluctuating Flow Alternatives

	Annual benefits (1991 $ millions)				
Type of release year	Anglers	Commercial white-water boating	Private white-water boating	White-water boating below Diamond Creek	Total
Low (1989)	1.3	5.4	1.1	.104	7.904
Moderate (1987)	1.2	6.4	1.2	.122	8.922
High 1 (1984)	1.1	12.4	2.0	.230	15.730
High 2 (1985)	1.1	11.0	1.7	.204	14.004
High 3 (1986)	1.1	10.4	1.6	.186	13.286

Restricted Fluctuating Flows

The effects of restricted fluctuating flow alternatives on net recreation benefits would vary depending on the type of water year and the actual water volume and pattern of releases during that year. Daily fluctuations over 10,000 cfs would be greatly reduced as the alternatives become progressively more restrictive. For example, under the High Fluctuating Flow Alternative, daily fluctuations over 10,000 cfs would be relatively common, while under the Interim Low Fluctuating Flow Alternative, daily fluctuations exceeding 10,000 cfs would never occur.

High Fluctuating Flow Alternative. There would be no difference between the economic benefits generated under this alternative and those generated under no action in any water year (see table IV-21).

Moderate Fluctuating Flow Alternative. In a typical low water release year, habitat maintenance flows would take place for approximately 10 days in March, resulting in a small decrease between the benefits under the Moderate Fluctuating Flow Alternative and benefits under no action. In moderate and high water release years, habitat maintenance flows would not be scheduled, and benefits would be the same as under no action. The results for commercial white-water boating, private white-water boating, and angling are shown in table IV-22.

Modified Low Fluctuating Flow Alternative. Habitat maintenance flows are a component of the Modified Low Fluctuating Flow Alternative. Including these flows during March changes the volume of water released during the remaining 11 months of the year. In a low water release year, the total recreation benefits generated under this alternative would be approximately 17 percent more than under no action.

In a moderate water release year, recreational benefits under this alternative would be approximately 36 percent more than under no action. Because habitat maintenance flows would not take place in moderate release years, there is no difference between modified low and interim low fluctuating flows in these years. Both would increase recreation benefits by approximately 45 percent over no action.

In a high water release year such as 1984, the Modified Low Fluctuating Flow Alternative would produce recreation benefits of approximately 8 percent more than under no action. Because habitat maintenance flows would not take place in high release years such as 1984, 1985, or 1986, there is no difference between modified low and interim low fluctuating flows in these years. Net economic benefits are listed by activity in table IV-23.

In years when they occur, endangered fish research flows would have impacts on recreation similar to those described under the Seasonally Adjusted Steady Flow Alternative.

Table IV-22.—Net economic benefits of recreation under the Moderate Fluctuating Flow Alternative

Type of release year	Annual benefits (1991 $ millions)				
	Anglers	Commercial white-water boating	Private white-water boating	White-water boating below Diamond Creek	Total
Low (1989)	1.5	5.2	0.9	.098	7.698
Moderate (1987)	1.2	6.4	1.2	.122	8.922
High 1 (1984)	1.1	12.4	2.0	.230	15.730
High 2 (1985)	1.1	11.0	1.7	.204	14.004
High 3 (1986)	1.1	10.4	1.6	.186	13.286

Table IV-23.—Net economic benefits of recreation under the Modified Low Fluctuating Flow Alternative

Type of release year	Anglers	Commercial white-water boating	Private white-water boating	White-water boating below Diamond Creek	Total
	Annual benefits (1991 $ millions)				
Low (1989)	1.8	6.3	1.0	.117	9.217
Moderate (1987)	1.3	9.1	1.6	.174	12.974
High 1 (1984)	1.1	13.3	2.1	.247	16.947
High 2 (1985)	1.2	13.6	2.1	.259	17.759
High 3 (1986)	1.2	12.9	2.0	.236	16.536

Interim Low Fluctuating Flow Alternative. Habitat maintenance flows are not included in the Interim Low Fluctuating Flow Alternative. In a low water release year, the total recreational benefits generated would be approximately 22 percent more than under no action.

In a moderate water release year, recreational benefits of this alternative would be approximately 45 percent more than under no action. In a high water release year such as 1984, recreation benefits would be approximately 8 percent more than under no action. Net economic benefits, by activity, are presented in table IV-24.

Steady Flows

The effect of each steady flow alternative on net recreation benefits would vary depending on the type of water year and actual water volume and pattern of releases during that year. The steady flow alternatives would eliminate daily flow fluctuations exceeding 10,000 cfs. In general, reducing these fluctuations would increase net recreation benefits over no action. However, the Existing Monthly Volume and Seasonally Adjusted Steady Flow Alternatives would decrease mean monthly flows during the season when white-water boating use is high. Depending on the water year, this decrease could offset the benefits gained by eliminating flow fluctuations.

Existing Monthly Volume Steady Flow Alternative. In a low water year, this alternative would generate approximately 22 percent more recreation benefits than no action. In a moderate water release year, the Existing Monthly Volume Steady Flow Alternative would produce a 45-percent

Table IV-24.—Net economic benefits of recreation under the Interim Low Fluctuating Flow Alternative

Type of release year	Anglers	Commercial white-water boating	Private white-water boating	White-water boating below Diamond Creek	Total
	Annual benefits (1991 $ millions)				
Low (1989)	1.8	6.6	1.1	.122	9.622
Moderate (1987)	1.7	9.4	1.7	.174	12.974
High 1 (1984)	1.2	13.4	2.1	.247	16.947
High 2 (1985)	1.4	13.0	2.3	.259	17.759
High 3 (1986)	1.4	12.9	2.0	.236	16.536

Table IV-25.—Net economic benefits of recreation under the Existing Monthly Volume Steady Flow Alternative

Type of release year	Annual benefits (1991 $ mlllions)				
	Anglers	Commercial white-water boating	Private white-water boating	White-water boating below Diamond Creek	Total
Low (1989)	1.8	6.6	1.1	.122	9.622
Moderate (1987)	1.7	9.4	1.7	.174	12.975
High 1 (1984)	1.2	13.4	2.1	.248	16.948
High 2 (1985)	1.4	13.8	2.3	.259	17.759
High 3 (1986)	1.4	12.9	2.0	.236	16.536

increase in recreation benefits compared to no action. In a high water release year such as 1984, recreation benefits would be 8 percent more than no action. The results for angling, commercial white-water boating, and private white-water boating are presented in table IV-25.

Seasonally Adjusted Steady Flow Alternative. In a typical low water year, habitat maintenance flows would be scheduled for approximately 10 days during March; otherwise, there would be little flow fluctuation within the season. In a low water year like 1989, net recreation benefits would increase by 20 percent over no action.

On the whole, reduced flow fluctuations in a moderate release year would result in increased benefits to white-water boaters and anglers. Compared to no action, this alternative would result in a 51-percent increase in total net benefits.

In high water volume years, the Seasonally Adjusted Steady Flow Alternative would be characterized by relatively high flows during the summer. The flows for 1984 (a representative high flow year) would be higher than the optimal flows for white-water boating and angling, which would decrease net economic benefits by 4 percent from no action.

For comparison, two other high water years—1985 and 1986—were analyzed. The releases in these years may be more typical of high water years. Based on the 1985 flows, seasonally adjusted steady flows would result in a 21-percent increase in total recreation benefits compared to no action. Based on the 1986 flows, seasonally adjusted steady flows would increase 34 percent over no action. Net economic benefits are presented in table IV-26.

Table IV-26.—Net economic benefits of recreation under the Seasonally Adjusted Steady Flow Alternative

Type of release year	Annual benefits (1991 $ millions)				
	Anglers	Commercial white-water boating	Private white-water boating	White-water boating below Diamond Creek	Total
Low (1989)	1.7	6.7	1.0	.128	9.528
Moderate (1987)	1.6	9.9	1.8	.189	13.489
High 1 (1984)	1.2	11.6	2.0	.233	15.033
High 2 (1985)	1.4	13.1	2.2	.252	16.952
High 3 (1986)	1.5	13.8	2.2	.260	17.760

Table IV-27.—Net economic benefits of recreation under the Year-Round Steady Flow Alternative

Type of release year	Annual benefits (1991 $ millions) Anglers	Commercial white-water boating	Private white-water boating	White-water boating below Diamond Creek	Total
Low (1989)	1.9	5.8	1.0	.110	8.81
Moderate (1987)	1.6	9.9	1.8	.189	13.489
High 1 (1984)	1.2	11.7	2.0	.233	15.133
High 2 (1985)	1.4	13.1	2.2	.251	16.951
High 3 (1986)	1.5	13.8	2.3	.260	17.860

Year-Round Steady Flow Alternative. Minimum flows in low and moderate water years would be higher than under no action and flow fluctuations would be nearly eliminated. Net economic benefits would be increased by 11 percent over no action in a typical low water year. In a moderate water release year, net economic benefits would increase by 51 percent.

In high water years, the Year-Round Steady Flow Alternative would be characterized by relatively high constant flows. In some months, the flows for the 1984 high water release year would be in excess of the optimal flows for white-water boating and angling. Under these conditions, recreation benefits would decrease by 4 percent.

Net economic benefits for all activities under this alternative are shown in table IV-27. Two other high water years—1985 and 1986—were analyzed also. The releases in these years may be more typical of high water years. Under the 1985 water year, net recreation benefits under year-round steady flows would increase 21 percent over no action. Based on the 1986 water year, net recreation benefits would increase 34 percent over no action.

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

Impacts on power operations relate to changes in how Western interacts with and provides electrical services to other utilities in the region. Impacts on power marketing are based on effects on long-term firm power marketing in a regional market of more than 180 utilities and 3 million consumers primarily in six Western States: Arizona, Colorado, Nevada, New Mexico, Utah, and Wyoming.

Analysis Methods

This impact analysis was based on studies prepared by the GCES Power Resources Committee. The analysis used the latest available data to quantify the impacts of operational changes at Glen Canyon Dam. Computer models used were: CRSS (to simulate future hydrological conditions), the Electric Power Research Institute's Electric Generation Expansion Analysis System and Environmental Defense Fund's Electric Utility Financial and Production Cost (to simulate operations of the regional interconnected power system), and Western's Power Repayment Study (to calculate the SLCA/IP firm power rates).

Long-term firm power marketing impacts were based on the following factors:

- SLCA/IP marketable resource (how much would be available to market)
- Economic costs (to power industry productivity)
- Financial costs (to individual utilities or groups of utilities)
- Wholesale and retail power rates (how much the resource will cost)

The latest hydrologic information was used in the CRSS model to provide the most up-to-date monthly capacity and energy projections. Use of the latest hydrology data resulted in slightly lower marketable capacity and energy values than those developed for post-1989 criteria. To compensate, the no action seasonal capacity and energy values were scaled upward to match these levels. Capacity and energy values for the other alternatives also were scaled upward to provide a consistent basis for comparison.

The terms "economic" and "financial" often are used interchangeably, but here they represent two different concepts. The economic analysis takes a societal or national perspective. It focuses on economic gains or losses within the electrical power industry as a whole. The financial analysis looks at individual utilities or groups of utilities.

The economic analysis assumed two marketing arrangements: hydrology and contract rate of delivery (CROD). The hydrology approach assumed that Western would sell only capacity generated by the SLCA/IP powerplants and that customers would have to purchase firm capacity and energy elsewhere to meet any additional needs.

The CROD analysis assumed capacity and energy would be marketed according to the post-1989 criteria. Under this arrangement, Western would purchase firm capacity—in addition to what it could generate—to meet customer contracts.

The financial analysis examined impacts on utilities, including their costs to build new facilities or buy power elsewhere (utility economic impacts) and costs of transfer payments to buy power elsewhere (interutility transfers). Transfer payments were excluded from the economic analysis because they were considered a redistribution of wealth that would not affect national economic development. However, interutility transfer payments are a real cost to individual utilities, and so were included in the financial analysis.

Part of the financial analysis used wholesale rates, purchase costs, and administrative costs to estimate resulting retail rates. Revenue requirements (how much a utility must make to stay in business) are determined by:

- Increases in the SLCA/IP wholesale rate
- Reductions in Federal firm power allocation
- Increased costs of purchased power (including transfer payments)

The Power Resources Committee did not specifically study short-term impacts on hydropower. However, impacts would occur immediately following the Record of Decision (ROD). Until contracts between Western and its customers are renegotiated, Western might have to purchase replacement capacity to fulfill its contract obligations. These replacement purchases would increase Western's firm power rate.

Long-term impacts (up to 50 years) would include both reduced operational flexibility and less available firm capacity and on-peak firm energy for the region's electrical power market. Long-term impacts to capacity would likely accelerate construction of new coal- and gas-fired thermal generation facilities to replace capacity lost at Glen Canyon Dam—construction that otherwise would have been deferred for 5 to 10 years.

Direct impacts would be those that affect day-to-day operations and change the character of the power resource available to Western's customers. Direct impacts also would include those that affect future planning for hydroelectric service, wholesale customers, other interconnected utilities, and power rates. Indirect impacts would affect end-use customers and the goods and services they provide.

Three alternatives include habitat maintenance flows, which result in less water available for electrical generation during peak power months. These additional impacts were estimated under the CROD cases based on new capacity calculations for each alternative. The hydrology case impact analyses did not include habitat maintenance flows, so results for the alternatives that include such flows are slightly under- estimated. However, the results should still be representative.

Summary of Impacts: Hydropower

The principal values of Glen Canyon Powerplant are its ability to generate electricity without pollution or using nonrenewable resources and its flexibility to quickly and effectively respond to changes in an interconnected generation and transmission network. Removing the components that make hydropower so flexible and responsive—namely, control of how and when water is released—diminishes those values.

Impacts on power operations and marketing are summarized in table IV-28. Since effects on operations are difficult to quantify in economic and financial terms, they are discussed qualitatively in terms of operational flexibility. The power marketing analysis identifies impacts on long-term firm power marketing due to changes in the amount of marketable resource, economic and financial costs, and wholesale and retail rates.

Initially, endangered fish research flows would be included in the Modified Low Fluctuating Flow Alternative during minimum release years. The extent to which steady flows would be permanently incorporated would depend on evaluation of the research results. Because these 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 table of impacts. Endangered fish research flows would have impacts on power economics that fall within the range of impacts between the Modified Low Fluctuating and Seasonally Adjusted Steady Flow Alternatives.

Power Operations

Impacts on power operations range from minor under the Maximum Powerplant Capacity Alternative to major under the Seasonally Adjusted and Year-Round Steady Flow Alternatives. Many factors go into determining the ultimate impact of an alternative on power operations, and changing one factor may affect all the others. Operational restrictions imposed by all but the No Action and Maximum Powerplant Capacity Alternatives would reduce Western's ability to meet its obligations with maximum efficiency and economy and would reduce Glen Canyon's value as a load following and peaking facility.

Although restrictions on dam operations result in reduced flexibility for power operations, it is important to point out that, given the number of variables involved, impacts can vary from minor to major even within an alternative, depending on the frequency and duration of particular events. An example of how these variable electrical system events can result in different effects is provided in Appendix E, Hydropower.

Power Marketing

All alternatives, except the No Action and Maximum Powerplant Capacity Alternatives, would restrict Glen Canyon Powerplant's flexibility to operate in a way most beneficial to electrical generation. Operational restrictions would reduce how much long-term firm power could be marketed. In general, the relative magnitude of impacts to long-term firm power marketing would be:

1. Minor to no impact: No Action, Maximum Powerplant Capacity, and High Fluctuating Flow Alternatives

Table IV-28.—Summary of anticipated impacts on HYDROPOWER during the 50-year period of analysis by alternative

HYDROPOWER	No Action	Maximum Powerplant Capacity	High Fluctuating Flow	Moderate Fluctuating Flow	Modified Low Fluctuating Flow[1]	Interim Low Fluctuating Flow	Existing Monthly Volume Steady Flow	Seasonally Adjusted Steady Flow	Year-Round Steady Flow
Power operations									
Operational flexibility	No effect	Minor/ moderate increase	Minor/ moderate decrease	Moderate decrease	Moderate/ potential to become major decrease	Moderate/ potential to become major decrease	Major decrease	Major decrease	Major decrease
Power marketing									
Marketable resource									
Annual energy (GWh)	6,010	6,010	6,010	6,010	6,010	6,010	6,010	6,007 (-0.1%)	6,001 (-0.2%)
Winter capacity (MW)	1,407	1,407	1,383 (-2%)	1,023 (-27.2%)	965 (-31.4%)	1,035 (-26.4%)	840 (-40.3%)	640 (-54.5%)	735 (-47.8%)
Summer capacity (MW)	1,315	1,315	1,272 (-3.3%)	882 (-32.9%)	852 (-35.2%)	876 (-33.4%)	711 (-45.9%)	498 (-62.4%)	615 (-53.2%)
Annual economic costs (1991 million $)									
Hydrology	0	-2	+2	+44	Not available	+36	+65	+76	+67
Contract rate of delivery	0	0	+3	+36	+41	+36	+69	+119	+86
Annual financial costs (1991 millions $)									
Utility economic analysis	0	0	+7	+76	+85	+75	+125	+187	+147
Interutility transfers	0	0	+4	+40	+44	+39	+56	+68	+61
Wholesale and retail rates (1991 mills/kWh)									
Wholesale rate	18.78	18.78	19.38 (+3.2%)	23.18 (+23.4%)	23.67 (+26.0%)	23.18 (+23.4%)	25.22 (+34.3%)	28.32 (+50.8%)	26.78 (+42.6%)
Retail rate (median)	62.17	62.17	62.72 (+0.9%)	65.77 (+5.8%)	66.15 (+6.4%)	65.77 (+5.8%)	67.20 (+8.1%)	69.03 (+11.0%)	68.09 (+9.5%)

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[1] Impacts of endangered fish research flows would be within the range of impacts described for the Modified Low Fluctuating (without the research flows) and Seasonally Adjusted Steady Flow Alternative.

2. Moderate to potentially major impacts: Moderate Fluctuating, Modified Low Fluctuating, and Interim Low Fluctuating Flow Alternatives

3. Major impacts: Existing Monthly Volume, Seasonally Adjusted, and Year-Round Steady Flow Alternatives

SLCA/IP Marketable Resources. Limiting maximum allowable releases would result in less available capacity; restrictions on ramp rates and allowable daily change in flow would further reduce available capacity. Increasing the minimum flows would reduce the value of energy by forcing increased off-peak releases and limiting the ability to make economy energy sales and purchases.

Capacity.—In going from no action to restricted fluctuating and steady flows, operational flexibility would be increasingly limited. The maximum allowable water releases would go down, and the minimum allowable water releases would go up. This pattern would result in a narrower range of flows that would be further restricted by limits on the allowable daily change in flow. Reduced capacity would mean customers would need to generate or purchase additional capacity from other suppliers. Costs of these transactions have been analyzed and are described under individual alternatives.

Also, the limits on allowable up and down ramp rates would determine how fast water releases could get from an existing flow to a desired flow. Figure IV-16 illustrates the drop in seasonal marketable capacity, primarily due to the decreased maximum allowable releases from fluctuating flows to steady flows.

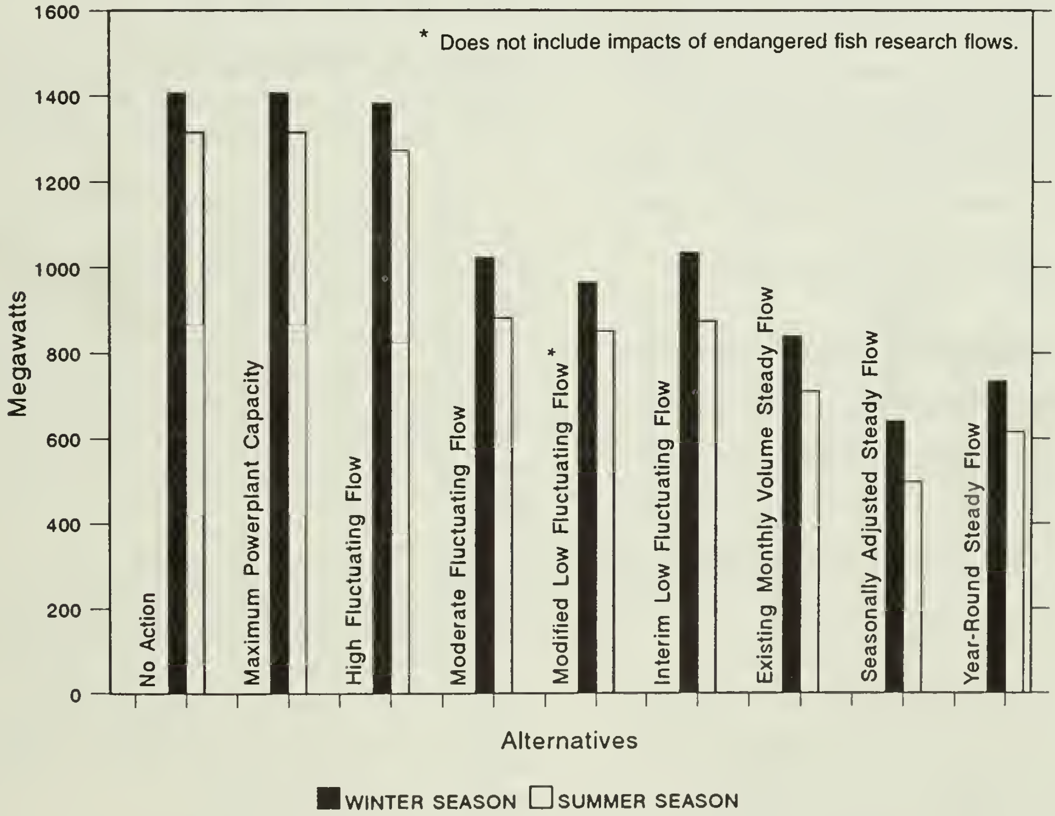

Figure IV-16.—Total SLCA/IP marketable capacity during critical seasons (winter and summer) would vary by alternative.

Figures in appendix E show impacts of the alternatives on the cumulative distribution of capacity used to determine SLCA/IP marketable capacity during critical months for the next 20 years.

Energy.—The times when water is released (time of day and season) also would make a difference. Although there would be little or no impact on the quantity of energy produced daily, releasing more water during off-peak hours (nighttime) means more power would be produced when it is less valuable and less water would be available for release during on-peak periods (daytime) when power is most valuable. Other operational restrictions would make it less likely that the maximum allowable releases could be achieved. These restrictions would become even more important during critical summer and winter peak load months.

Economic Costs. Relatively minor short-term economic costs were estimated because firm capacity reductions would be replaced by existing surplus generation. Eventually, the loss of Glen Canyon capacity would mean that new power generation facilities would be required sooner than they otherwise would have been. To replace this capacity, Western's larger customers could:

- Purchase replacement capacity from other utilities
- Adjust generation from their own resources
- Build additional generation resources

Smaller utilities, without significant generating resources, could:

- Purchase capacity and energy from auxiliary suppliers
- Build their own peaking resources

Because of the large amounts of surplus capacity in the regional power market for a considerable portion of the study period, the economic costs of Glen Canyon alternatives were significantly reduced (by over 50 percent) due to cost discounting procedures. Because of discounting at 8.5-percent interest, any low values early in the study period significantly weight the results to the low side of the range (e.g., at an 8.5-percent discount rate, $1 promised 10 years in the future has the present worth of only 44 cents). Conversely, large values later in the study period have little impact in weighing the impacts one way or another.

Table IV-28 summarizes the economic costs of each alternative. Figure IV-17 shows the range of costs associated with replacing lost capacity from Glen Canyon Dam.

Financial Costs. The total cost of new generating resources and power purchases for all utilities combined is shown by alternative in table IV-28. This table also shows costs for transfer payments, mostly made by small public utilities to large investor-owned utilities. The range of financial impacts on utilities is shown in table IV-29. Some utilities would receive higher financial impacts than others, depending on the extent to which they rely on SLCA/IP power.

Wholesale and Retail Rates. Western primarily markets power at wholesale rates to customers who, in turn, sell at retail rates to their customers.

Wholesale Power Rates.—The SLCA/IP combined (wholesale) long-term firm power rate is set at a level consistent with repayment of allocated project costs over a project's useful life or 50 years, whichever is less. Changes in Glen Canyon Dam operations—with possible resulting changes in the marketable resource and in nonfirm sales and purchases—would affect allocated costs, project revenues, and wholesale rates.

The effects of reduced hydropower production at Glen Canyon Powerplant on long-term firm power rates—used to repay Federal investment in the CRSP and participating projects—are shown in figure IV-18. These rates assume that the current SLCA/IP repayment obligation remains unchanged, and they are used in calculating the impacts on retail power rates.

Table IV-29.—Financial impacts on large and small utilities by alternative

Alternative	Large systems Low	Large systems Median (1991 million $)	Large systems High	Small systems Low	Small systems Median (1991 million $)	Small systems High
No action	0	0	0	0	0	0
Maximum powerplant capacity	0	0	0	0	0	0
High fluctuating flow	0	0.01	0.50	0	0.04	0.74
Moderate fluctuating flow	0.03	1.57	3.33	0	0.45	8.71
Modified low fluctuating flow[1]	0.05	1.81	3.75	0	0.50	9.59
Interim low fluctuating flow	0.03	1.55	3.30	0	0.45	8.65
Existing monthly volume steady flow	1.13	4.58	11.14	0	0.65	12.56
Seasonally adjusted steady flow	2.61	8.91	29.15	0	0.88	17.00
Year-round steady flow	0.98	5.19	15.77	0	0.78	14.76

[1] Does not include impacts of endangered fish research flows.

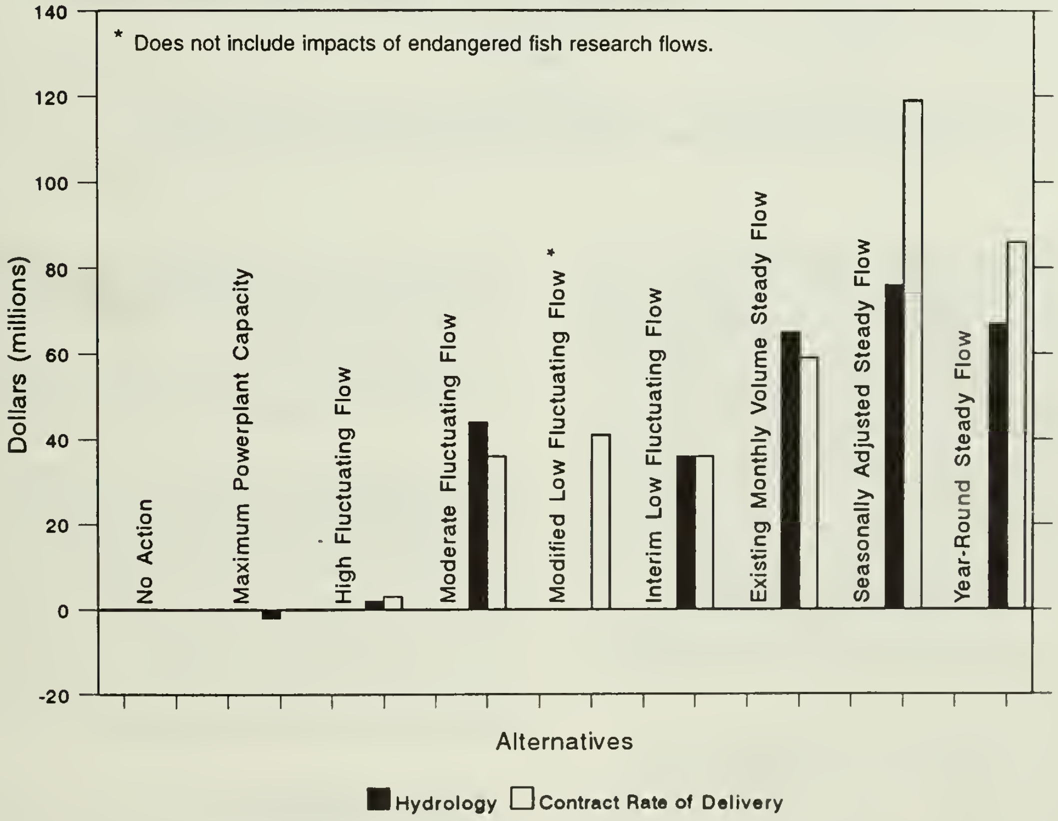

Figure IV-17.—Net annual economic costs would decrease slightly under the Maximum Powerplant Capacity Alternative and increase under all other alternatives compared to no action.

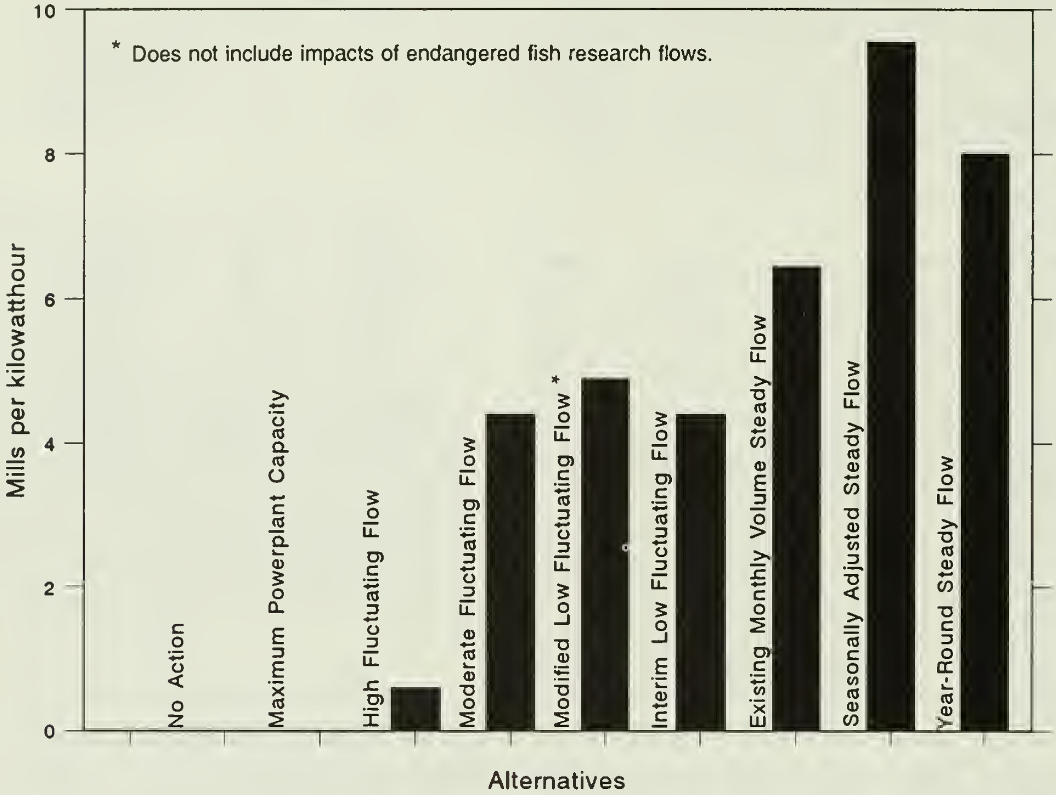

Figure IV-18.—Wholesale rates would increase compared to no action under all alternatives except the Maximum Powerplant Capacity Alternative.

Retail Power Rates.— The retail rate analysis examines impacts on the end-user. Retail rate impacts were assessed for the small SLCA/IP wholesale customers (those that typically do not own generation and transmission facilities) serving retail (industrial, commercial, and residential) consumers. Expected changes in retail rates by alternative are shown in table IV-28. A range of high and low estimates is shown in table IV-30. A breakdown of retail rates by state and type of utility is included in appendix E.

Impacts on small SLCA/IP customer retail rates would depend on:

- How much a customer's allocation is affected by a change in the SLCA/IP marketable resource
- The resulting SLCA/IP firm power rate required to meet Federal repayment obligations
- How much a customer relies on SLCA/IP firm power to meet the electric power service needs of its retail customers
- Availability and cost of replacement power from auxiliary suppliers

Many customers use revenues from the sale of electricity to supplement other sectors of their government, such as parks and recreation, water systems, city maintenance, etc. A loss of this resource would affect city government budgets and services as revenues diminish.

Unrestricted Fluctuating Flows

No Action Alternative

Power Operations. Operations under the No Action Alternative would be as flexible as they were prior to implementation of interim flows.

Table IV-30.—Range of estimated retail power rates by alternative

Alternative	Retail rate range (mills/kWh) High	Median	Low
No action	88.13	62.17	23.86
Maximum powerplant capacity	Same as no action	Same as no action	Same as no action
High fluctuating flow	88.32 (+0.22%)	62.72 (+0.88%)	23.91 (+0.21%)
Moderate fluctuating flow	91.21 (+3.49%)	65.77 (+5.79%)	24.35 (+2.05%)
Modified low fluctuating flow[1]	92.33 (+4.77%)	66.15 (+6.40%)	24.41 (+2.31%)
Interim low fluctuating flow	91.36 (+3.67%)	65.77 (+5.79%)	24.35 (+2.05%)
Existing monthly volume steady flow	95.13 (+7.94%)	67.20 (+8.09%)	24.56 (+2.93%)
Seasonally adjusted steady flow	99.67 (+13.09%)	69.03 (+11.03%)	24.87 (+4.23%)
Year-round steady flow	97.36 (+10.47%)	68.09 (+9.52)	24.86 (+4.19%

[1] Does not include impacts of endangered fish research flows.

There would be an allowable daily range of fluctuation of up to 30,500 cfs and no ramp rate restrictions. The full uprated generating capacity would not be used because the maximum allowable discharge would continue to be administratively limited to 31,500 cfs.

Power Marketing. Impacts would be based on changes in marketable resource, economic and financial costs, and wholesale and retail rates.

SLCA/IP Marketable Resource.—Quantities of SLCA long-term firm capacity and energy under the No Action Alternative are summarized in table IV-28.

Economic Costs.—Studies concluded that, for the next decade (1991-2001), electrical load growth would be met by purchasing existing surplus capacity from interconnected utilities within the regional power market. Energy conservation would prolong this surplus. Aside from the addition of two small combustion turbines in 1996 and 1997 to replace older systems to meet capacity reserve requirements, no significant capacity additions would be made until the year 2001. The total capacity added under the No Action Alternative would be 2,239 MW for the 20-year planning period. The significant capacity additions would include: 600 MW of coal-fired generation, 350 MW of purchased power, 530 MW of combustion turbines, 200 MW of pumped storage, and 560 MW from energy conservation.

Financial Costs.—The utility economic analysis focused on how and where economic impacts would be distributed. This analysis includes the same procedures performed for the economic analysis except that it describes impacts on small and large utilities and includes transfer payments. As explained in the economic analysis, 2,239 MW would be added to the regional power market by the year 2011. This added capacity would be due to planned expansion by individual utilities to meet projected load growth.

A description of interutility transfers was not available for the No Action Alternative; however, changes against a base of zero were calculated for each of the other alternatives. A breakdown of impacts to large and small utilities is shown in table IV-29. Again, a total production cost for the No Action Alternative was not available, so the other alternatives were compared to a zero baseline for no action.

Wholesale and Retail Rates.—Scaling the marketable resource numbers, as described earlier, resulted in increased levels of risk for SLCA/IP in supplying marketable resources.

The results of these increased capacity and energy commitments would be increased capacity and energy purchases, driving up the wholesale long-term firm power rate for the No Action Alternative (table IV-28). In addition, adjustments were made in the power repayment study to prevent additional debt being incurred, increasing the no action firm power rate by nearly 2.06 mills. The current firm power rate (under interim flows) is 16.72 mills/kWh compared to 18.78 mills/kWh for the No Action Alternative.

The rate-setting year for this hypothetical rate is fiscal year 1993, chosen because it was the year when estimated revenues most closely matched estimated costs. The minimum rate required to ensure project repayment would include expenses for project operation and maintenance and for extensive environmental studies.

Table IV-28 shows the expected retail rates under each alternative for small systems within the SLCA/IP. Estimates of minimum and maximum retail rates are shown in table IV-30.

Maximum Powerplant Capacity Alternative

Uprating and rewinding of Glen Canyon Powerplant units (completed in 1987) has improved efficiency. Power operations under the Maximum Powerplant Capacity Alternative would be the same as those under the No Action Alternative, except that the full uprated capacity of the powerplant (33,200 cfs) would be available for use.

Maximum powerplant capacity is achieved by releasing 33,200 cfs, which would occur only when Lake Powell is at elevation 3641 feet or higher. CRSS model projections show Lake Powell would be at that elevation over 60 percent of the time during the next 50 years. At times during those years, Glen Canyon Powerplant could generate up to 56 MW more capacity than under no action. Additional capacity and energy would then be available for regulation, emergencies, reserve, and the economy energy program.

Impacts on all aspects of long-term firm power marketing would be the same as under no action.

Restricted Fluctuating Flows

Power Operations

The following discussion is a general description of impacts to operational flexibility for all restricted fluctuating flow alternatives.

Scheduling. Under restricted fluctuating flows, other variables (water levels, unit outages, and special water releases) would affect the amount of energy that needs to be prescheduled and the price paid for that energy. Extended low-volume releases might result in the need for Western to purchase firm capacity with energy to ensure its customers of a dependable source.

Assuming appropriate market conditions and full unit availability, the criteria limiting use of Glen Canyon Powerplant to provide economy energy would be restrictions on ramping and daily fluctuations. Also, the higher the minimum release, the more limited the flexibility.

Each restricted fluctuating flow alternative has higher minimum flows during off-peak hours compared to the No Action or Maximum Powerplant Capacity Alternatives; therefore, forced economy, off-peak energy sales would be necessary. In other words, when more energy is generated than required to meet load during off-peak hours, Western would be forced to lower its price to a level below that of the most expensive thermal sources in order to sell the power. Western's customers would then be charged more for the power purchased during on-peak hours in order to generate the revenue necessary to meet repayment requirements.

The additional hydroelectric generation at off-peak times means fossil fuel plants could lose money as a result of losing sales to Western's cheaper energy. Western also would not be purchasing energy from the fossil fuel plants during off-peak times, as it would under no action operations. However, since the fossil fuel plants would have to generate more on-peak energy when Glen Canyon Powerplant is less able to respond to demand, sales to other utilities would be expected to increase.

Compared to operations under no action, less on-peak energy would be generated at Glen Canyon Powerplant. Consequently, there would be little if any on-peak energy that could be sold to or exchanged with other utilities at prices lower than generation costs at alternative thermal units.

Impacts on scheduling generation, purchases, water patterns, and other elements depend on the allowable daily change in flows and ramp rates. The more operations are restricted, the more significant the impact. Effects on scheduling would occur hourly and result in increased costs. Under restricted fluctuating flows, Western would have limited options in responding to energy shortages when loads become higher than generation. Power dispatchers would have decreased flexibility to take advantage of market conditions in purchasing or selling capacity and energy.

Discussion of changes expected under restricted fluctuating flow alternatives is based on changes occurring under interim flows (same as the Interim Low Fluctuating Flow Alternative). These changes would include:

1. System efficiency would be reduced.

2. Customers would have to do their own load forecasting, and many small utilities do not have the expertise to make accurate predictions. Inaccurate predictions could be a financial risk for these customers, since some suppliers charge much higher rates to provide generation over and above the forecasted amount.

3. Customers would have to follow load with their own units or with purchases from alternate suppliers. The availability of alternate suppliers is limited at times and frequently costs more.

Western lost about 400 MW of capacity due to the restrictions imposed by interim flows. This figure represents about 21 percent of the total SLCA/IP maximum operating capacity. To date, under interim flows, the tendency for system component loads to peak at different times (system diversity[4]) has saved Western from having to purchase capacity. Western currently averages about 10 to 15 percent available capacity above peak needs due to system diversity. Prior to implementation of interim flows, Western averaged about 30 percent available capacity above peak needs.

Under the High Fluctuating Flow Alternative, system efficiency would be reduced compared to that under no action, but not as much as under Moderate Fluctuating Flows, due to the greater allowable daily change in flows, greater allowable ramp rates, and lower allowable minimum discharge. Under the Moderate Fluctuating Flow

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[4] System diversity is the difference between actual firm load requirements (hourly) and total firm contractual commitments and control area regulation requirements. Diversity changes hourly depending on contractor scheduling practices. Western must maintain operating reserves equivalent to its firm contractual commitments and regulation requirements. Western could not reduce capacity in relation to diversity without affecting responsiveness and the ability to conform to NERC guidelines.

Alternative, the availability of Glen Canyon Powerplant to provide customer services and contribute to system efficiency would be reduced, compared to that under no action. Customer services and operational efficiency would not be reduced as much under Interim Low Fluctuating Flows, due to the greater system flexibility, including allowable daily change in flows, greater allowable ramp rates, higher allowable maximum discharge, and lower allowable minimum discharge.

Load Following. Daily fluctuation limits would restrict use of Glen Canyon Powerplant to respond to changing firm load requirements. For example, a 5,000-cfs change per day allows for only a 190-MW load following capability, and firm load requirements change more than this. Western would find it necessary to make hourly purchases of on-peak, nonfirm energy against the restricted capacity at Glen Canyon Dam to meet firm contract commitments.

The daily fluctuation limit also is tied very closely to up and down ramp rates and the maximum flow limits. For example, under the Interim Low Fluctuating Flow Alternative, the maximum release is 20,000 cfs and the maximum allowable daily change in flows is 8,000 cfs; maximum allowable ramping rates are 2,500 cfs up and 1,500 cfs down. Given those restrictions, if the minimum allowable discharge of 5,000 cfs were released during the night, then water releases could increase to no more than 13,000 cfs during that day. The fastest that releases could increase from 5,000 cfs to 13,000 cfs would be 4 hours (2,500 cfs/hour). Releases could be returned to 5,000 cfs in 6 hours (1,500 cfs/hour)—a major change compared to no action, where flow change capability is plus or minus 33,200 cfs in less than 10 minutes.

When water releases are constrained, operable capacity would be reclassified as inoperable capacity and the contracted amount might have to be changed. Given restrictions under interim operations, total operable capacity from Glen Canyon Powerplant and the other CRSP units could be less than that required to simultaneously satisfy firm load requirements and maintain an acceptable amount of capacity in reserve to cover emergencies. Western would have to acquire a substitute uninterruptible source, at higher expense, to replace this lost capacity.

Regulation and Control. As a load control area operator, Western's function is to ensure that each area utility or group of utilities generates the exact amount of power to meet its load and export responsibilities without relying on the resources of others.

System control would be unaffected if there were no stability, frequency, or voltage problems anywhere in the system; however, impacts ranging from minor to major could result if other CRSP units had problems. Problems with system regulation occur frequently, while problems with system control are fairly infrequent. The degree of impact to system regulation and control would depend on the nature of the problem, what period of the day the problem occurred, and how much of Glen Canyon's daily release fluctuation limit had already been used.

For example, if Flaming Gorge Powerplant were being used for system regulation and one of its generating units went down, one of the other resources within the CRSP would be used, most likely Glen Canyon Powerplant. If Glen Canyon had already used its maximum allowable fluctuations for the day, and the Flaming Gorge unit went down during a peak hour, Western would be forced to use one of the Aspinall units or go outside its CRSP resources to cover load requirements. Uninterrupted service is the purpose of an interconnected utility system. However, options are sometimes limited—and the fewer options available, the more significant the impact would be in terms of cost to find and acquire the energy or capacity needed.

Under all restricted fluctuating flow alternatives, less Glen Canyon capacity would be available for regulation service, so some regulation would have to be provided by another CRSP powerplant. If another CRSP powerplant were not available, Western would not be able to meet WSCC criteria. WAUC members would then have to use other, less responsive and more expensive thermal resources. Compared to operations under the No Action Alternative, the High Fluctuating Flow Alternative would reduce capacity by a small percentage. The Moderate, Modified Low, and Interim Low Fluctuating Flow Alternatives would reduce capacity substantially.

Emergencies and Outage Assistance. Restrictions on ramping and maximum allowable releases would result in reduced emergency assistance service. A reduction in this service would result in increased costs and inconvenience, as customers turn to more costly and less reliable thermal sources.

Western would be able to respond only to extensive control area emergencies. Such emergencies usually develop from smaller, localized events and could be kept short term and manageable by using hydropower. Without access to a hydropower source for emergency assistance, a utility may have to search for help from a less responsive thermal unit. Meanwhile, the electrical emergency could progress from local to area-wide, forcing the use of Glen Canyon Powerplant to correct the situation.

Financial impacts of reduced emergency assistance from Glen Canyon can be seen in comparisons of 1991 interim flows and 1988 flows, shown in table IV-31. This table is meant to show comparable impacts of the No Action Alternative (1988 flows) to conditions under interim flows.

Under the interim flows of 1991, less emergency energy was available compared to the no action conditions in 1988 and, therefore, less revenue was realized. Utilities that normally would have used hydropower for assistance were forced to seek out less responsive, more expensive sources. Additional expenses varied and were determined by market conditions at the time. The cost impacts for emergency assistance would be expected to be less under the High and Moderate Fluctuating Flow Alternatives because operational limits would be less restrictive and the service could be offered more frequently. It is important to note that wholesale rates would vary among the alternatives to produce the same revenue over the long term for project repayment purposes.

The relative frequency of IPP emergency assistance requests during the 2 years was the same, but the amount of assistance provided by Western decreased considerably. In 1991, Western provided only up to its reserve requirement, except in cases where a major systemwide or loss of load emergency occurred. Under all restricted fluctuating flow alternatives, Western would provide only up to its share of IPP spinning reserve requirements.

Under all restricted fluctuating flows, the ability to provide scheduled outage assistance could be reduced to zero, resulting in increased costs to other members of the IPP. Financial impacts of reduced scheduled outage assistance to IPP members from CRSP facilities for the 1988 flow year compared to the 1991 flow year are shown below, in table IV-32.

Transmission System. Restricted fluctuating flows would result in scheduling problems across transmission lines. The greater the restrictions at Glen Canyon, the greater the potential for problems. Transmission scheduling problems arise from physical limitations of the Glen Canyon Dam and Western Colorado transmission systems.

Table IV-31.—Comparison of emergency assistance under no action and interim operations

1988 (no action)	1991 (interim flows)
31,757 MWh provided (returned at 1.5 x 31,757 MWh or a net gain of 15,879 MWh)	8,134 MWh provided (returned at 1.5 x 8,134 MWh or a net gain of 4,067 MWh)
349 MW/hour peak delivery (valued at 20 mills/kWh or a net gain of $317,570)	161 MW/hour peak delivery (valued at 20 mills/kWh or a net gain of $81,340)

Table IV-32.—Comparison of scheduled outage assistance under no action and interim flows

1988 (no action)	1991 (interim flows)
9,334 MW of capacity provided a net gain of $111,125 (100 MW peak amount sold)	No scheduled outage assistance provided
14,001 MWh energy returned for a net gain of 4,667 MWh (valued at 20 mills/kWh for a net gain of $93,340)	No revenue

If problems occurred—such as heavy power flows, out-of-service transmission lines, or loss of other generating resources—Western would not be able to accommodate the subsequent system schedule changes now usually resolved by rescheduling generation at Glen Canyon Dam and another interconnected powerplant.

Western's ability to wheel firm and nonfirm transmission service would be less. The value of wheeling depends on how much the service is needed, whether Western is situated appropriately within the grid, and the market conditions at the time. Under restricted fluctuating flows, the Glen Canyon-Pinnacle Peak transmission line uprate would be an under-utilized investment.

Discussion of impacts to physical transmission components assumes Western would not have financial exception criteria for unscheduled transmission operations and maintenance work. The restricted fluctuating flow alternatives would limit the capability to quickly and efficiently alter the generation pattern of the interconnected system, particularly for short-notice outages and unforeseen heavy loading of the Western Colorado or Glen Canyon transmission system. The degree of impact would depend on when the problem occurred.

Should the Shiprock-Kayenta transmission line go out of service while either or both Glen Canyon and Aspinall Unit Powerplants are restricted, Western would be forced to seek outside assistance through an exchange with the SRP or by purchasing additional energy.

Depending on generation capability at Glen Canyon and electricity demands, a full hydro-thermal exchange might not be possible. Therefore, SRP would not be able to fully use the power generated at Four Corners, Craig, and Hayden Powerplants to meet its loads. Limitations also would be placed on wheeling SRP power across Western's transmission lines. SRP would incur added expense due to purchase of other power generation.

Power Marketing

Since impacts on power marketing would vary, they are discussed under each alternative.

High Fluctuating Flow Alternative

The marketable resource available for firm **power marketing** under the High Fluctuating Flow Alternative would decrease by 24 MW of capacity in winter and 43 MW in summer compared to no action. The amount of annual energy would be the same as under no action; however, restrictions would shift generation from on-peak to off-peak hours, resulting in a minor impact in energy value.

The High Fluctuating Flow Alternative would result in minor economic costs compared to no action. Economic costs would increase by $2 million to $3 million per year compared to no action. In addition to power resources added under no action, 3 MW of energy conservation would be added.

Financial costs to utilities would increase by $7 million over no action. Transfer payments—mostly from small to large utilities—would be approximately $4 million more per year. A comparison of costs to large and small utility systems also is presented (table IV-29).

The wholesale firm power rate would increase by 3.2 percent and the median retail rate would increase by 0.9 percent compared to no action (see table IV-30).

Moderate Fluctuating Flow Alternative

The marketable resource available for firm **power marketing** under the Moderate Fluctuating Flow Alternative would decrease by 384 MW of capacity in winter and 433 MW in summer compared to the No Action Alternative. The annual quantity of energy would be the same; however, a shift in generation from on-peak to off-peak would have a moderate to potentially major impact on energy value.

The Moderate Fluctuating Flow Alternative would result in moderate to potentially major economic costs compared to no action. Significant amounts of existing surplus capacity compounded by the addition of energy conservation during this period would prolong the surplus capacity market condition, but not for as long as under the three previous alternatives. Economic costs would increase by $36 million to $44 million per year over no action. In addition to power resources added under no action, the following would be added under moderate fluctuating flows for the 20-year planning period: 50 MW of purchased power, 50 MW of pumped storage, and 3 MW of energy conservation.

Financial costs to utilities would increase by $76 million per year; transfer payments would increase by $41 million per year. Differences in costs to large and small utility systems relative to no action are summarized in table IV-29.

The wholesale firm power rate would increase by 23 percent and the median retail rate would increase by 5.8 percent compared to no action. A range of estimated retail rates is presented in table IV-30.

Modified Low Fluctuating Flow Alternative

The marketable resource available for firm power **marketing** under this alternative would be reduced by 442 MW of capacity in winter and 463 MW in summer compared to no action. The annual quantity of energy would be the same as under no action; however, a shift in generation from on-peak to off-peak would have a moderate to potentially major impact on energy value.

Under the Modified Low Fluctuating Flow Alternative, moderate to potentially major economic costs would result. Economic costs would increase by $45 million per year. Again, surplus capacity would exist and energy conservation would extend the surplus. Power resources added would be essentially the same as under moderate fluctuating flows.

Financial costs to utilities would increase by $85 million per year. Transfer payments would increase by $44 million compared to no action. Differences in costs to large and small utility systems relative to no action are summarized in table IV-29.

The wholesale firm power rate under modified low fluctuating flows would increase by 31 percent, and the median retail rate would increase by 6.4 percent compared to the No Action Alternative. A range of estimated retail rates is shown in table IV-30.

Endangered fish research flows would have impacts on power economics that fall within the range of impacts between this alternative and the Seasonally Adjusted Steady Flow Alternative. If such research flows occur only during the initial years of implementation, impacts would be closer to those under the Modified Low Fluctuating Flow Alternative. However, if steady flows were permanently incorporated in the operating criteria, impacts would be closer to those under the Seasonally Adjusted Steady Flow Alternative.

Interim Low Fluctuating Flow Alternative

Under this alternative, the marketable resource available for firm **power marketing** would decrease by 372 MW of capacity in winter and 439 MW in summer compared to the No Action Alternative. The annual quantity of energy would be the same as under no action; however, a shift in generation from on-peak to off-peak would have a moderate to potentially major impact on the value of the energy.

Moderate to potentially major economic costs would result under interim low fluctuating flows compared to no action. Economic costs would increase by $36 million per year. Power resources added would be essentially identical to those added for the Moderate Fluctuating Flow Alternative.

Under this alternative, financial costs to utilities would increase by $75 million per year compared to no action, and transfer payments would increase by $39 million per year—approximately the same impact as under the Moderate Fluctuating Flow Alternative. Differences in costs to large and small utility systems are summarized in table IV-29.

The wholesale firm power rate would increase by 23 percent, and the median retail rate would increase by 5.8 percent compared to no action. A range of estimated retail rates is presented in table IV-30.

Steady Flows

Power Operations

Under the steady flow alternatives, impacts on power operations usually would be much greater than impacts under the restricted fluctuating flow alternatives. Additional impacts to hydropower operations under the steady flow alternatives are described below.

Scheduling. Major impacts to scheduling could occur since plus or minus 1,000 cfs would be the maximum allowable change per 24 hours under the steady flow alternatives. Purchases and sales of firm capacity would result in major cost increases because Western would not be able to buy or sell during economical periods.

Load Following. Western would not be able to provide load following under steady flows due to restrictions on daily fluctuations, up and down ramp rates, and the cap on maximum flows.

Regulation and Control. Impacts on regulation service and control under steady flows would be considered major because releases would not fluctuate.

Emergencies and Outage Assistance. Steady flows would be expected to result in a loss of this service. Under steady flows, Western could provide only its share of IPP capacity reserve requirements and could provide operating reserves equivalent to the WAUC peak load for a minimum of 4 hours per day, except for extensive emergencies. Scheduled outage assistance would be reduced to no more than plus or minus 35 MW (1,000 cfs).

Transmission System. A major loss of operating flexibility would prevent Western from accommodating schedule changes. Impacts on the transmission system actual would be major compared to no action and restricted fluctuating flows.

Power Marketing

Since impacts on power marketing would vary, they are described under each alternative.

Existing Monthly Volume Steady Flow Alternative

Under the Existing Monthly Volume Steady Flow Alternative, the marketable resource available for firm **power marketing** would decrease by 567 MW of capacity in winter and 604 MW in summer compared to the No Action Alternative. The annual quantity of energy would be the same as under no action; however, a shift in generation from on-peak to off-peak would result in a major decrease in energy value.

Major economic costs would result under the Existing Monthly Volume Steady Flow Alternative compared to no action. Economic costs would increase by $65 million to $69 million per year. The existing system surplus would mean no capacity would be added immediately. Total added capacity would be 2,731 MW for the 20-year planning period—more than 400 MW greater than under the most restrictive fluctuating flow alternative. Power resource additions over no action would include: 300 MW of purchased power, 142 MW of combustion turbines, and 50 MW of pumped storage.

Financial costs to utilities under this alternative would increase by $125 million a year, and transfer payments would increase by $56 million per year. Differences in costs to large and small utility systems relative to no action are summarized in table IV-29.

The wholesale firm power rate under the Existing Monthly Volume Steady Flow Alternative would increase by 34 percent, and the expected retail rate would increase by 8 percent compared to the No Action Alternative. A range of estimated retail rates is presented in table IV-30.

Seasonally Adjusted Steady Flow Alternative

Under the Seasonally Adjusted Steady Flow Alternative, the marketable resource available for firm **power marketing** would decrease by 748 MW of capacity in winter and 788 MW in summer compared to the No Action Alternative. The annual quantity of energy would be nearly the same as under no action; however, a shift in generation from on-peak to off-peak would have major impact on energy value.

Major economic costs would result under this alternative compared to no action. Economic costs would increase by $76 million to $119 million per year. Power resources added would require significantly larger quantities of each resource than those added under no action, any of the fluctuating flow alternatives, or any of the other steady flow alternatives. Again, existing surplus capacity and energy conservation would mean new capacity would not be added immediately. However, the large capacity loss would require capacity additions sooner and of greater magnitude. Total capacity added under the Seasonally Adjusted Steady Flow Alternative would be 3,006 MW for the 20-year planning period. Significant capacity increases would include: 450 additional MW of purchased power, 250 MW of combustion turbines, 50 MW of pumped storage, and 17 MW of energy conservation.

Financial costs to utilities under this alternative would increase by $187 million per year compared to no action, and transfer payments would total $68 million per year. Differences in costs to large and small utility systems relative to no action are summarized in table IV-29.

Under seasonally adjusted steady flows, the wholesale firm power rate would increase by 51 percent, and the median retail rate would increase by 11 percent compared to no action. A range of estimated retail rates is presented in table IV-30.

Year-Round Steady Flow Alternative

Under the Year-Round Steady Flow Alternative, the marketable resource available for firm **power marketing** would decrease by 672 MW of capacity in winter and 700 MW in summer compared to the No Action Alternative. The annual quantity of energy would be nearly the same as under no action; however, a shift in generation from on-peak to off-peak would result in a major decrease in the value of energy.

Major economic costs would result under this alternative, increasing by $67 million to $86 million per year. Resource options added for the Year-Round Steady Flow Alternative would be significantly larger than under no action or any of the fluctuating flow alternatives. Again, surplus capacity and energy conservation would mean replacement capacity would not be added immediately. However, the large capacity loss would require capacity additions sooner and of greater magnitude. The total capacity added would be 2,748 MW for the 20-year planning period. Specific capacity additions would include:

- 280 MW of purchased power
- 251 MW of combustion turbines
- 25 MW of pumped storage
- 10 MW from wind generators
- 17 MW from energy conservation

Financial costs to utilities under this alternative would increase by $147 million per year and transfer payments would increase by $61 million per year. Differences in costs to large and small utility systems compared to no action are summarized in table IV-29.

Under the Year-Round Steady Flow Alternative, the wholesale firm power rate would be increased by 43 percent, and the median retail rate would increase by 10.7 percent compared to no action. A range of estimated retail rates is presented in table IV-30.

NON-USE VALUE

A series of group (group discussions) were held at eight locations around the country to explore the feasibility of estimating non-use value for the specific resources affected by Glen Canyon Dam operations. These group discussions were held with selected individuals in New York, Tennessee, Nebraska, Arizona, and Utah (HBRS, Inc., 1992).

Discussion participants were given a summary of the environmental impacts resulting from Glen Canyon Dam operations. They were then asked to predict how changes in flow patterns might affect the ecosystem associated with the Colorado River in Grand Canyon. Participants also were asked to indicate which impacts they cared about most.

Information Gained From Focus Groups

Focus group participants were able to predict, in a general way, the impacts of dam releases on the downstream ecosystem.

Participants indicated that they care most about impacts to vegetation and associated wildlife, native fish, Native Americans currently living near Grand Canyon, and archeological sites. The discussions indicated that participants were able to distinguish between impacts to the river corridor and those to Grand Canyon in general. Participants also expressed a clear desire to undertake actions to reduce or eliminate some of the impacts.

The fact that participants felt they would benefit from changes in dam operations indicates that some level of quantification might be feasible. This quantification could take several forms. Individuals could be asked to indicate how important the impacts of the alternatives are when compared to other issues facing society, or they could be asked to indicate the maximum amount they would be willing to pay for various changes in dam operations. The second approach would allow measurement of the non-use value associated with the various alternatives in dollar terms that could be compared to dollar impacts on recreation and electric power production.

Plan for Further Study

Focus groups results indicate that non-use value for operational changes may be estimable. As reported in chapter III, the cooperating agencies have jointly decided to continue the investigation in a stepwise manner.

The next step in this process is a pilot testing research phase with the following goals:

- Explore suitable sampling schemes
- Design appropriate survey instruments
- Test the survey instruments
- Explore the possibility that non-use value for hydropower exists

The pilot testing phase is now underway, with results expected in early 1994. The results of the pilot testing phase will be reported in the final EIS. Based on the outcome, the cooperating agencies will decide whether or not to proceed with a full-scale study of non-use value. If the decision is made to continue, the results of the non-use value study also will be presented in the final EIS.

The methodology that will be employed in the full-scale study is discussed in HBRS, Inc. (1991). A more concise and readable description is found in Bishop and Welsh (1992a); Bishop and Welsh (1992b) is a related work on the applicability of non-use value in benefit-cost analyses and related issues.

Possible Results of Non-Use Value Study

At this point, there is not enough information to quantify non-use value for the alternatives. Also, it is impossible to predict the magnitude of non-use value for hydropower, if any, and how it might affect these estimates. While it is impossible to predict the magnitude of non-use values, it is possible to characterize, in a relative fashion, the likely results of a non-use value study.

Since non-users were most concerned about impacts to vegetation and associated wildlife, native fish, Native Americans, and archeological sites, alternatives that benefit these attributes would likely have higher non-use values.

The above assessment assumes that there is no non-use value for hydropower. This presumption has neither been demonstrated nor refuted.

CUMULATIVE IMPACTS

This section presents an analysis of impacts on the environment which 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. Cumulative impacts on the economy are described below.

Power

As regional population increases, the demand for electric power is expected to increase. Both public and private utilities plan for this eventuality by building new powerplants to meet expected demand. Also, there presently are a number of existing regional powerplants that are not being used to their full capacity.

A reduction in peaking power production at Glen Canyon Dam would have little short-term economic effect since existing facilities and energy conservation measures could satisfy short-term demand. In the long term, any reduction in peaking power capability at Glen Canyon Dam would mean that the demand for electricity would exceed the system's ability to supply electricity sooner than presently envisioned. As a result, some least-cost combination of thermal plants and energy conservation measures would be implemented sooner than planned. The economic impact (cost to society) of these actions has been estimated to range between minus $2 million and plus $119 million annually (see analysis of POWER impacts in this chapter).

Glen Canyon Dam is the least-cost source of peaking power in the affected region. Loss of peaking power generation at Glen Canyon Powerplant will increase wholesale and retail prices by some degree. There are two reasons for this increase.

First, CRSP project costs are prorated over the number of units of peaking power sold. Loss of generation capacity means that fewer units of power can be produced and sold. All other things being equal, this will cause the price per unit of available CRSP capacity to increase. The wholesale price is expected to increase by 26 percent under the preferred alternative.

Second, to the extent that a utility's allocation of CRSP power is reduced, affected utilities must purchase higher-cost replacement power from alternative suppliers. These additional costs will be passed on by utilities to their customers.

Rate impacts would vary substantially by supplier and by geographical location, since the extent to which wholesale power rates affect retail power rates depends on the amount of CRSP power used by a utility. Rate increases would be relatively small for a retail customer whose utility receives a relatively small portion of its power from CRSP. However, retail rate increases would be nearly as much as or more than the wholesale rate increase for a retail customer whose utility receives a substantial portion of its power from CRSP.

The impact of increases in power rates in the affected region potentially would be more significant for some economic sectors than estimates of average impact show. For example, any increase in the price of CRSP power increases the cost of irrigation, a significant part of agricultural production costs in this arid region. Consequently, the effective impact of any rate increase for irrigators may be quite large.

Agricultural producers cannot increase their prices to compensate for higher water costs. In the short run, farmers are likely to respond to such increases by applying less water, producing crops that require less water, and/or removing less suitable land from production. In the long run, some irrigation districts and producers may install more water-efficient irrigation systems or systems that use alternative fuels such as natural gas, or they may cease production altogether.

A substantial percentage of the pumping for irrigated agriculture occurs during off-peak hours, so the price charged to irrigators is typically less than the rate charged to other users. The amount of electricity produced off-peak would not be reduced by the preferred alternative and may, in fact, be increased. Therefore, the effect on the power rates charged to irrigators is difficult to project.

Air Quality

Regional air quality would change only slightly under any of the alternatives. The loss of peaking power from Glen Canyon Powerplant is likely to be made up by increased operation of existing thermal plants and the construction of additional thermal plants. Some of these thermal plants would be coal-fired plants and some would be less polluting gas-turbine units. However, changes in total emissions of SO_2 and NO_x would be less than plus or minus 1 percent under any of the alternatives over the 50-year period of analysis. These impacts are described in detail for each alternative in the AIR QUALITY section of this chapter.

Additional pollution control measures could mitigate the decline in air quality but would result in increased construction costs with correspondingly higher power rates.

UNAVOIDABLE ADVERSE IMPACTS

Unavoidable loss of peaking power would result from implementation of any of the restricted fluctuating or steady flow alternatives. These impacts are discussed in detail in the HYDROPOWER section of the chapter.

The existence of Glen Canyon Dam has resulted in unavoidable adverse impacts to most cultural resources in the study area. These impacts are discussed in this chapter and in the accompanying compliance documentation in attachment 5.

RELATIONSHIP BETWEEN SHORT-TERM USES AND LONG-TERM PRODUCTIVITY

Under the restricted fluctuating and steady flow alternatives, there would be a trade-off between peaking power and long-term sediment stability and, therefore, the stability of those resources linked to sediment (see discussion of resource linkages in chapter III).

IRREVERSIBLE AND IRRETRIEVABLE COMMITMENTS OF RESOURCES

Peaking power production foregone on a given day under any alternative would be irretrievably lost. Any loss of archeological sites also would be irretrievable.

INDIAN TRUST ASSETS

Bureau of Reclamation policy is to protect American Indian trust assets from adverse impacts of 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.

The United States has a trust responsibility to protect and maintain rights reserved by or granted to Indian Tribes or individuals by treaties, statutes, and executive orders. This responsibility is sometimes further interpreted through court decisions and regulation. Although there is no concise legal definition of Indian trust assets, courts have traditionally interpreted them as being tied to property.

No adverse impacts to Indian trust assets are anticipated from the preferred alternative. However, flood frequency reduction measures for other alternatives may include dedicating a million acre-feet of Lake Powell space to flood control. The Navajo Nation is concerned that this flood frequency reduction method would prevent the full development of the Navajo Indian Irrigation Project.

Reclamation concluded that no Indian trust assets were located within the river corridor. However, the Hualapai Tribe has asserted that it does have trust assets within its reservation boundary and that these are affected by dam operations. The claimed resources include fish, vegetation, wildlife, and cultural resources.

Even though Reclamation does not agree with the Hualapai claim of trust assets within the affected area, impacts to the claimed resources were assessed as part of this EIS. The conclusion was that the restricted fluctuating and steady flow alternatives (including the preferred alternative) would have beneficial impacts on fish, vegetation, wildlife, and cultural resources relative to the No Action Alternative. A detailed analysis of the impacts on these resources for each alternative are described earlier in this chapter.

Other Concerns

The Federal government's responsibilities to and concerns about Indian people are broader than Indian trust assets; they also include economics and cultural resources.

The Navajo Tribal Utility Authority, which provides service to the majority of electricity consumers on the Navajo Reservation, purchases about a fourth of its power capacity from Western. Navajo Agricultural Products Industries also receives capacity and energy from Western as part of the Navajo Indian Irrigation Project. Dam operations that result in reduced generating capacity would impact energy rates to Western's customers and, in turn, Navajo electricity consumers.

No measurable economic impacts on Native American-owned or operated recreation enterprises were identified (see RECREATION in this chapter).

Some impacts to archeological sites and traditional cultural properties would likely continue in the future because of the existence of Glen Canyon Dam, regardless of how it is operated. The No Action, Maximum Powerplant Capacity, and High Fluctuating Flow Alternatives are anticipated to result in greater impacts to archeological sites and traditional cultural properties than other alternatives, including the preferred alternative (see CULTURAL RESOURCES in this chapter).

In cooperation with involved entities, Reclamation participated in developing a programmatic agreement that documents how the Federal government will protect archeological sites and traditional cultural properties within the geographic area affected by Glen Canyon Dam operations. The involved entities included:

- Advisory Council on Historic Preservation
- Arizona State Historic Preservation Officer
- National Park Service
- Havasupai Tribe
- Hopi Tribe
- Hualapai Tribe
- Kaibab Paiute Tribe
- Navajo Nation
- San Juan Southern Paiute Tribe
- Shivwits Paiute Tribe
- Zuni Pueblo

As a component of the programmatic agreement, Reclamation is coordinating plan formulation for the continual monitoring of cultural resources. This Monitoring and Remedial Action Plan will outline a step-by-step program to address any resource degradation identified by the monitoring process. Any future impacts to archeological sites and traditional cultural properties would be minimized through the implementation of the programmatic agreement (attachment 5).

IMPACTS ON OTHER FEDERAL AND NON-FEDERAL PROJECTS AND PLANS

Inexpensive CRSP power has allowed agricultural development to flourish in this arid region. CRSP power is used extensively by participating irrigation districts and federally funded irrigation projects such as the Central Arizona Project.

Far-ranging effects on the economic and financial viability of irrigation projects in the region may result from increases in CRSP power rates. These increases may contribute to the insolvency of marginal producers and this, in turn, may threaten existing project repayment. Increases in the price of power may make planned marginal projects economically or financially infeasible.

The amount of electricity produced off-peak would not be reduced by the preferred alternative and may, in fact, be increased. Therefore, the effect on the power rates and, thus, the economic and financial viability of existing and future projects is difficult to project.

Management Plans

The alternatives are not expected to cause changes in NPS or tribal management plans.

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

State of Arizona. Management of the Glen Canyon trout fishery may likely change in the future under any of the restricted fluctuating or steady flow alternatives. Stocking could be reduced since there would be decreased stranding of adults, improved spawning, enhanced recruitment, and increases in growth rates. Potential improvements in the quality of the fishery also would provide the opportunity for relaxed fishing regulations.

CHAPTER V

Consultation and Coordination

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During the preparation of the Glen Canyon Dam Environmental Impact Statement (EIS), input was actively solicited from a broad range of public constituencies as part of the ongoing public involvement process. These public constituencies for the Colorado River, Glen Canyon National Recreation Area, and Grand Canyon National Park include (in alphabetical order): academia, concessionaires, congressional delegations, environmental groups, fish and wildlife groups, general unaffiliated publics, seven Basin State Governments, Indian Tribes, news media, power customers (represented by the Colorado River Energy Distributor's Association and individual power organizations), water users, white-water rafters and guides, recreation groups, and Colorado River Storage Project water and power entities.

This chapter summarizes public involvement during the Glen Canyon Dam EIS process and will serve as the Public Involvement Summary Report, in accordance with *Reclamation Instructions*.

BACKGROUND

Glen Canyon Dam was completed in 1963 prior to the passage of the National Environmental Policy Act (NEPA). Consequently, there was no requirement for an EIS on the project prior to construction.

In December 1982, the Bureau of Reclamation (Reclamation) published an environmental assessment (EA) and finding of no significant impact (FONSI) on the impacts of a proposed powerplant uprate and rewind project. Reclamation proceeded with the uprate and rewind project but agreed not to use the increased powerplant capacity for flows above 31,500 cubic feet per second (cfs) until completion of a more comprehensive study.

Glen Canyon Environmental Studies

Beginning in December 1982, Reclamation initiated the multi-agency, interdisciplinary Glen Canyon Environmental Studies (GCES) at the direction of the Secretary of the Interior (Secretary) to address the concerns of the public and other Federal and State agencies about possible negative effects of the operations of Glen Canyon Dam on the existing downstream environmental and recreational resources.

Numerous information activities were conducted during the GCES (1987-89):

- Department of the Interior briefings
- Environmental group briefings
- Congressional briefings
- Constituent review meetings
- News releases and media contacts
- Speeches
- Video briefings

GCES Phase I

Between 1982 and 1987, 39 technical reports were prepared evaluating terrestrial biology, aquatic biology, sediment and hydrology, recreation, and dam operations. These technical reports were consolidated into a final technical report, program summaries, and review reports. No studies were conducted regarding the economic impact of changes in dam operations. A team composed of interagency technical staff and key researchers completed the *GCES Final Report* in January 1988, (U.S. Department of the Interior, 1988) consolidating the results of the individual studies into a summary document.

An Executive Review Committee made up of policy level representatives from Reclamation, National Park Service (NPS), U.S. Fish and Wildlife Service (FWS), Department of the

Interior's Office of Environmental Project Review (now the Office of Environmental Affairs), and Western Area Power Administration (Western) prepared a report containing recommendations and options for decision. Using technical data presented in the *GCES Final Report*, a review by the National Research Council, and individual management priorities, the review committee determined that additional studies were required before any changes in the operations at Glen Canyon Dam could be recommended. That decision was not unanimous.

GCES Phase II

After review of the *Final Report* and committee recommendations, the Secretary directed Reclamation to initiate additional studies to gather more data on specific operational elements. This second effort, GCES Phase II, began in 1988. These studies assess the impacts of low and fluctuating flows and potential impacts to resources and power revenues. Various constituent groups were involved in review of the study plans.

An additional principal purpose of GCES Phase II is to provide scientific information as input to the EIS. Most of the research conducted or underway has facilitated the ability to describe the existing environment and the impacts of EIS alternatives on that environment.

On July 27, 1989, Secretary of the Interior Lujan announced that an EIS was to be prepared on the operation of Glen Canyon Dam. The Notice of Intent was published in the *Federal Register* on October 27, 1989.

With the decision to prepare an EIS, it became clear that the original timing for a 4- to 5-year Phase II effort would need to be condensed if the Phase II studies were to be effective in producing information for the EIS. Concern over shortening the research period was expressed. In establishing the timeframe for the EIS, the discussion centered on the conflict between the need for thorough (lengthy) research to completely answer the outstanding questions, the need for interim flows, and the need to complete the NEPA process in a timely manner.

In June 1990, research flows were implemented at Glen Canyon Dam. Following completion of the research flows on July 31, 1991, a 90-day test period of the proposed interim flow criteria was conducted from August 1 to October 31. This interim test period allowed Reclamation to more fully evaluate data gathered from research, determine the suitability of the proposed criteria to protect downstream resources, develop exception criteria, and comply with NEPA requirements before implementation.

An EA on the interim operating criteria was issued by Reclamation in October 1991. Since the proposed action did not constitute a major Federal action having significant effects on the quality of the human environment, a FONSI was determined appropriate and was signed on October 31, 1991.

Interim operating criteria were implemented by the Secretary on November 1, 1991, as a temporary measure designed to reduce adverse impacts on downstream resources until the EIS is completed and the record of decision (ROD) is implemented. These criteria also allow for the continued gathering of information pending completion of the EIS.

The EIS schedule was revised several times, but in October of 1992—with the signing of the Grand Canyon Protection Act—the President directed that the final EIS be completed by October 30, 1994.

Cooperating Agencies

Acting as lead agency, Reclamation requested the participation of cooperating agencies that either had jurisdiction by law or interest in certain aspects of Glen Canyon Dam operations or Colorado River resources below the dam. In addition, three of the Indian Tribes (Pueblo of Zuni, San Juan Southern Paiute Tribe, and Southern Utah Paiute Consortium) requested to be designated as cooperating agencies in January 1993. The cooperating agencies are listed below.

Department of the Interior
- Bureau of Reclamation (lead agency)
- Bureau of Indian Affairs
- National Park Service
- U.S. Fish and Wildlife Service

Department of Energy
  Western Area Power Administration
Arizona Game and Fish Department
Hopi Tribe
Hualapai Tribe
Navajo Nation
Pueblo of Zuni
San Juan Southern Paiute Tribe
Southern Utah Paiute Consortium

This management-level coordinating group oversees both the preparation of the EIS and the related GCES research activities.

A interagency, interdisciplinary team was formed to prepare the EIS. Representatives from Reclamation; NPS; FWS; Western; Arizona Game and Fish Department; U.S. Geological Survey; Hopi, Hualapai, Navajo; and a private consulting firm served on the EIS team. (See the list of preparers that follows this chapter.)

CONSULTATION

The National Historic Preservation Act of 1966 (as amended in 1992) requires Federal agencies to consult with the Advisory Council on Historic Preservation concerning potential effects of Federal actions on historic properties. Therefore, Reclamation, in conjunction with NPS, the Arizona State Historic Preservation Office, Indian Tribes, and the advisory council, developed a programmatic agreement on cultural properties that include identifying, monitoring, and protecting cultural sites potentially affected by Glen Canyon Dam operations (see attachment 5).

In compliance with the Endangered Species Act, Reclamation entered into formal consultation with the FWS. FWS submitted a draft biological opinion on the preferred alternative that contained a nonjeopardy opinion for the bald eagle, Kanab ambersnail, and peregrine falcon; a draft jeopardy opinion was issued for the humpback chub and razorback sucker. Therefore, the preferred alternative was designed to be consistent with the "reasonable and prudent alternative" (see attachment 4) included in the draft biological opinion. The reasonable and prudent alternative was provided as a plan that could remove the likelihood of jeopardizing the continued existence of the humpback chub and razorback sucker in Grand Canyon.

A proposed rule to list the southwestern willow flycatcher (a small bird) as endangered with critical habitat, was published in the *Federal Register* on July 23, 1993. A portion of the proposed critical habitat is within the area affected by releases from Glen Canyon Dam. The declining status of the species has been a concern to all the cooperating agencies and, therefore, specific research and population monitoring has been a part of GCES—even prior to the proposed rule. This species and its critical habitat were considered in the assessment of impacts on vegetation and bird species.

Reclamation is informally conferencing with FWS, in accordance with the rules and regulations governing proposed species and proposed critical habitat. If this process indicates that operations under the preferred alternative would jeopardize the southwestern willow flycatcher or adversely modify critical habitat, Reclamation will formally conference with FWS on this species and will consult as necessary if the proposed rule results in listing the species.

Consultation with FWS under the Fish and Wildlife Coordination Act (FWCA) has been ongoing throughout the EIS process. FWS recommendations from the FWCA report and Reclamation's responses are included in attachment 4.

Since none of the alternatives include development in the flood plain as described in Executive Order 11988, Floodplain Management, this action complies with that order. Also, none of the alternatives include development that would affect wetlands. Therefore, the action contemplated here is in compliance with Executive Order 11990, Protection of Wetlands.

The marshes along the Colorado River in Glen and Grand Canyons are dynamic; some are destroyed and others created, depending on the actions of water and sediment.

PUBLIC INVOLVEMENT

One of the most important objectives of public involvement is to obtain information from a well-informed public to assist the decisionmaker (Secretary of the Interior) throughout the entire process, culminating in a ROD and eventual implementation of the selected alternative. The three primary goals of the public involvement for this EIS were:

1. *Credibility*: creating an open and visible decisionmaking process for groups with highly divergent viewpoints
2. *Identifying public concerns and values*: providing a mechanism by which the involved agencies can understand the problems, issues, and possible solutions from the perspectives of the various publics
3. *Developing a consensus*: providing a process for reaching consensus about specific actions

In order to identify issues, address public concerns, obtain public input, and keep the public informed, Reclamation initiated an ongoing public involvement program when the decision to prepare an EIS was announced in July 1989. This program included meetings with local government officials, public scoping meetings, slide presentations, user group meetings and conferences, newsletters, news releases, participation of interested parties at cooperating agency meetings, and one-on-one contacts.

During preparation of this draft EIS, the cooperating agencies met at least every 3 months to review progress and to reach agreement on major issues. Interested parties were invited to attend these meetings as observers and, until May 1992, separate evening sessions were held for interested parties. From then on, time was allotted for questions from the audience during the cooperating agency meetings and evening sessions were discontinued.

Scoping

During EIS preparation, the process of soliciting input from groups and individuals is called scoping. The purpose of scoping is to identify issues, criteria, and alternatives for analysis. The following section describes the major actions that occurred during the scoping process. In addition to these major actions, Reclamation initiated many meetings with individuals, environmental groups, hydropower agencies, Indian Tribes, universities and colleges, and officials of local, State and Federal governments.

The formal public scoping period for the EIS began with a *Federal Register* Notice on February 23, 1990, to receive public input on and determine the appropriate scope of the EIS, consistent with NEPA and its implementing regulations.

Eight public meetings were held between March 12 and April 3, 1990, in Salt Lake City, Denver, Phoenix, Flagstaff (two), Los Angeles, San Francisco, and Washington, DC, to determine the significant issues to be analyzed in depth in the EIS. These meetings were attended by about 1,400 people. Comments were presented by about 250 people, a few of whom spoke at more than one meeting.

The comment period was extended to May 4, 1990, and more than 17,000 written and oral scoping comments were received. Each original comment letter was read at least twice to better understand the issues, concerns, and suggestions expressed. These letters are on file in Reclamation's Upper Colorado Regional Office in Salt Lake City, Utah.

A scoping report was prepared by Bear West Consulting Team (Bureau of Reclamation, 1990b), a private business that assisted in public involvement activities. The report summarizes the comments received during the scoping process. The methods used by Bear West to code and summarize public comments were approved by the cooperating agencies.

Comments were summarized as issues or resources of concern in the following categories: beaches, endangered species, ecosystem, fish, electric power costs, electric power production, sediment, water conservation, rafting and boating, air quality, the Grand Canyon wilderness, and a category designated as "other" for remaining concerns. The 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 (Bureau of Reclamation, 1990b). The following is a brief summary of these public comments.

Resources

Beaches. The main concerns noted were erosion, degradation, and inadequacy of beaches. Causes of beaches deteriorating were identified as: fluctuating flows in water releases from Glen Canyon Dam, the floods of 1983, the lack of sediment in the waters, and overuse by rafters and hikers. The replacement of native vegetation by non-native vegetation also was listed as a problem.

Endangered Species. The most common concern expressed was for the humpback chub, followed by the razorback sucker and willow flycatcher. Broad support for the protection of endangered species, especially fish and birds, was expressed. Comments also included requests that some efforts be made to restore the fish species now missing from the Colorado River in Grand Canyon.

Ecosystem. Some specific elements of the ecosystem identified as special concerns included wildlife, aquatic ecosystem, riparian community, waterfowl, wetlands, and the food chain. Comments were made that it was time to return the ecosystem to a more natural condition. Many felt that the integrity of the ecosystem needed to be given priority over power generation considerations and that fluctuating flows were the main source of ecosystem damage.

Fish. The trout fishery below the dam was an area of concern. The main comment was that the fish are being killed by fluctuating flows and that the dam could be managed in a manner more supportive of the fishery. The major concern was fish stranding—particularly of spawning fish—that occurs during low flows. It was also mentioned that native fish have been or are being lost. According to the comments, much of the problem centers on the water temperature. Other problems identified were danger to anglers caused by fluctuating water levels and ramp rates, lack of angler access to certain areas during low flows, problems controlling striped bass, and the possibility that current regulations allow overfishing.

Power Costs. The most frequent comments were that the present cost of power generated at the dam represents a subsidy and that market rates should be charged and adjusted seasonally. Others flatly denied that any subsidy was involved. It was suggested that an independent audit is needed to determine the true operating costs of the Colorado River Storage Project and to determine whether or not a subsidy is actually occurring. Maintaining access to low-cost power was particularly important to people in rural areas. It was also suggested that conservation measures are vital to keeping power costs down.

Power Production. The most frequent comment regarding power production was that power resources do not or should not have priority over other resources. Others recognized that peaking power operations were causing severe damage to downstream resources. Comments encouraged study of alternatives that would reduce the need for peaking power production at the dam. According to some, contracts for firm power sales should be based only on the 8.23 million acre-feet annual water release requirement, and increasing the power generation capacity at Hoover Dam should be studied.

Those who argued against changes in dam operation stated that hydropower is critical to the economic development and general well-being of the rural Southwest. Power customers believe that hydropower is compatible with the environment and that alternative power sources pose environmental problems of their own. Those who use power produced by the dam fear they will bear the brunt of operational changes at the dam and feel that their needs should be given equal consideration with environmental protection.

Sediment. Many comments suggested that, because most sediment is being trapped behind the dam, the downstream sediment needs to be augmented and conserved. Many comments claimed that a great deal of existing sediment is carried away in high flows and deposited at the upper end of Lake Mead, making access upriver impossible for power boats. Caution was raised that any sediment used for augmentation must be studied for toxic elements that would damage the system instead of helping it.

Water Conservation. The commentors recognized the need for water conservation. The major concern was that changes in dam operation could affect water allocation deliveries and place undue burdens on irrigation users.

Rafting and Boating. Some argued that flows since the construction of the dam are more reliable and enhance boating, but others said that dam operations are making the boating experience less pleasant and even hazardous. In addition, increased beach erosion has resulted in fewer beaches for camping. Others feel that the beaches are overused, the number of permits should be reduced, and the size of groups carefully regulated.

Air Quality. Most comments referred to the decrease in visibility caused by air pollution affecting Grand Canyon. Concern was expressed that pollution might get worse if alternatives to hydropower are used.

Grand Canyon Wilderness. Most of the comments made about Grand Canyon wilderness centered on the desire to promote the long-term well-being of the canyon and its resources. While some pointed out that recreational use is causing damage, others considered this damage minor compared to the damage caused by power production.

Other Concerns. The variety of comments in this category included statements that dam operations adversely affect recreational and other resources and that the reservoir is filling up with silt. Some felt that removing the dam ought to be a choice. Concern also was expressed about the value of archeological and anthropological ruins and cultural resources.

Social Values

Expressions about Grand Canyon. The national and international significance of this canyon was the focus of most comments in this category. A deep love and concern was expressed for its beauty and the intangible benefits that come to those who view, hike, and raft through it. The preservation of the fragile canyon for future generations was felt to be worth any cost associated with it—especially the cost associated with changing power production methods.

Economics. Several economic issues were identified. First, it was noted that little attention has been given to the economic contributions of power customers to the environmental studies. Second, it was suggested that the economic tradeoffs involved in these issues be thoroughly studied. Third, it was noted that environmental damage has been the price paid in the past for cheap power and that in the future we face a choice between higher power costs or continued environmental damage. The economic value of tourism in the canyon and the profitability of the rafting industry were both acknowledged. It was suggested that nonprofit (public power) agencies should be given more priority in power allocations than profit-making ones, since the dam was built using public funds. Some comments stated that the cost of power should be the last consideration in deciding on dam management and that protecting the canyon is worth any price. Others said that the result of the benefit/cost process should be the greatest benefit at the lowest societal cost.

Nonquantifiable Values. The majority of comments expressed that environmental awareness and a desire to preserve natural resources are increasing in this country. While some noted that the dam has had some positive environmental effects, others expressed the feeling that building the dam and flooding Glen Canyon was a major mistake. Some stated that natural resources have a finite capacity for intrusion, but others emphasized that while wise use of resources is necessary, we should use them.

Nature Versus Human Use. Most of the comments in this area dealt with the fact that people tamper with the environment using imperfect knowledge and create problems which we then must try to solve. Those commenting felt that interference with the delicate ecosystem of Grand Canyon is no exception. Others pointed out that man's interference with Grand Canyon is insignificant when compared to the natural, historic changes that have taken place there.

Complexity of Issues. The fact that the issues to be studied as part of the EIS process, including the canyon, are very complex and interrelated was reflected in all comments on this issue. The EIS was described as a complex balancing act.

Summary of Public Meetings on Preliminary Alternatives

The scoping process was used to identity the relevant issues and concerns to be considered in the EIS. As a result of scoping, it was apparent that the issues and potential alternatives were diverse, and compromise and consensus would be difficult to reach.

Following the formal public scoping period and review of the comments, representatives from the cooperating agencies and public interest groups met in July 1990 to determine criteria for developing reasonable alternatives for the EIS. These criteria included:

- Be consistent with the scope of the EIS
- Be economically and technically feasible
- Reflect legal considerations
- Have general institutional acceptability
- Be timely to implement
- Be able to be monitored and adjusted
- Meet various agency mandates
- Be supported by data
- Be multipurpose (integrated) and not eliminate any major resources
- Include mitigation

The EIS team reviewed the scoping comments with the concept of reasonableness in mind, and using the above criteria, formulated 10 preliminary alternatives. All reasonable concerns expressed during the scoping process were treated fairly and objectively in order to produce an array of alternatives for the EIS. The 10 preliminary alternatives provided a wide range of possible flow patterns and supporting actions in response to public issues and concerns.

The EIS team presented the 10 preliminary alternatives to the public for review and comment before preparing the EIS. These preliminary alternatives were summarized in a newsletter sent in mid-March 1991 to about 20,000 addresses. Three public meetings were held to explain the preliminary alternatives, to respond to questions, and to solicit comments. These meetings were held in Salt Lake City, Utah (April 1); Flagstaff, Arizona (April 2); and Phoenix, Arizona (April 4). The public was notified of these meetings through the local news media and an announcement in the *Federal Register*. The public comment period on the alternatives ran from April 1 to May 1, 1991.

The public was informed that the alternatives judged to be "reasonable" would be subjected to detailed analysis in the EIS. Those determined to be not reasonable would be briefly identified in the EIS, but eliminated from further study. The public was asked to use the above criteria and determine the "reasonableness" of the alternatives; general views and comments also were accepted.

The EIS team received 456 letters—112 from organizations and 344 from private individuals. These letters were reviewed and categorized by the Bear West Consulting Team and summarized in the *Glen Canyon Dam Environmental Impact Statement Preliminary Alternatives Report, April – May 1991* (Bureau of Reclamation, 1991b).

The predominant public comment was the need for "operation only" alternatives or separate analysis of the operation and nonoperational measures rather than the complete package approach. Other comments most frequently voiced were:

- An alternative should be developed that maximizes benefits to endangered species and recreation.
- The reregulation dam is not a reasonable alternative and should not be considered.
- Alternative dam operations should be considered that will reduce the frequency of floods and daily fluctuations.
- Not only is a reregulation dam a viable alternative, but a powerplant should be added to help pay the cost.
- The historic or natural flow patterns should serve as the baseline (No Action Alternative).
- None of the alternatives should include structural elements.
- The environmental, social, and economic effects of reduced electrical generation should be evaluated in steady flow alternatives.
- A lower fluctuating flow alternative should be formulated with a maximum of 20,000 cfs and a minimum of 8,000 cfs. Ramp rates should be 1,000 cfs per hour up and 500 cfs per hour down, with no more than 3,000 cfs change from day to day. (Many comments on flow regime variations were received.)

Alternatives Selected for Detailed Analysis

The EIS team reviewed the public comments on the preliminary alternatives. That review and early technical analysis allowed the EIS team to reduce the alternatives studied in detail from ten to seven for analysis.

These seven alternatives were presented to the cooperating agencies at a meeting in Phoenix on September 16–18, 1991, and to interested parties at an evening session on September 17. A synopsis of these alternatives was distributed to more than 19,000 people in a January 1992 newsletter. The EIS team subsequently formulated two additional alternatives in order to present a full range of reasonable operations.

Public Review of Draft EIS

Written Public Comments

A *Federal Register* Notice and media announcements initiate the beginning of a formal public comment period on this draft EIS. The comment period will run for 90 days starting on the date stamped on the first page of this document. During this period, all interested agencies, groups, and individuals are invited to review the document and submit comments. Written comments should be submitted to:

Lee J. McQuivey
Bureau of Reclamation
125 South State Street
PO Box 11568
Salt Lake City UT 84147

Open House Sessions

During the comment period but ***prior to public hearings***, Reclamation will host three open house information sessions. These open houses will provide the public an informal opportunity to learn about the EIS in general and the results of the impact analyses of the alternatives. Open houses will be held in Phoenix, Flagstaff, and Washington, DC. The date, time, and location of each open house will be announced in the *Federal Register*, in the *Colorado River Studies Office Newsletter*, and in local news media.

Public Hearings

Formal public hearings on the draft EIS will be held in the following cities during the latter part of the public comment period:

Flagstaff and Phoenix, Arizona
Los Angeles and San Francisco, California
Denver, Colorado
Washington, DC
Salt Lake City, Utah

The date, time, and location of each hearing will be announced in the *Federal Register*, in the *Colorado River Studies Office Newsletter*, and in local news media. All oral comments received at the public hearings will be recorded verbatim by a court reporter. So that all who wish to may speak, the public hearings officer will place time limits on oral statements. Additional written comments may be submitted to the hearings officer for inclusion in the official record. Comments should address the accuracy and adequacy of the draft EIS. Those who wish to comment orally at the public hearings must register prior to or at the hearing.

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Department of the Army
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Department of Energy
  Department of Energy, Albuquerque, New Mexico
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- Office of the Regional Solicitor, Salt Lake City, Utah
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Department of Transportation
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Environmental Protection Agency, Region VIII, Denver, Colorado; Region IX, San Francisco, California

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- Game and Fish Department
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- State Clearinghouse, Department of Administration (10 copies)

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San Juan Southern Paiute Tribe, Tuba City, Arizona
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Arizona Wildlife Federation, Scottsdale, Flagstaff, Phoenix, Mesa, and Prescott Valley, Arizona
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National Park Foundation, Washington, DC
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National Wildlife Federation, Washington, DC; Sacramento, California; Ft. Carson, Colorado
Natural Resources Council of America, Washington, DC
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Nature Conservancy, The, Arlington, Virginia; San Francisco, California; Boulder, Colorado
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  California Council, Huntington Beach, California;
  Utah Council, West Valley, Utah
Truth or Consequences, City of; New Mexico
Tucson Active Management Area, Tucson, Arizona
Tucson, City of; Tucson Water Department, Tucson, Arizona

Tucson Rod & Gun Club, Tucson, Arizona
Upper Colorado River Commission, Denver, Colorado; Salt Lake City, Utah; Santa Fe, New Mexico
U.S. Canoe and Kayak Team, Bethesda, Maryland
Utah Energy Office, Salt Lake City, Utah
Utah Farm Bureau Federation, Salt Lake City, Utah

Utah Municipal Power Agency, Spanish Fork, Utah
Utah Power and Light, Salt Lake City, Utah
Utah Water Users Association, Bountiful, Utah
Utah Wilderness Association, Salt Lake City, Utah
Utah Wildlife Federation, Salt Lake City, Utah

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Washington County Water Conservation District, St. George, Utah
Western Interstate Energy Board, Denver, Colorado
Western River Guides Association, Flagstaff, Arizona; Englewood, Colorado
Wilderness River Adventures, Page, Arizona

Wilderness Society, the, Washington, DC;
San Francisco, California; Santa Fe, New Mexico;
Phoenix, Arizona; Denver, Colorado
Wildlife Society, The, Bethesda, Maryland;
Western Section, Lakeview and Fresno, California;
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Y-W Electric Association, Inc., Akron, Colorado

List of Preparers

Many people contributed to the environmental impact study process over a period of years. This section is organized to acknowledge the types of contributions made by these individuals. Those listed as contributors to the document made direct written and/or graphic contributions to the draft Environmental Impact Statement (EIS). Contributors to the process provided research, policy, administrative, or technical expertise and support.

CONTRIBUTORS TO THE DOCUMENT

Michael J. Armbruster is an ecologist with the Bureau of Reclamation who provided general impact assessment with emphasis on vegetation and wildlife impacts for the EIS. He has 15 years of experience in wildlife biology and has worked for Reclamation for the past 4 years. Mike earned a B.A. in zoology; an M.S. in forestry, fisheries, and wildlife; and a Ph. D. in wildlife management.

Janet R. Balsom is the National Park Service archeologist at Grand Canyon National Park. She was responsible for cultural resource analysis, including archeological and tribal issues and compliance with the National Historic Preservation Act. Jan has been with NPS for 10 years and has a B.A. and M.A. in anthropology.

Frank M. Baucom is a supervisory biologist with the U.S. Fish and Wildlife Service. He was responsible for endangered fish species issues and impact analysis and for drafting the biological opinion for the operation of Glen Canyon Dam. Frank has a B.S. in wildlife biology.

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Lawrence M. Riley, an environmental compliance program manager for the Arizona Game and Fish Department, was responsible for the analysis of fish and related issues for the EIS. He earned a B.A. in biology and an M.S. in zoology/fisheries. Larry has 15 years of experience and has worked for AGFD for 10 years.

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Mary I. Voita was lead technical writer and editor for the EIS. Mary has written and managed production of many technical and non-technical documents during her 16-year tenure at Bureau of Reclamation. She earned a B.A. in liberal arts.

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James E. Whitfield produced the frontispiece and all other maps presented in this EIS. He has been a cartographic technician with the Bureau of Reclamation for 2 years.

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Conversion Tables

U.S. Customary to Metric

Multiply	By	To Obtain
inches (inches)	25.4	millimeters
inches (inches)	2.54	centimeters
feet (ft)	0.3048	meters
miles (mi)	1.609	kilometers
square feet (ft^2)	0.0929	square meters
acres	0.4047	hectares
square miles (mi^2)	2.590	square kilometers
gallons (gal)	3.785	liters
cubic feet (ft^3)	0.02832	cubic meters
acre-feet	1,233.0	cubic meters
pounds (lb)	0.4536	kilograms
tons (ton)	0.9072	metric tons

Temperature in degrees Fahrenheit (°F) can be converted to degrees Celsius (°C) as follows:

°C = 5/9 (°F - 32)

Metric to U.S. Customary

millimeters (mm)	0.03937	inches
centimeters (cm)	0.3937	inches
meters (m)	3.281	feet
kilometers (km)	0.6214	miles
square meters (m^2)	10.76	square feet
square kilometers (km^2)	0.3861	square miles
hectares (ha)	2.471	acres
liters (L)	0.2642	gallons
cubic meters (m^3)	35.31	cubic feet
cubic meters (m^3)	0.0008110	acre-feet
grams (g)	0.03527	ounces
kilograms (kg)	2.205	pounds
metric tons (t)	1.102	tons

Temperature in degrees Celsius (°C) can be converted to degrees Fahrenheit (°F) as follows:

°F = 1.8 (°C) + 32

Other Useful Conversion Factors

acre-feet	43,560	cubic feet
acre-feet	325,851	gallons
cubic feet per second (cfs)	1.9835	acre-feet per day
cubic feet per second (cfs)	724.0	acre-feet per year

Glossary

A

abiotic: The absence of living organisms.

abrasion: Wearing away of surfaces by friction.

absorption: Taking in of fluids or other substances through, or as if through, cells or tissues.

abutment: A structure that supports the ends of a dam or bridge.

acclimation: Adjustment of an organism to a new habitat or environment.

accretion: Gradual increase in flow of a stream due to seepage, ground-water discharge, or tributary inflow.

acre-foot: Volume of water (43,560 cubic feet) that would cover 1 acre, 1-foot deep.

active storage: Reservoir capacity that can be used for power generation; at Glen Canyon Dam this is the reservoir storage above the penstock openings at elevation 3490 feet.

aerate: To supply or charge with gas, usually air.

affected environment: Existing biological, physical, social, and economic conditions of an area subject to change, both directly and indirectly, as the result of a proposed human action. Also, the chapter in an environmental impact statement describing current environmental conditions.

aggradation: Process of filling and raising the level of a streambed, flood plain, or sandbar by deposition of sediment. The opposite of degradation.

air quality: Measure of the health-related and visual characteristics of the air, often derived from quantitative measurements of the concentrations of specific injurious or contaminating substances.

algae: Simple plants containing chlorophyll; most live submerged in water.

algal bloom: Rapid and flourishing growth of algae.

alluvial: Sedimentary material transported and deposited by the action of flowing water.

alternatives: Courses of action which may meet the objectives of a proposal at varying levels of accomplishment, including the most likely future conditions without the project or action.

ambient: Surrounding natural conditions (or environment) in a given place and time.

amphibian: Vertebrate animal that has a life stage in water and a life stage on land (e.g., salamanders, frogs, and toads).

anthropogenic: Human-created.

appropriation: Amount of water legally set apart or assigned to a particular purpose or use.

aquatic: Living or growing in or on the water.

archaic: In American archeology, a cultural stage following the earliest known human occupation in the New World (about 5,500 BC to AD 100). It was characterized by a hunting and gathering lifestyle and seasonal movement to take advantage of a variety of resources.

archeology: Study of human cultures through the recovery and analysis of their material relics.

artifact: A human-made object.

arroyo: A gully or channel cut by an ephemeral stream.

attribute survey: Survey to determine the important components of the recreational experience.

authorization: An act by the Congress of the United States which authorizes use of public funds to carry out a prescribed action.

automatic generation control (AGC): Computerized power system regulation to maintain scheduled generation within a prescribed area in response to changes in transmission system operational characteristics.

average year: In this report, a release from Glen Canyon Dam equal to 11.1 million acre-feet per water year.

B

backwater: A relatively small, generally shallow area of a river with little or no current. *(See return-current channel.)*

baseload: Minimum load in a power system over a given period of time.

baseload plant: Powerplant normally operated to carry baseload; consequently, it operates essentially at a constant load.

beach: In this EIS, a sandbar that generally is considered to have recreational value. *(See sandbar.)*

bed elevation: Height of streambed above a specified level. Change in bed elevation in pools of the Colorado River commonly is used as a measure of change in the amount of sediment stored on the riverbed.

bedload: Sediment moving on or near the streambed and frequently in contact with it.

bed material: Unconsolidated material of which a streambed is composed.

benefit-cost ratio: The ratio of the present value of project benefits to the present value of the project costs; used in economic analysis.

benthic: Bottom of rivers, lakes, or oceans; organisms that live on the bottom of water bodies.

biological diversity: Number and kinds of organisms per unit area or volume; the composition of species in a given area at the given time.

biological opinion: Document stating the U.S. Fish and Wildlife Service and the National Marine Fisheries Service opinion as to whether a Federal action is likely to jeopardize the continued existence of a threatened or endangered species or result in the destruction or adverse modification of critical habitat.

critical habitat - Specific areas with physical or biological features essential to the conservation of a listed species and which may require special management considerations or protection. These areas have been legally designated via Federal Register notices.

jeopardy opinion - U.S. Fish and Wildlife Service or National Marine Fisheries Service opinion that an action is likely to jeopardize the continued existence of a listed species or result in the destruction or adverse modification of critical habitat. The opinion includes reasonable and prudent alternatives, if any.

no jeopardy opinion - U.S. Fish and Wildlife Service or National Marine Fisheries Service opinion that an action is not likely to jeopardize the continued existence of a listed species or result in the destruction or adverse modification of critical habitat.

biomass: Total mass or amount of a living organisms in a particular area or environment.

built environment: Modifications to the environment by man—buildings, roads, cities, etc., as compared to the natural environment. *(See cultural resources.)*

C

candidate species: Plant or animal species not yet officially listed as threatened or endangered, but which is undergoing status review by the U.S. Fish and Wildlife Service.

capacity: In power terminology, the load for which a generator, transmission line, or system is rated; expressed in kilowatts. In this document, also refers to powerplant generation capability under specific operating conditions and the amount of marketable resource under such conditions.

carnivore: Any flesh-eating or predatory organism.

catch: At a recreational fishery, refers to the number of fish captured, whether they are kept or released. *(See harvest.)*

channel: Natural or artificial watercourse, with a definite bed and banks to confine and conduct continuously or periodically flowing water.

channel margin bar: Narrow sand deposits which continuously or discontinuously line the riverbank.

chironomid: Group of two-winged flying insects who live their larval stage underwater and emerge to fly about as adults.

Cladophora: Filamentous green alga that is very important to the food chain in the Colorado River below Glen Canyon Dam.

commercial river trip: Trip organized by a boating company that conducts tours for paying passengers.

community: All members of a specified group of species present in a specific area at a specific time; a group of people who see themselves as a unit.

compact point: The reference point designated by the Colorado River compact dividing the Upper and Lower Colorado River Basins—Lee Ferry, Arizona.

conservation: Increasing the efficiency of energy and water use, production, or distribution.

consumer surplus: The value of a commodity, good, or opportunity above the cost to the consumer; measured using willingness to pay, as specified in Federal guidelines for water resources planning.

consumptive water use: Total amount of water used by vegetation, man's activities, and evaporation of surface water.

contingent valuation: Survey method asking for the maximum values that users would pay for access to a particular activity.

control area: Part of a power system, or a combination of systems, to which a common electrical generation control scheme is applied.

coordinated operation: Generally, the operation of two or more interconnected electrical systems to achieve greater reliability and economy. As applied to hydropower resources, the operation of a group of hydropower plants to obtain optimal power benefits with due consideration for all other uses.

cross-sectional area: Area of a stream, channel, or waterway, usually measured perpendicular to the flow.

cubic foot per second (cfs): As a rate of streamflow, a cubic foot of water passing a reference section in 1 second of time. A measure of a moving volume of water (1 cfs = 0.0283 m^3/s).

cultural resource: Any buildings, sites, districts, structures, or objects significant in history, architecture, archeology, culture, or science.

D

dead storage: Reservoir capacity from which stored water cannot be evacuated by gravity; at Glen Canyon Dam this is the reservoir storage below the river outlet works openings at elevation 3374 feet.

debris fan: Sloping mass of boulders, cobbles, gravel, sand, silt, and clay formed by debris flows at the mouth of a tributary.

debris flow: Flash flood consisting of a mixture of rocks and sediment containing less than 40 percent water by volume; forms debris fan.

degradation: Process wherein elevation of streambeds, flood plains, and sandbars is lowered by erosion. The opposite of aggradation.

delta: Sediment deposit formed at the mouths of the Colorado River and other streams where they enter Lake Powell or Lake Mead.

depletion: Loss of water from a stream, river, or basin resulting from consumptive use.

deposition: Settlement of material out of the water column and on to the streambed. Occurs when the energy of flowing water is unable to support the load of suspended sediment.

diatom: Microscopic, single-celled, or colonial algae having cell walls of silica.

discharge (flow): Volume of water that passes a given point within a given period of time; expressed in this document in cfs.

dissolved oxygen (DO): Amount of free oxygen found in water; perhaps the most commonly employed measurement of water quality. Low DO levels adversely affect fish and other aquatic life. The ideal dissolved oxygen for fish life is between 7 and 9 mg/L; most fish cannot survive when DO falls below 3 mg/L.

drawdown: Lowering of a reservoir's water level; process of depleting reservoir or groundwater storage.

drift: Food organisms dislodged and moved by river current. Can include algae, plankton, and even larval fish.

dynamic equilibrium: Condition achieved when the average sand load transported by the Colorado River is in balance with the sand load being supplied by its tributaries.

E

ecology: The relationship between living organisms and their environments.

ecosystem: Complex system composed of a community of fauna and flora and that system's chemical and physical environments.

eddy: Current of water moving against the main current in a circular pattern. *(See recirculation zone.)*

efficiency: Ratio of useful energy output to total energy input, usually expressed as percent.

electric power system: Physically connected electric generating, transmission, and distribution facilities operated as a unit under one control.

electrical demand: Energy requirement placed upon a utility's generation at a given instant or averaged over any designated period of time; expressed in kilowatts.

endangered species: A species or subspecies whose survival is in danger of extinction throughout all or a significant portion of its range.

energy: Electric capacity generated and/or delivered over time; usually measured in kilowatthours.

epilimnion: *See stratification.*

excess capacity: Power generation capacity available on a short-term basis in excess of the firm capacity available through long-term contracts.

existence value: Value people place on simply knowing an area or feature continues to exist in a particular condition.

extirpated species: A species which has become extinct in a given area.

F

Federal Energy Regulatory Commission (FERC): Agency primarily responsible for ensuring adequate energy supplies at just and reasonable rates and providing regulatory incentives for increased productivity, efficiency, and competition.

firm energy or power: Non-interruptible energy and power guaranteed by the supplier to be available at all times except for reasons of uncontrollable forces or continuity of service provisions.

flood control pool: Reservoir volume above the active conservation and joint-use pool that is reserved for flood runoff and then evacuated as soon as possible to keep that space in readiness for the next flood. (*See reservoir capacity.*)

floodflows: In this report, water releases from Glen Canyon Dam in excess of powerplant capacity; with Lake Powell full, this is greater than 33,200 cfs. Damaging floodflows are those greater than 40,000 cfs.

flow: Volume of water passing a given point per unit of time.

instream flow requirements - Amount of water flowing through a stream course needed to sustain instream values.

minimum flow - Lowest flow in a specified period of time.

peak flow - Maximum instantaneous flow in a specified period of time.

return flow - Portion of water previously diverted from a stream and subsequently returned to that stream or to another body of water.

fluctuating flows: Water released from Glen Canyon Dam that varies in volume with time, within the range of 1,000 to 31,500 cfs, on a daily basis. For purposes of this report, flows are defined as fluctuating if they change by more than 2,000 cfs in a 24-hour period.

fluctuating zone: Area of a sandbar or vegetation zone that is within the range of fluctuating flow.

food chain: A succession of organisms in a community in which food energy is transferred from one organism to another as each consumes a lower member and in turn is consumed by a higher member.

forage fish: Generally, small fish that produce prolifically and are consumed by predators.

forced outage: Nonscheduled shutting down of a generating unit or other facility for emergency or other unforeseen reasons.

forebay: Impoundment immediately above a dam or hydroelectric plant intake structure. The term is applicable to all types of hydroelectric developments (storage, run-of-river, and pumped-storage).

fry: Life stage of fish between the egg and fingerling stages.

fuel replacement energy: Electrical energy generated at a hydroelectric plant as a substitute for energy which would have been generated by a thermal electric plant.

full pool: Volume of water in a reservoir at maximum design elevation. At Lake Powell this is at elevation 3700 feet. Total volume is 27 million acre-feet; this volume is decreasing as the lake fills with sediment.

G

gated spillway: Overflow section of dam restricted by use of gates which can be operated to control releases from the reservoir to ensure the safety of the dam.

gauging station: Specific location on a stream where systematic observations of hydrologic data are obtained through mechanical or electrical means. Also referred to as a "gauge."

generation: Process of producing electrical energy by transforming other forms of energy; also, amount of electric energy produced, expressed in kilowatthours.

generator: Machine that converts mechanical energy into electrical energy.

geomorphology: Geological study of the configuration and evolution of land forms and earth features.

gigawatthour (GWh): One billion watt-hours of electrical energy.

gradient: *See slope.*

gross generation: Total amount of electrical energy produced by a generating station or stations, measured at generator terminals; expressed in megawatthours.

H

habitat: Area where a plant or animal lives.

harvest: In a recreational fishery, refers to numbers of fish that are caught and kept. *(See catch.)*

headwater: The source and upper part of a stream; water upstream of a dam.

herbivore: Animal that feeds on plants.

herpetofauna: General grouping for reptiles and amphibians.

human environment: Natural and physical environment and the relationship of people with that environment including all combinations of physical, biological, cultural, social, and economic factors in a given area.

hydraulic: Powered by water.

hydroelectric plant: Electric powerplant using falling water as its motive force.

hydrograph: A graph showing, for a given point in a stream, the discharge, stage, velocity, or other property of water with respect to time.

hydrologic cycle: The continuous circulation of water from the atmosphere to Earth by precipitation, and from earth to the atmosphere by evaporation, and transpiration. The land phase includes infiltration, runoff, and exchange between surface water and ground water.

hydrology: Science dealing with water and snow, including their properties and distribution. Also used in this document to refer to a specified annual inflow to Lake Powell.

hydroelectric power: Electrical capacity produced by water.

hypolimnion: *See stratification.*

I

impoundment: Body of water created by a dam.

inactive storage: The reservoir capacity that can be released from the dam but is not available for power generation; at Glen Canyon Dam this is the reservoir storage above the river outlet works openings at elevation 3374 feet and below the penstock openings at elevation 3490 feet (about 3.9 million acre-feet).

indicator: Organism, species, or community which indicates presence of certain environmental conditions.

inflow: In this report, the water flowing into Lake Powell from the Colorado River and/or its tributaries; or water entering the Colorado River from tributaries between Glen Canyon Dam and Lake Mead; or water flowing into Lake Mead, mainly from the Colorado River.

interconnected systems: System consisting of two or more individual power systems normally operating with connecting tie lines.

inundate: To cover with impounded waters or floodwaters.

J

jetty: Pier or other structure built out into a body of water to influence the current or tide, or to protect a harbor or shoreline.

juvenile: Young fish older than 1 year but not having reached reproductive age.

K

kilovolt (kV): 1,000 volts.

kilowatt (kW): Unit of electric power (capacity) equal to 1,000 watts, or about 1.34 horsepower.

kilowatthour (kWh): Basic unit of electric energy equaling an average of 1 kilowatt of power applied over 1 hour.

L

larval fish: An immature stage that develops from the fertilized egg before assuming the characteristics of the adult.

"Law of the River": As applied to the Colorado River, a combination of Federal and State statutes, inter-State compacts, court decisions and decrees, Federal contracts, an international treaty with Mexico, and formally determined operating criteria. For more detail, see chapter I.

Lee Ferry: A reference point marking division between the Upper and Lower Colorado River Basins. The point is located in the mainstream of the Colorado River 1 mile below the mouth of the Paria River in Arizona.

Lees Ferry: Location of Colorado River ferry crossings (1873 to 1928) and site of the USGS stream gauge above the Paria River confluence.

limnology: Scientific study of the physical characteristics and biology of lakes, ponds, and streams.

load: Amount of electrical power or energy delivered or required at a given point.

Lower Basin: The part of Colorado River watershed below Lee Ferry, Arizona; covers parts of Arizona, California, Nevada, New Mexico, and Utah.

Lower Division: A division of the Colorado River system that includes the States of Arizona, Nevada, and California; defined by Article II of the Colorado River Compact.

M

main channel: The deepest or central part of the bed of a stream, containing the main current.

mainstem: The main course of a stream.

mainstream: The principal or largest stream of a given area or drainage basin; in this document, the Colorado River.

median: Middle value in a distribution, above and below which lie an equal number of values.

megawatt (MW): One million watts of electrical power (capacity).

megawatthour (MWh): One million watt-hours of electrical energy.

metalimnion: *See stratification.*

mill: Monetary cost and billing unit used by utilities; equal to 1/1,000 of U.S. dollar (equivalent to 1/10 of one cent).

milligram per liter: Equivalent to 1 part per million.

million acre-feet (maf): A unit of volume; the volume of water that would cover 1 million acres to a depth of 1 foot.

mitigation (measures): Action taken to avoid, reduce the severity of, or eliminate an adverse impact. Mitigation can include one or more of the following: (1) avoiding impacts; (2) minimizing impacts by limiting the degree or magnitude of an action; (3) rectifying impacts by restoration, rehabilitation, or repair of the affected environment; (4) reducing or eliminating impacts over time; and (5) compensating for the impact by replacing or providing substitute resources or environments to offset the loss.

mitigation (as used in Cultural Resource Compliance Procedures): Any treatment of historic or prehistoric property that will offset adverse effects that may result from an agency's action, e.g., construction of a canal may partially destroy a prehistoric Indian village. Mitigation of this effect might include excavation of the village before construction to retrieve information before it is destroyed.

multipurpose dam: Barrier constructed for two or more purposes such as storage, flood control, navigation, power generation, recreation, and fish and wildlife enhancement.

multiple-purpose reservoir: Reservoir planned to operate for more than one purpose.

N

National Register of Historic Places: A federally maintained register of districts, sites, buildings, structures, architecture, archeology, and culture.

new high water zone (NHWZ): The area located next to the river, corresponding to riverflows of 25,000 to 40,500 cfs, colonized with vegetation since the construction of Glen Canyon Dam; typically composed of riparian species, both native and non-native.

nitrogen dioxide (NO_x): A form of gas produced from burning fossil fuels.

nonconsumptive water use: Water uses including swimming, boating, waterskiing, fishing, maintenance of stream-related fish and wildlife habitat, hydropower generation, and other uses that do not substantially deplete water supplies.

nonfirm power: Power that is not available continuously and may be interruptible; may be marketed on a short-term basis.

non-use value: The economic benefit which arises from the knowledge that a resource exists (existence value), has been preserved for potential use in the future (option value), and will be available for use by one's heirs (bequest value). Non-use value is theoretically and conceptually distinct from use value. Contingent valuation is the only technique currently available for estimating non-use value.

normal year: *See average year.*

North American Electric Reliability Council (NERC): Principal organization for coordinating, promoting, and communicating about reliability for North America's electric utilities. NERC was formed in 1968 in the aftermath of the November 9, 1965, northeast blackout.

O

off-peak energy: Electric energy supplied during periods of relatively low system demand.

old high water zone (OHWZ): An area of vegetation above the level corresponding to floodflows of about 120,000 to 125,000 cfs and typically composed of native tree species.

omnivore: Animal that eats both vegetable and animal substances.

on-peak energy: Electric energy supplied during periods of relatively high system demand.

operational losses: Losses of water resulting from evaporation and seepage.

outage: Period during which a generating unit, transmission line, or other facility is out of service.

outflow: Water flowing out; in this report refers to water leaving Lake Powell by way of Glen Canyon Dam.

P

peak demand: *See peak load.*

peak load: Maximum electrical demand in a stated period of time.

peaking power: Powerplant capacity typically used to meet the highest levels of demand in a utility's load or demand profile.

peak load plant: Powerplant that normally is operated to provide power during maximum load periods.

penstock: Conduit pipe used to convey water under pressure to the turbines of a hydroelectric plant.

permeability (soil): Ease with which gasses, liquids, or plant roots penetrate or pass through a layer of soil.

plankton: Tiny plants (phytoplankton) and animals (zooplankton) with limited powers of locomotion usually living free in the water away from substrates.

pool: A deep area of a stream between rapids or where the current is slow.

power: Electrical capacity generated, transferred, or used; usually expressed in kilowatts.

power demand: Rate at which electric energy is required and delivered to or by a system over any designated period of time.

powerplant: Structure that houses turbines, generators, and associated control equipment.

powerplant capacity: Maximum flow that can pass through the turbines at Glen Canyon Dam when Lake Powell is full (33,200 cfs). Also refers to the electrical capacity of the generators; expressed in megawatts.

power pool: Two or more interconnected electric systems which operate on a coordinated basis to achieve economy and reliability in supplying their combined loads.

preference customers: In accordance with congressional directives, publicly-owned systems, and nonprofit cooperatives that have preference over investor-owned systems for purchase of power from Federal projects.

production expenses: Costs incurred in production of electrical power and conforming to accounting requirements of the Operation and Maintenance Expense Accounts of the FERC Uniform System of Accounts.

public involvement: Process of obtaining citizen input into each stage of development of planning documents. Required as a major input into any EIS.

R

ramp rate: The rate of change in instantaneous output from a powerplant. The ramp rate is established to prevent undesirable effects due to rapid changes in loading or, in the case of hydroelectric plants, discharge.

range: Geographic region in which a given plant or animal normally lives or grows.

rapid: A section of a river where the current is very fast moving, caused by a steep descent in the riverbed through a constriction of the main channel.

rated head: Water depth for which a hydroelectric generator and turbines were designed.

reach: Any specified length of a stream, channel, or other water conveyance.

reattachment bar: Sandbar located where downstream flow meets the riverbank at the downstream end of a recirculation zone.

recirculation zone: Area of flow composed of one or more eddies immediately downstream from a constriction in the channel, such as a debris fan or rock outcrop.

recreational benefit: Value of recreational activity to the recreationist, usually measured in dollars above the cost of participating in the recreational activity (travel, entrance fees, etc.). Used for valuing recreational resources produced through Federal projects and synonymous with the consumer surplus associated with the recreational activity.

recruitment: Survival of young plants and animals from birth to a life stage less vulnerable to environmental change.

redd: Depression in river or lake bed dug by fish for the deposition of eggs.

reregulation dam: Low dam located downstream from a large hydroelectric powerplant used to even out the flows further downstream.

reserve generating capacity: Extra generating capacity available to meet unanticipated capacity demand for power in the event of generation loss due to scheduled or unscheduled outages of regularly used generating capacity.

reservoir: Artificially impounded body of water.

reservoir capacity:

active capacity - Reservoir capacity normally usable for storage and regulation of reservoir inflows to meet established reservoir operating requirement.

flood control capacity - Reservoir capacity assigned to the sole purpose of regulating flood inflows to reduce flood damage downstream.

active conservation capacity - Capacity assigned to regulate reservoir inflow for irrigation, power, municipal and industrial use, fish and wildlife, navigation, recreation water quality, and other purposes.

surcharge capacity - Reservoir capacity provided for use in passing the inflow design flood through the reservoir. Reservoir capacity between maximum water surface elevation and the highest of the following elevations: (1) top of exclusive flood control capacity, (2) top of joint use capacity, or (3) top of active conservation capacity.

resilience: Ability of any system to resist or to recover from stress.

return-current channel: The channel excavated by upstream eddy flow that forms behind a reattachment bar.

rewind: Act of putting new insulated copper wire in the armature windings of a generator.

riffle: A stretch of choppy water caused by an underlying rock shoal or sandbar.

riparian: Of, on, or pertaining to the bank of a river, pond, or lake.

riprap: Stones placed on the face of a dam, on stream banks, or on other land surfaces to protect them from erosion.

river corridor: The Colorado River and the strips of land adjacent to it, including the talus slopes at the bases of cliffs, but not the cliffs themselves.

river mile (RM): A unit of measurement (in miles) used on the Colorado River with River Mile 0 located at the U.S. Geological Survey gauge at Lees Ferry; miles downstream from that point are positive and miles upstream are negative.

S

sandbar: In this EIS, any of the fine-grained alluvial deposits that intermittently form the riverbank. These fine-grained deposits are in contrast to the rocky surfaces predominately found throughout the canyon. *(See beaches.)*

sand load: *See sediment load.*

scheduled outage: Shutdown of a generating unit or other facility for inspection or maintenance, in accordance with an advance schedule.

sediment: Unconsolidated solid material that comes from weathering of rock and is carried by, suspended in, or deposited by water or wind.

sediment load: Mass of sediment passing through a stream cross-section in a specified period of time, expressed in millions of tons.

seepage: Relatively slow movement of water through a medium, such as sand.

separation bar: Sandbar located at the upstream end of a recirculation zone, where downstream flow becomes separated from the riverbank, creating an eddy.

simulid: Group of two-winged flying insects who live their larval stage underwater and emerge to fly about as adults.

site: In archeology, any location of past human activity.

slope: Change in elevation per unit of horizontal distance.

spawn: To lay eggs, especially fish.

spawning beds: Places in which eggs of aquatic animals lodge or are placed during or after fertilization.

spills: Water releases from Glen Canyon Dam that cannot be put to use for project purposes (includes floodflows).

spillway: Overflow channel of a dam.

spinning reserves: Available capacity of generating facilities synchronized to the interconnected electric system where it can be called upon for immediate use in response to system problems or sudden load changes.

standby reserves: Unused capacity of an electric system found in generators that are not in operation but that are available for immediate use if required.

stage: *See water surface elevation.*

steady flow: In this report, flow released from Glen Canyon Dam at any volume which does not vary by more than 2,000 cfs over a 24-hour period.

stratification: Thermal layering of water in lakes and streams. Lakes usually have three zones of varying temperature: *epilimnion*—top layer with essentially uniform warmer temperature; *metalimnion*—middle layer of rapid temperature decrease with depth; and *hypolimnion*—bottom layer with essentially uniform colder temperatures.

stream: Natural water course.
- *ephemeral* - Stream that flows briefly only in direct response to precipitation and whose channel is above the water table.
- *intermittent or seasonal* - Stream on or in contact with the ground-water table that flows only at certain times of the year when the ground-water table is high.
- *perennial* - Stream that flows continuously throughout the year.

structural elements: In this report, physical facilities rather than a change in dam operations.

substrate: Surface on which a plant or animal grows or is attached.

sulfur dioxide (SO_2): A colorless gas released from many sources, especially burning fossil fuels and smelting metals.

surplus energy: Energy surplus to contracted firm load which may be available for a short-term period to serve additional load, usually attributed to favorable but unanticipated hydrologic conditions.

T

tailwater: Water immediately downstream of a dam.

talus: Sloping accumulation of rock debris; also, rock fragments at the base of a cliff as the result of sliding or falling.

temporary structure: Any structure that can be readily and completely dismantled and removed from the site between periods of actual use. It may or may not be authorized at the same site from season to season or from year to year.

terrace: The surface form of a high sediment deposit having a relatively flat surface and steep slope facing the river.

thalweg: Line connecting the deepest points along a riverbed.

toe: The point at which the bottom of a slope or embankment intersects the natural ground, such as the upstream or downstream toe of the dam or the downstream toe of a landslide or debris fan.

topography: Physical shape of the ground surface.

traditional cultural property: A site or resource that is eligible for inclusion in the *National Register of Historic Places* because of its association with cultural practices or beliefs of a living community.

transmission line: Facility for transmitting electrical energy at high voltage from one point to another point. Transmission line voltages are normally 115 kV or larger.

transport capacity: The capacity of a river to carry sediment in suspension or to move sediment along the riverbed. Usually expressed as mass per unit of time.

tributary: River or stream flowing into a larger river or stream.

turbidity: Cloudiness of water, measured by how deeply light can penetrate into the water from the surface.

U

Upper Basin: The part of the Colorado River watershed above Lee Ferry, Arizona; covers parts of Arizona, Colorado, New Mexico, Utah, and Wyoming.

Upper Colorado River Commission: Commission established by the Upper Colorado River Basin Compact of five appointed members from the Upper Division States (Colorado, New Mexico, Utah, Wyoming) whose purpose is to secure the storage of water for beneficial consumptive use in the Upper Basin.

Upper Division: A division of the Colorado River system that includes the States of Colorado, New Mexico, Utah, and Wyoming; defined by Article II of the Colorado River Compact.

uprate: Modification or replacement of generator equipment that would enable operation beyond present capacity, included in the act of rewinding; involves replacing field windings, strengthening rotor arms, and making mechanical modifications.

use value: The economic benefit associated with the physical use of a resource, usually measured by the consumer surplus or net economic value associated with such use. The contingent value method is one technique used to estimate use value.

V

velocity: Rate of flow of water or water-sediment mixture; expressed in feet per second or miles per hour.

visitor day: Twelve visitor hours which may be aggregated by one or more persons in single or multiple visits.

visitor use: Visitor use of recreation and wilderness resources for inspiration, stimulation, solitude, relaxation, education, pleasure, or satisfaction.

W

watershed: Surface drainage areas above a specified point on a stream.

water-surface elevation (stage): The elevation of a water surface above or below an established reference level, such as sea level.

water year: Period of time beginning October 1 of one year and ending September 30 of the following year and designated by the calendar year in which it ends.

wetlands: Lands including swamps, marshes, bogs, and similar areas such as wet meadows, river overflows, mud flats, and natural ponds.

wilderness: Tract or region of land uncultivated and uninhabited by human beings, or unoccupied by human settlements. [See 78 Stat. 891, Wilderness Act of 1964, sec. 2, (c) for legal definition.]

willingness to pay: Method of estimating the value of activities, services, or other goods, where value is defined as the maximum amount a consumer would be willing to pay for the opportunity rather than do without. The total willingness to pay, minus the user's costs of participating in the opportunity, defines the consumer surplus and benefits.

Y

young-of-year: Refers to young (usually fish) produced in one reproductive year. Small fish, hatched from eggs spawned in the current year, are considered young-of-year (age 0).

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Attachments

ATTACHMENT 1

Environmental Commitments

The following is a list of environmental commitments that would be honored under any of the restricted fluctuating or steady flow alternatives described in this document. These commitments are described in detail in chapter II.

1. *Adaptive Management:* This commitment includes long-term monitoring, research, and experimentation possibly leading to operational changes. However, operational changes would not be implemented without further NEPA compliance.

2. *Monitoring and Protection of Cultural Resources:* Cultural sites in Glen and Grand Canyons include prehistoric and historic sites, and Native American traditional use and sacred sites. Some of these sites may erode in the future under any EIS alternative. Reclamation and NPS, in consultation with Native American groups, would develop and implement a long-term monitoring program for these sites. Any necessary mitigation would be carried out according to a programmatic agreement written in compliance with the National Historic Preservation Act (see attachment 5).

3. *Flood Frequency Reduction Measures:* Under this commitment, the frequency of unanticipated floods in excess of 45,000 cfs would be reduced to an average of once in 100 years. This would be accomplished by raising the height of the spillway gates at Glen Canyon Dam 4.5 feet.

4. *Beach/Habitat-Building Flows:* Under certain conditions, flows in excess of a given alternatives' maximum would be scheduled in April for periods ranging from 1 to 2 weeks. Scheduling, duration, and flow magnitude would be recommended by the Adaptive Management Work Group. The objectives of these flows would be to:

   - Deposit sediment at high elevations
   - Re-form backwater channels
   - Deposit nutrients
   - Provide for system dynamics
   - Help NPS to manage riparian habitats

5. *New Population of Humpback Chub:* In consultation with the FWS, NPS, and AGFD, Reclamation would make every effort—through funding, facilitating, and technical support—to ensure that a new population of humpback chub is established in one or more of the tributaries within the Grand Canyon.

6. *Further Study of Selective Withdrawal:* Reclamation would support research on the effects of multilevel intake structures at Glen Canyon Dam and use the results of this research 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.

7. *Emergency Exception Criteria:* Operating criteria would be established to allow Western to respond to various emergency situations in accordance with their obligations to the North American Electric Reliability Council. This commitment also provides for exceptions to a given alternative's operating criteria during search and rescue situations, special studies and monitoring, dam and powerplant maintenance, and spinning reserves.

ATTACHMENT 2

Grand Canyon Protection Act

SEC. 1801. SHORT TITLE.

This Act may be cited as the "Grand Canyon Protection Act of 1992".

SEC. 1802. PROTECTION OF GRAND CANYON NATIONAL PARK

(a) IN GENERAL.—The Secretary shall operate Glen Canyon Dam in accordance with the additional criteria and operating plans specified in section 1804 and exercise other authorities under existing law in such a manner as to protect, mitigate adverse impacts to, and improve the values for which Grand Canyon National Park and Glen Canyon National Recreation Area were established, including, but not limited to natural and cultural resources and visitor use.

(b) COMPLIANCE WITH EXISTING LAW.—The Secretary shall implement this section in a manner fully consistent with and subject to the Colorado River Compact, the Upper Colorado River Basin Compact, the Water Treaty of 1944 with Mexico, the decree of the Supreme Court in Arizona vs. California, and the provisions of the Colorado River Storage Project Act of 1956 and the Colorado River Basin Project Act of 1968 that govern allocation, appropriation, development, and exportation of the waters of the Colorado River Basin.

(c) RULE OF CONSTRUCTION.—Nothing in this title alters the purposes for which the Grand Canyon National Park or the Glen Canyon National Recreation Area were established or affects the authority and responsibility of the Secretary with respect to the management and administration of the Grand Canyon National Park and Glen Canyon National Recreation Area, including natural and cultural resources and visitor use, under laws applicable to those areas, including, but not limited to, the Act of August 25, 1916 (39 Stat. 535) as amended and supplemented.

SEC. 1803. INTERIM PROTECTION OF GRAND CANYON NATIONAL PARK

(a) INTERIM OPERATIONS.—Pending compliance by the Secretary with section 1804, the Secretary shall, on an interim basis, continue to operate Glen Canyon Dam under the Secretary's announced interim operating criteria and the Interagency Agreement between the Bureau of Reclamation and the Western Area Power Administration executed October 2, 1991 and exercise other authorities under existing law, in accordance with the standards set forth in section 1802, utilizing the best and most recent scientific data available.

(b) CONSULTATION.—The Secretary shall continue to implement Interim Operations in consultation with—

(1) Appropriate agencies of the Department of the Interior, including the Bureau of Reclamation, United States Fish and Wildlife Service, and the National Park Service;
(2) The Secretary of Energy;
(3) The Governors of the States of Arizona, California, Colorado, Nevada, New Mexico, Utah, and Wyoming;
(4) Indian Tribes; and
(5) The general public, including representatives of the academic and scientific communities, environmental organizations, the recreation industry, and contractors for the purchase of Federal power produced at Glen Canyon Dam.

(c) DEVIATION FROM INTERIM OPERATIONS.—The Secretary may deviate from Interim Operations upon a finding that deviation is necessary and in the public interest to—

(1) comply with the requirements of Section 1804(a);
(2) respond to hydrologic extremes or power system operation emergencies;

(3) comply with the standards set forth in Section 1802;
(4) respond to advances in scientific data; or
(5) comply with the terms of the Interagency Agreement.

(d) TERMINATION OF INTERIM OPERATIONS.—Interim operations described in this section shall terminate upon compliance by the Secretary with section 1804.

SEC. 1804. GLEN CANYON DAM ENVIRONMENTAL IMPACT STATEMENT; LONG-TERM OPERATION OF GLEN CANYON DAM.

(a) FINAL ENVIRONMENTAL IMPACT STATEMENT.—Not later than 2 years after the date of enactment of this Act, the Secretary shall complete a final Glen Canyon Dam environmental impact statement, in accordance with the National Environmental Policy Act of 1969 (42 U.S.C. 4321 et seq.).

(b) AUDIT.—The Comptroller General shall—

(1) audit the cost and benefits to water and power users and to natural, recreational, and cultural resources resulting from management policies and dam operations identified pursuant to the environmental impact statement described in subsection (a); and

(2) report the results of the audit to the Secretary and the Congress.

(c) ADOPTION OF CRITERIA AND PLANS.—(1) Based on the findings, conclusions, and recommendations made in the environmental impact statement prepared pursuant to subsection (a) and the audit performed pursuant to subsection (b), the Secretary shall—

(A) adopt criteria and operating plans separate from and in addition to those specified in section 602(b) of the Colorado River Basin Project Act of 1968; and

(B) exercise other authorities under existing law, so as to ensure that Glen Canyon Dam is operated in a manner consistent with section 1802.

(2) Each year after the date of the adoption of criteria and operating plans pursuant to paragraph (1), the Secretary shall transmit to the Congress and to the Governors of the Colorado River Basin States a report, separate from and in addition to the report specified in section 602(b) of the Colorado River Basin Project Act of 1968 on the preceding year and the projected year operations undertaken pursuant to this Act.

(3) In preparing the criteria and operating plans described in section 602(b) of the Colorado River Basin Project Act of 1968 and in this subsection, the Secretary shall consult with the Governors of the Colorado River Basin States and with the general public, including—
(A) representatives of academic and scientific communities;
(B) environmental organizations;
(C) the recreation industry; and
(D) contractors for the purpose of Federal power produced at Glen Canyon Dam.

(d) REPORT TO CONGRESS.—Upon implementation of long-term operations under subsection (c), the Secretary shall submit to the Congress the environmental impact statement described in subsection (a) and a report describing the long-term operations and other reasonable mitigation measures taken to protect, mitigate adverse impacts to, and improve the condition of the natural, recreational, and cultural resources of the Colorado River downstream of Glen Canyon Dam.

(e) ALLOCATION OF COSTS.—The Secretary of the Interior, in consultation with the Secretary of Energy, is directed to reallocate the costs of construction, operation, maintenance, replacement and emergency expenditures for Glen Canyon Dam among the purposes directed in section 1802 of this Act and the purposes established in the Colorado River Storage Project Act of April 11, 1956 (70 Stat. 170). Costs allocated to section 1802 purposes shall be nonreimbursable. Except that in fiscal year 1993 through 1997 such costs shall be nonreimbursable only to the extent to which the Secretary finds the effect of all provisions of this Act is to increase net offsetting receipts; Provided, That if the Secretary finds in any such year that the enactment of this Act does cause a reduction in net offsetting receipts generated by all provisions of this Act, the costs allocated to section 1802 purposes shall remain reimbursable. The Secretary shall determine the effect of all the provisions of this Act and submit a report to the appropriate House and Senate committees by January 31 of each fiscal year, and such report shall contain for that fiscal year a detailed accounting of expenditures incurred pursuant to this Act, offsetting receipts generated by this Act, and any increase or reduction in net offsetting receipts generated by this Act.

SEC. 1805. LONG-TERM MONITORING.

(a) IN GENERAL.—The Secretary shall establish and implement long-term monitoring programs and activities that will ensure that Glen Canyon Dam is operated in a manner consistent with that of section 1802.

(b) RESEARCH.—Long-term monitoring of Glen Canyon Dam shall include any necessary research and studies to determine the effect of the Secretary's actions under section 1804(c) on the natural, recreational, and cultural resources of Grand Canyon National Park and Glen Canyon National Recreation Area.

(c) CONSULTATION.—The monitoring programs and activities conducted under subsection (a) shall be established and implemented in consultation with—

(1) the Secretary of Energy;

(2) the Governors of the States of Arizona, California, Colorado, Nevada, New Mexico, Utah, and Wyoming;

(3) Indian tribes; and

(4) the general public, including representatives of academic and scientific communities, environmental organizations, the recreation industry, and contractors for the purchase of Federal power produced at Glen Canyon Dam.

SEC. 1806. RULES OF CONSTRUCTION.

Nothing in this title is intended to affect in any way—

(1) the allocations of water secured to the Colorado Basin States by any compact, law, or decree; or

(2) any Federal environmental law, including the Endangered Species Act (16 U.S.C. 1531 et seq.).

SEC. 1807. STUDIES NONREIMBURSABLE.

All costs of preparing the environmental impact statement described in section 1804, including supporting studies, and the long-term monitoring programs and activities described in section 1805 shall be nonreimbursable. The Secretary is authorized to use funds received from the sale of electric power and energy from the Colorado River Storage Project to prepare the environmental impact statement described in section 1804, including supporting studies, and the long-term monitoring programs and activities described in section 1805, except that such funds will be treated as having been repaid and returned to the general fund of the Treasury as costs assigned to power for repayment under section 5 of the Act of April 11, 1956 (70 Stat. 170). Except that in fiscal year 1993 through 1997 such provisions shall take effect only to the extent to which the Secretary finds the effect of all the provisions of this Act is to increase net offsetting receipts; Provided, That if the Secretary finds in any such year that the enactment of this Act does cause a reduction in net offsetting receipts generated by all provisions of this Act, all costs described in this section shall remain reimbursable. The Secretary shall determine the effect of all the provisions of this Act and submit a report to the appropriate House and Senate committees by January 31 of each fiscal year, and such report shall contain for that fiscal year a detailed accounting of expenditures incurred pursuant to this Act, offsetting receipts generated by this Act, and any increase or reduction in net offsetting receipts generated by this Act.

SEC. 1808. AUTHORIZATION OF APPROPRIATIONS.

There are authorized to be appropriated such sums as are necessary to carry out this title.

SEC. 1809. REPLACEMENT POWER.

The Secretary of Energy in consultation with the Secretary of the Interior and with representatives of the Colorado River Storage Project power customers, environmental organizations and the States of Arizona, California, Colorado, Nevada, New Mexico, Utah, and Wyoming shall identify economically and technically feasible methods of replacing any power generation that is lost through adoption of long-term operational criteria for Glen Canyon Dam as required by section 1804 of this title. The Secretary shall present a report of the findings, and implementing draft legislation, if necessary, not later than two years after adoption of long-term operating criteria. The Secretary shall include an investigation of the feasibility of adjusting operations at Hoover Dam to replace all or part of such lost generation. The Secretary shall include an investigation of the modifications or additions to the transmission system that may be required to acquire and deliver replacement power.

ATTACHMENT 3

Long-Range Operating Criteria

CRITERIA FOR COORDINATED LONG-RANGE OPERATION OF COLORADO RIVER RESERVOIRS PURSUANT TO THE COLORADO RIVER BASIN PROJECT ACT OF SEPTEMBER 30, 1968 (P.L. 90-537)

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

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

I. *ANNUAL REPORT*

(1) On January 1, 1972, and on January 1 of each year thereafter, the Secretary shall transmit to the Congress and to the Governors of the Colorado River Basin States a report describing the actual operation under the adopted criteria for the preceding compact water year and the projected plan of operation for the current year.

(2) The plan of operation shall include such detailed rules and quantities as may be necessary and consistent with the criteria contained herein, and shall reflect appropriate consideration of the uses of the reservoirs for all purposes, including flood control, river regulation, beneficial consumptive uses, power production, water quality control, recreation, enhancement of fish and wildlife, and other environmental factors. The projected plan of operation may be revised to reflect the current hydrologic conditions, and the Congress and the Governors of the Colorado River Basin States shall be advised of any changes by June of each year.

II. *OPERATION OF UPPER BASIN RESERVOIRS*

(1) The annual plan of operation shall include a determination by the Secretary of the quantity of water considered necessary as of September 30 of each year to be in storage as required by Section 602(a) of P.L. 90-537 (hereinafter "602(a) Storage"). The quantity of 602(a) Storage shall be determined by the Secretary after consideration of all applicable laws and relevant factors, including, but not limited to, the following:

(a) Historic streamflows;
(b) The most critical period of record;
(c) Probabilities of water supply;
(d) Estimated future depletions in the upper basin, including the effects of recurrence of critical periods of water supply;
(e) The "Report of the Committee on Probabilities and Test Studies to the Task Force on Operating Criteria for the Colorado River," dated October 30, 1969, and such additional studies as the Secretary deems necessary;
(f) The necessity to assure that upper basin consumptive uses not be impaired because of failure to store sufficient water to assure deliveries under Section 602(a)(1) and (2) of P.L. 90-537.

(2) If in the plan of operation, either:

(a) the Upper Basin Storage Reservoirs active storage forecast for September 30 of the current year is less than the quantity of 602(a) Storage determined by the Secretary under Article II(1) hereof, for that date; or
(b) the Lake Powell active storage forecast for that date is less than the Lake Mead active storage forecast for that date:

the objective shall be to maintain a minimum release of water from Lake Powell of 8.23 million acre-feet for that year. However, for the years ending September 30, 1971 and 1972, the release may be greater than 8.23 million acre-feet if necessary to deliver 75,000,000 acre-feet at Lee Ferry for the 10-year period ending September 30, 1972.

(3) If, in the plan of operation, the Upper Basin Storage Reservoirs active storage forecast for September 30 of the current water year is greater than the quantity of 602(a) Storage determination for that date, water shall be released annually from Lake Powell at a rate greater than 8.23 million acre-feet per year to the extent necessary to accomplish any or all of the following objectives:

(a) to the extent it can be reasonably applied in the States of the Lower Division to the uses specified in Article III(e) of the Colorado River Compact, but no such releases shall be made when the active storage in Lake Powell is less than the active storage in Lake Mead,
(b) to maintain, as nearly as practicable, active storage in Lake Mead equal to the active storage in Lake Powell, and
(c) to avoid anticipated spills from Lake Powell.

(4) In the application of Article II(3)(b) herein, the annual release will be made to the extent that it can be passed through Glen Canyon Powerplant when operated at the available capability of the powerplant. Any water thus retained in Lake Powell to avoid bypass of water at the Glen Canyon Powerplant will be released through the Glen Canyon Powerplant as soon as practicable to equalize the active storage in Lake Powell and Lake Mead.

(5) Releases from Lake Powell pursuant to these criteria shall not prejudice the position of either the upper or lower basin interests with respect to required deliveries at Lee Ferry pursuant to the Colorado River Compact.

III. OPERATION OF LAKE MEAD

(1) Water released from Lake Powell, plus the tributary inflows between Lake Powell and Lake Mead, shall be regulated in Lake Mead and either pumped from Lake Mead or released to the Colorado River to meet requirements as follows:

(a) Mexican Treaty obligations;
(b) Reasonable consumptive use requirements of mainstream users in the Lower Basin;
(c) Net river losses;
(d) Net reservoir losses;
(e) Regulatory wastes.

(2) Until such time as mainstream water is delivered by means of the Central Arizona Project, the consumptive use requirements of Article III(1)(b) of these Operating Criteria will be met.

(3) After commencement of delivery of mainstream water by means of the Central Arizona Project, the consumptive use requirements of Article III(1)(b) of these Operating Criteria will be met to the following extent:

(a) *Normal*: The annual pumping and release from Lake Mead will be sufficient to satisfy 7,500,000 acre-feet of annual consumptive use in accordance with the decree in *Arizona v. California*, 376 U.S. 340 (1964).
(b) *Surplus*: The Secretary shall determine from time to time when water in quantities greater than "Normal" is available for either pumping or release from Lake Mead pursuant to Article II(b)(2) of the decree in *Arizona v. California* after consideration of all relevant factors, including, but not limited to, the following:

(i) the requirements stated in Article III(1) of these Operating Criteria;
(ii) requests for water by holders of water delivery contracts with the United States, and of other rights recognized in the decree in *Arizona v. California;*
(iii) actual and forecast quantities of active storage in Lake Mead and the Upper Basin Storage Reservoirs; and
(iv) estimated net inflow to Lake Mead.

(c) *Storage*: The Secretary shall determine from time to time when insufficient mainstream water is available to satisfy annual consumptive use requirements of 7,500,000 acre-feet after consideration of all relevant factors, including, but not limited to, the following:

(i) the requirements stated in Article III(1) of these Operating Criteria;
(ii) actual and forecast quantities of active storage in Lake Mead;
(iii) estimate of net inflow to Lake Mead for the current year;
(iv) historic streamflows, including the most critical period of record;
(v) priorities set forth in Article II(A) of the decree in *Arizona v. California*; and
(vi) the purposes stated in Article I(2) of these Operating Criteria.

The storage provisions of Article II(B)(3) of the decree in *Arizona v. California* shall thereupon become effective and consumptive uses from the mainstream shall be restricted to the extent determined by the Secretary to be required by Section 301(b) of Public Law 90-537.

IV. DEFINITIONS

(1) In addition to the definitions in Section 606 of P. L. 90-537, the following shall also apply:

(a) "Spills," as used in Article II(3)(c) herein, means water released form Lake Powell which cannot be utilized for project purposes, including, but not limited to, the generation of power and energy.
(b) "Surplus," as used in Article III(3)(b) herein, is water which can be used to meet consumptive use demands in the three Lower Division States in excess of 7,500,000 acre-feet annually. The term"surplus" as used in these Operating Criteria is not to be construed as applied to, being interpretive of, or in any manner having reference to the term "surplus" in the Colorado River Compact.
(c) "Net inflow to Lake Mead," as used in Article III(3) (b)(iv) and (c)(iii) herein, represents the annual inflow to Lake Mead in excess of losses from Lake Mead.
(d) "Available capability," as used in Article II(4) herein, means that portion of the total capacity of the powerplant that is physically available for generation.

ATTACHMENT 4

Fish and Wildlife Consultation

RECOMMENDATIONS AND RESPONSES

In accordance with the Fish and Wildlife Coordination Act (FWCA), the U.S. Fish and Wildlife Service (FWS) submitted recommendations to the Bureau of Reclamation (Reclamation) in connection with Glen Canyon Dam operations. These recommendations were included in the FWS's draft FWCA report dated April 14, 1993. Copies of this draft report can be obtained by writing to the Field Supervisor, U.S. Fish and Wildlife Service, Arizona Ecological Services Field Office, 3616 West Thomas Road, Suite 6, Phoenix, Arizona 85019.

Recommendation 1. The historical operations of Glen Canyon Dam have eliminated the features of a natural hydrograph from river operations. To provide conditions more suitable for native fish species, a hydrological pattern comparable to the natural hydrograph should be implemented.

a. Water should be released in a pattern which most closely mimics the natural hydrograph to facilitate natural ecosystem processes. High flows should occur during the spring run-off, peaking sometime between April and June, and lower steady flows should occur throughout the remainder of the year. Flows would include beach/habitat building flows to be released during the spring in low waters years.

Response

FWS recommends that ". . . a hydrological pattern comparable to the natural hydrograph should be implemented." The EIS team, composed of representatives from the FWS, Reclamation, National Park Service, U.S. Geological Survey, Western Area Power Administration (Western), Arizona Game and Fish Department, Hopi Tribe, Hualapai Tribe, Navajo Nation, and others rejected such an alternative early in the analysis process (see chapter II, Alternatives Considered and Eliminated from Detailed Study).

The alternative, known as Run-of-the-River, was eliminated because it incorporated structural features such as a sediment augmentation system and selective withdrawal structures to increase water temperatures. The public (including FWS) did not want alternatives with additional structural features; they asked for an evaluation of operational alternatives without structural features. Without sediment augmentation, any attempt to duplicate predam flows would threaten sediment and those downstream resources linked to sediment. Another alternative, the Historic Pattern Alternative, attempted to mimic predam flow patterns. It also was eliminated because it would require structural features to attain predam conditions and would have adverse effects on existing resources.

One of the specific purposes of any storage facility is to modify or, in some cases, eliminate natural hydrographs in order to provide society with benefits such as flood control, water storage, hydropower, recreation, fish and wildlife, and others. Glen Canyon Dam was authorized and constructed before passage of the National Environmental Policy Act (NEPA) and the Endangered Species Act, in a period of American history when water storage and production of electricity were perceived to provide greater public benefits than guaranteed streamflows or healthy native fish populations. Today, we understand that natural resource management is a complex process in which activities that enhance one resource may have adverse effects on another.

Reclamation (the lead agency in developing the Glen Canyon Dam EIS), the cooperating Federal and State agencies, and Indian Tribes involved in this study are all committed to identifying alternative ways of operating the dam in order to either enhance or minimize negative effects on downstream resources. This is a challenging goal given the strong linkages between various resources and dam operations.

The system that exists downstream from Glen Canyon Dam did not exist before the dam was constructed. The existing system and the individual resources within it have high public value. Returning to predam flow patterns would threaten the existing system and individual resources such as sediment, riparian vegetation and the diverse assemblage of wildlife associated with it, the rainbow trout fishery, and perhaps habitat components important to endangered peregrine falcons and bald eagles.

Reclamation and the cooperating agencies, including FWS, agreed with the EIS team when it recommended elimination of predam-type flow alternatives. Since that agreement, there has been no new information indicating that such flows would be any less damaging to existing downstream resources. More importantly, no information has been presented indicating that flow patterns comparable to those that occurred prior to the dam would benefit native fish in the system that exists today. FWS is mandated to make recommendations which optimize conditions for fish, wildlife, and their habitats, regardless of the impacts on other resources such as power. Reclamation recognizes and respects this position. However, in an effort to balance the needs of many resource users, the cooperating agencies have taken a broader perspective and endorsed the Modified Low Fluctuating Flow Alternative.

a. In effect, the FWS recommendation calls for a change in the preferred alternative from modified low fluctuating flows to seasonally adjusted steady flows. While the Seasonally Adjusted Steady Flow Alternative provides a rising spring hydrograph, it does not provide predam hydrology or a flow regime that would restore the predam ecosystem. Neither it nor any other alternative increases water temperatures to a level that would permit spawning and egg/larval survival of native fish.

   Glen Canyon Dam created an ecosystem which is quite different from the system supported by predam conditions. This "naturalized" ecosystem contains components (resources) which did not exist under predam conditions. Conversely, today's system either does not support, or only marginally supports, aquatic components from the predam system. We do not believe that "Water . . . released in a pattern which. . . closely mimics the natural hydrograph . . ." would ". . . facilitate natural ecosystem processes" if the ecosystem of interest is the one that exists in Glen and Grand Canyons today.

   When Reclamation and the cooperating agencies rejected the Run-of-the-River and similar alternatives, they affirmed the value of today's naturalized ecosystem supported by the dam. It does not appear possible to return to true predam conditions and a predam ecosystem, while retaining the components of the present ecosystem. Predam conditions would not support postdam resources as we know them. Given these constraints, our challenge is to improve conditions for native fish within the existing naturalized ecosystem that we value.

   We believe that the native fish problems in today's system are primarily the result of cold water released from the dam. Currently, there is no compelling scientific evidence to indicate that any of the alternatives under consideration would improve habitat conditions to the point of significantly influencing populations of native fish. We commit to addressing the issues of native fish and their habitats as part of further studies of selective withdrawal structures.

   For these reasons, this recommendation will not be implemented.

Recommendation 2. In order to maintain the integrity of the Grand Canyon ecosystem, the sediment resource should be maintained or enhanced. Associated resources that provide habitat such as backwaters, substrate, and vegetation depend upon the availability and placement of sediment.

a. Daily flows should be steady with the exception of system regulation and adjustments that would allow fluctuations limited to 2,000 cubic feet per second, per day. Ramp rates for greater flow adjustments should be limited to 2,000 cfs per hour. These restrictions would minimize erosion of sediment deposits. Alternative sources of energy for lost capacity at Glen Canyon Dam and conservation programs should be considered.

b. Annual controlled high flows within powerplant capacity and periodic (approximately once in ten years) controlled high flows that exceed powerplant capacity should be conducted to reform the channel and translocate sediment and nutrients. These high flows should coincide with the pre-dam, spring run-off peak. Implementation of these flows should take into consideration sediment storage and availability, channel configuration, and vulnerable species' life cycles. The frequency and magnitude of these flows should be determined after an assessment is made of resource response to trial flows.

Response

All of the steady flow alternatives and the Moderate, Modified Low, and Interim Low Fluctuating Flow Alternatives would be expected to maintain a long-term sediment balance.

a. Steady flows are not necessary to maintain the integrity of the postdam ecosystem in Grand Canyon. The postdam ecosystem has developed under a regime of strong daily flow fluctuations. Data collected during the GCES indicated that moderation of the strong daily fluctuations is necessary to maintain and provide some enhancement for this dynamic system. Experience with interim flow criteria since August, 1991, has confirmed this analysis. The steady flow alternatives all have ramp rates of 2,000 cfs per day for adjustments between months.

   Section 1809 of the Grand Canyon Protection Act directs the Secretary of Energy, in consultation with the Secretary of the Interior and others, to ". . . identify economically and technically feasible methods of replacing any power generation that is lost through the adoption of long-term operational criteria for Glen Canyon Dam . . ." The Power Resources Committee has studied alternative sources of energy to replace lost capacity at Glen Canyon Dam. Conservation programs have been and will continue to be aggressively analyzed and pursued. Western's customers have energy conservation programs in place, and we would expect these programs to receive even more attention as electric rates increase.

b. Reclamation agrees. The habitat maintenance flows, which are a part of the Moderate and Modified Low Fluctuating Flow and Seasonally Adjusted Steady Flow Alternatives, and beach/habitat-building flows, which are a part of all of the restricted fluctuating and steady flow alternatives, accomplish this.

Recommendation 3. The aquatic environment has been greatly modified with the construction of Glen Canyon Dam and has resulted in degraded conditions for native fish species. Every attempt should be made to ensure native fish life stage requirements are met. These requirements include a reliable food resource and availability of and access to suitable spawning and rearing habitat.

a. Extended periods of flows less than 8,000 cfs should be avoided to protect aquatic food resources. Studies indicate that extended periods of low flow limit occupation of the wetted perimeter of the channel by Cladophora and its associated invertebrate community (Angradi et al., 1992, Blinn et al., 1992). Cladophora production should continue to be monitored.

b. Flows should be steady on a seasonal basis, particularly during the summer months, to provide warmer, stable backwaters and other low velocity sites suitable for native fish rearing habitat.

c. Information on the life stage requirements, distribution, and abundance of non-native warmwater fishes collected by the AGFD, Arizona State University, Navajo Nation, BIO/WEST, Service and other sources should be collated and analyzed.

d. Reintroduction possibilities for native fishes should be considered.

Response

The aquatic environment has been greatly modified by Glen Canyon Dam. Turbidity has been greatly reduced, *Cladophora* and its associated organisms now exist, and backwaters are less ephemeral.

a. The criteria for the Existing Monthly Volume, Seasonally Adjusted, and Year-Round Steady Flow Alternatives provide minimum flows of 8,000 cfs 24 hours a day. The Modified Low and Interim Low Fluctuating Flow Alternatives provide 8,000-cfs minimum flows of for at least 12 hours each day, and an absolute minimum flow of 5,000 cfs (see Table II-2). Monitoring of *Cladophora* production would continue as part of the Adaptive Management Program.

b. Most backwaters currently exist at flows below 11,000 cfs (Weiss, 1992). Therefore, while steady flows during the summer months may provide warmer, stable backwaters, these flows have to be low enough to make sufficient backwaters available for native fish rearing habitat. None of the steady flow alternatives would provide flows under 11,000 cfs in May, June, or July. In August and September, the Seasonally Adjusted Steady Flow Alternative would provide 9,000-cfs flows, but this may be too late for young native fish that exit the tributaries in May through July.

   Selective withdrawal structures have a much greater potential to provide suitable rearing and spawning habitat for native fish in the Colorado River mainstem than any possible incremental benefit of seasonally adjusted steady flows over modified low fluctuating flows (the preferred alternative).

c. Review and analysis of these data would be a part of the studies to be undertaken on selective withdrawal.

d. This recommendation appears to be referring to those native fish that have been extirpated from the river corridor in Glen and Grand Canyons (Colorado squawfish and bonytail chub). Consideration of such a reintroduction is beyond the scope of this document. Construction of major dams has modified flow extremes, cleared and cooled water, converted rivers to lakes, and cut off natural movement corridors. In addition to these physical modifications, fish not native to the Colorado River drainage have been introduced and may compete with or prey on the natives (see chapter III, FISH). It would be appropriate to consider this recommendation only after a final decision (including NEPA compliance) on selective withdrawal is made.

Recommendation 4. Trout health problems in the Lees Ferry reach are significant. Infestation by nematode parasites, possibly caused by a copepod intermediate host, continues to be the prime factor.

a. The life cycle of this parasite should be verified.

b. Environmental stressors such as flow regime, food reduction, angling pressure, and stocking rate that may exacerbate parasitic infestations should be quantified.

Response

Through consultation with the Adaptive Management Work Group, these recommendations would be considered during implementation of the long-term monitoring and research portion of the Adaptive Management Program.

Recommendation 5. Special status species and their habitats should continue to be monitored, taking measures to protect species and promote their recovery as information is developed.

a. The minimum patch-size and vegetation-structure requirements of nesting Southwestern willow flycatchers should be determined. The rates of cowbird parasitism on Southwestern willow flycatchers as a function of patch-size should also be determined. Population numbers and associated habitats should continue to be monitored.

b. Wintering and migrating bald eagle habitat utilization and foraging patterns should continue to be monitored.

c. Native and non-native fish interactions and responses to changes in dam operations should be monitored. If operations are found to be detrimental or offer no improvement in conditions for native fishes, operations should be reevaluated and potentially modified.

Response

Through consultation with the Adaptive Management Work Group, these recommendations would be considered during implementation of the long-term monitoring and research portion of the Adaptive Management Program.

Recommendation 6. Neotropical and other avifauna that may be potentially affected by operations of Glen Canyon Dam should continue to be monitored in association with shoreline emergent marsh and other riparian vegetation they utilize.

Response

Through consultation with the Adaptive Management Work Group, these recommendations would be considered during implementation of the long-term monitoring and research portion of the Adaptive Management Program.

Recommendation 7. Reclamation should continue to evaluate alternatives characteristic of the BIO/WEST proposal which include high spring flows, stable summer flows, temperature modification, and sediment augmentation.

Response

The Adaptive Management Program would be used to evaluate the preferred alternative as it is implemented, and any changes in the criteria deemed necessary would be carried out in accordance with that program.

Recommendation 8. The Service recommends that Reclamation continue the necessary studies to evaluate the feasibility of a selective withdrawal structure, including necessary NEPA compliance. We offer the following guidelines for inclusion in the NEPA process:

a. Review historic information and employ existing modeling with possible updates using alternative reservoir and operating conditions to prepare a set of possible scenarios of temperature change of the mainstem.

b. Determine from the literature, experimentation, and/or consultation with the AGFD, Native Americans, National Park Service, Service, and other native species experts the effects on native fish populations which may result from implementation of temperature changes from a selective withdrawal structure. Determine the range of temperatures for successful larval fish development and recruitment and the relationship between larval/juvenile growth and temperature.

c. Assess the temperature induced interactions between native and non-native fish competitors/predators.

d. Assess the effects of elevated temperature on Cladophora and associated diatoms Gammarus, and aquatic insects.

e. Investigate the effects of withdrawing water on the heat budget of Lake Powell, the effects of potentially warmer inflow into Lake Mead, and the concomitant effects on the biota within both reservoirs.

f. Investigate the effects of reservoir withdrawal level on fine particulate organic matter to understand the relationship between withdrawal level and reservoir and downstream resources.

Response

Further study of selective withdrawal is an element common to all restricted fluctuating flow and steady flow alternatives. The guidelines offered would be used in the formulation of a plan of study.

REASONABLE AND PRUDENT ALTERNATIVE

Regulations implementing section 7 define reasonable and prudent alternatives as alternative actions, identified during formal consultation, that (1) can be implemented in a manner consistent with the intended purpose of the action, (2) can be implemented consistent with the scope of the Federal agency's legal authority and jurisdiction, (3) are economically and technologically feasible, and (4) would, the Service believes, avoid the likelihood of jeopardizing the continued existence of listed species or of resulting in the destruction or adverse modification of critical habitat.

The Service believes that elements of the reasonable and prudent alternative developed for this consultation meet the above four tests because of the following:

(1) There is an unique opportunity to conserve and protect endangered and other native fish fauna in an ecosystem (National Park Service lands) that has been established for the preservation of these and other natural resource protection values from Glen Canyon Dam to Lake Mead. The Grand Canyon Protection Act of 1992 requires the Secretary of the Interior to "... protect, mitigate adverse impacts to, and improve values for which Grand Canyon National Park and Glen Canyon National Recreation Area were established ..."

(2) Providing water storage and annual water releases of at least 8.23 maf to the lower basin States is a primary function of Glen Canyon Dam. The reasonable and prudent alternative will not conflict with this annual delivery of water. All flows requested in the reasonable and prudent alternative that are not part of the proposed action are within powerplant capacity. Lower basin deliveries of water are met from releases from Hoover Dam and, to a lesser extent, from Lake Mead and do not depend on daily or monthly releases from Glen Canyon Dam. Elements previously defined as conservation measures by Reclamation and Service are presently being conducted within Reclamation's authority. The element that seeks the addition of a structural component (selective withdrawal) has been built in the upper basin by Reclamation and is being operated for purposes similar to those identified here.

(3) Elements of the reasonable and prudent alternative that address operations have been reviewed and included in the Preliminary Draft EIS as viable alternatives. Additional NEPA compliance would be necessary for a selective withdrawal structural element.

(4) The Service believes, that to prevent jeopardy to the endangered fish of Grand Canyon, restoration of the aquatic ecosystem by reducing, to the extent possible, known limiting factors and conducting appropriate research to identify and reduce suspected limiting factors will be necessary and can be accomplished with cooperation, innovative approaches, and elements of the following reasonable and prudent alternative.

ELEMENTS OF THE REASONABLE AND PRUDENT ALTERNATIVE

The following Reasonable and Prudent Alternative contains elements that will focus on the community of endangered and native fish present in the Grand Canyon. The Service believes that actions for one native species would be supportive of other species in the ecosystem. As the trend of more species become endangered or threatened continues in the Colorado River, the difficulties of recovering an ecosystem that is losing functional parts may become insurmountable. The Service realizes that not all of the elements can be implemented at once, and that a schedule of implementation will be provided. Those elements that can be accomplished without further verification or NEPA compliance should be implemented. Refinement of the specific spring high flows and summer and fall low flows will depend on studies conducted during a period of experimental flows that would identify mainstem habitats affected by those flows and the endangered fishes responses to those habitats. Successful completion of the reasonable and prudent alternative is necessary to remove jeopardy to the humpback chub and razorback sucker from the proposed action. The reasonable and prudent alternative is accomplished when all elements of the selected alternative have been effected and studies confirm compatibility between these species requirements and the operation of Glen Canyon Dam.

The Preliminary Draft EIS has seven elements common to all but the unrestricted fluctuating flow alternatives. Six of those EIS common elements that would influence native and endangered fish are adaptive management, flood frequency reduction measures, habitat and beach building flows, establishing a new population of humpback chub, further study of selective withdrawal, and emergency operations exception criteria. Three of the EIS common elements that were identified by Reclamation and the Service as conservation measures (see BACKGROUND) are research or long-term monitoring (adaptive management), flood frequency reduction, and the second spawning population of humpback chub. Development of a management plan for the LCR was another conservation measure being conducted by Reclamation through GCES.

Because of the importance of the EIS common elements and conservation measures to the continued existence of the humpback chub, razorback sucker, and other Colorado River native fish, some are included below as elements of the Reasonable and Prudent Alternative to assist in identification of those actions that would be necessary to be included in any future modification of the preferred alternative that may be developed between the Draft and Final EIS. We foresee that flood frequency reduction and habitat and beach building flows will be closely aligned with both Element 1 experimental flows and Element 3 research.

1A. Attainment of a more natural riverine condition is essential to the survival of endangered and native species dependent on the Colorado River ecosystem. The preferred alternative will be used as a platform from which to conduct studies of an experimental flow regime that more closely resembles the pattern of the natural hydrograph. Experimental flows will include high steady flows in the spring and low steady flows in summer and fall carried out during low water years (releases of approximately 8.23 maf). Research design and hypotheses to be tested will use the flow pattern of the SASF where applicable, and be developed by a team of aquatic biologists with final review and approval by the Service. Reclamation will provide technical assistance and funding. The studies of the experimental flows will be initiated prior to, or with the Record of Decision for, the Glen Canyon Dam EIS. Further direction for the research program is provided in Element 3. Within 6 months of the conclusion of the research program, summary research reports will be provided to the Service. Reclamation shall implement operational flows determined by the Service to be in compliance with section 7(a)(2) through the Adaptive Management Program.

1B. During moderate and high release years, Reclamation shall operate Glen Canyon Dam according to requirements of the MLFF. These operations are expected to occur in 50% of the years.

Further investigations will be necessary to determine an effective high spring flow and low summer and fall flow for endangered fishes. For example, although not optimal, the SASF alternative selected 9,000 cfs based on best available information as the highest low flow that would still allow formation of backwaters. This element is based on low release years (8.23 maf) occurring approximately 50% of the time. Further improvement of the means for determining the release volume that would initiate the implementation of research flows in a given year will be developed by Reclamation with approval by the Service, that may include, for example, methods based on volume of Lake Powell at a given date. Experimental flows will be conducted for a sufficient period of time to allow biological processes to function and for variability inherent in riverine ecosystems to be expressed. Preliminary estimate of the time necessary to provide experimental flows for study is approximately five years.

Operations during moderate and high water years would assist in achieving the variability that was always present in the historic Colorado River and under which the endangered and other native fish evolved. Further refinement of this element for these water years is anticipated after the public review process for the draft EIS is completed. The Service will review any proposed modifications to these release criteria.

2. Protect humpback chub spawning population and habitat in the LCR by being instrumental in developing a management plan for this river.

This element remains very important to the survival of the humpback chub in Grand Canyon. Reclamation has, through contracts with the Navajo Nation, developed an extensive database for use in developing the plan. Reclamation will take the lead to work with the Service, Navajo Nation, Hopi Tribe, National Park Service, Bureau of Indian Affairs, Arizona Game and Fish

Department, and others to develop a management plan that includes actions to avoid possible adverse impacts to humpback chubs and their spawning and rearing habitats in the LCR. The principle objective of this plan shall be the protection of humpback chub habitat in the Colorado River and LCR from catastrophic event or adverse habitat modification. A draft plan will be prepared within two years from the date of this biological opinion and submitted to Native Americans, agencies, and others having the authority to implement the plan.

3. Research Program

A. Determine the responses and impacts on endangered and native fishes in Grand Canyon by experimental flows provided in Element 1 and obtain information necessary to adjust operational criteria so they are beneficial for the endangered fishes and other resources affected by Glen Canyon Dam. Reclamation will provide technical assistance and funding for research on the following aspects of endangered and native fish in Grand Canyon.

(1) Effects of water temperature on reproductive success, growth, and survivorship of Grand Canyon fishes.

(2) Relationships among tributary hydrology, reproductive success of fishes, and the abundance of fishes in mainstem rearing habitats.

(3) Effects of mainstem hydrology on the number of nearshore rearing habitats, the environmental conditions in these habitats, and their successful utilization by fishes.

(4) Determine biotic interactions between native and non-native fishes, particularly those that occur in nearshore rearing habitats affected by dam operations.

(5) Determine the life history schedule for the population of humpback chub and other long-lived native fishes of Grand Canyon.

(6) Determine the origins of endangered and native fish food resources and energy pathways and nutrient sources important to their production, and the effects of Glen Canyon Dam operations on these resources.

(7) Determine the effects of dam operations, including modifications to regulate water temperatures, on the parasites and disease organisms of endangered and native fishes in Grand Canyon.

B. Prior to a request for consultation on a major Glen Canyon Dam action, Reclamation shall require that comprehensive and contemporary reports be provided by research groups they have directed or funded having information on the area or species in question. Research in progress would be summarized and analysis provided to the extent possible. The reports should summarize information gained during the respective research efforts, identify important gaps in knowledge of the ecology of Grand Canyon fishes, and provide recommendations for future research.

C. To provide a basis for review of the endangered fish research program, a common date for submission of reports as identified above shall be established. Services of knowledgeable and respected scientists will be procured to integrate the research information and coalesce the findings and recommendations for future research.

Emphasis should be placed on experimental approaches using various flow and temperature scenarios to determine cause and effect relationships between dam operations and responses of the community of endangered and native Grand Canyon fishes. Efforts should be hypothesis driven and specific in objectives. Explanation of the above research efforts is provided in Appendix 1 along with suggested hypotheses. The success of these research efforts will require sufficient flexibility in operations to design and carry out the experiments. Wherever feasible, off-site experiments should be considered as a means of generating hypotheses that can be field-tested in relatively short-term studies. Long-term measurements should more appropriately be incorporated into the monitoring program, but there must be an active synergism between the two efforts.

The long-term monitoring plan should define objectives and methods for tracking the status of native fishes in Grand Canyon. Relevant indices should be developed and measured for this purpose as part of that program. A major advantage of the current intensive marking studies using PIT tags is the ability to measure future movements, growth rates, and population sizes of these fishes. This legacy, and others made available by this period of intensive research effort, should be effectively incorporated into the long-term monitoring program for fishes. Adaptive management, an EIS common element, would likely include a number of the above research objectives.

4. Develop actions that will help ensure the continued existence of the razorback sucker by first sponsoring a workshop within one year following the biological opinion to enlist the advise of species experts, endangered fish researchers in Grand Canyon, Native Fish Work Group biologists, and others, such as Colorado River Recovery Team members, to develop a management plan for the species in the Grand Canyon. Following review of the workshop results, the Service will recommend a course of action and develop a memorandum of understanding with Reclamation and other entities who may wish to participate. The memorandum will provide detail on development of the management plan and implementation of actions identified in the plan.

Activities establishing razorback suckers in the Grand Canyon might include development of spawning and rearing areas that would function like flooded river bottom lands. Opportunities for such actions could be at (1) Lee's Ferry in a former gravel storage area along the mainstem and Paria River or (2) near the inflow area of the Colorado River into Lake Mead (Lake Mead National Recreation Area and Hualapai Indian Reservation). Cooperation of land managing agencies, such as the National Park Service and Hualapai Indian Reservation, would be necessary.

5. Make every effort to establish a second spawning aggregation of humpback chub downstream of Glen Canyon Dam.

Baseline information on possible tributary use or suitability for use by spawning humpback chub is being collected. Using that information, information from other Grand Canyon endangered fish research, and information from the *Gila* taxonomy study (Reclamation contract 1-CS-40-0970), Reclamation, in consultation with the Service, National Park Service, Arizona Game and Fish Department, and land management agencies such as the Havasupai Tribe, will make every reasonable effort through funding, facilitating, and provide technical assistance to establish a program for additional spawning aggregations (or populations depending on genetic status) in the mainstem or tributaries. This effort has been identified as one of the EIS common elements.

6. Reclamation shall determine the feasibility of a selective withdrawal program for Lake Powell waters using the following guidelines. If the Service determines from the studies that such an action would be beneficial to endangered fish, Reclamation will take appropriate actions to implement a project for selective withdrawal.

   A. Review historical information and employ existing modeling with possible updates using alternative reservoir and operating conditions to prepare a set of possible scenarios of temperature change of the mainstem.

   B. Determine from the literature, experimentation, and/or consultation with the Arizona Game and Fish Department, Native Americans, National Park Service, Service, and other native fish species experts the effects on native fish populations which may result from implementation of temperature changes from a selective withdrawal structure. Determine the range of temperatures for successful larval fish development and recruitment, and the relationship between larval/juvenile growth and temperature.

   C. Assess the temperature induced interactions between native and non-native fish competitors and predators.

   D. Assess the effects of temperature, including seasonality and magnitude, on *Cladophora* and associated diatoms, *Gammarus*, and aquatic insects.

   E. Investigate the effects of withdrawing water on the heat budget of Lake Powell, the effects of potentially warmer inflow into Lake Mead, and the concomitant effects on the biota within both reservoirs.

   F. Investigate the effects of reservoir withdrawal level on fine particulate organic matter and important plant nutrients to understand the relationship between withdrawal level and reservoir and downstream resources.

Establishment of a selective withdrawal strategy such as a multi-level intake structure (MLIS) on Glen Canyon Dam may be essential in order to increase the temperature of releases from Glen Canyon Dam to warm mainstem temperatures sufficiently for successful spawning and recruitment of endangered and native fishes in the mainstem. Research identified for this element should be integrated or combined with the Element 3 research program. A MLIS also would provide considerable ability to maintain variability in the management of the aquatic ecosystem downstream of Glen Canyon Dam. Management options, such as when to release warmer temperature water, seasonal pattern to releases to avoid establishment of permanent backwater areas, and use of floods, would all be available to limit expansion or invasion of non-native fish species. The Service cautions that the MLIS should not be considered the only action needed to provide successful mainstem spawning and recruitment. Aspects of the natural hydrograph, including low, steady releases in the summer would still be necessary based on our present knowledge of MLIS. However, future studies might identify opportunities to operate Glen Canyon Dam that would be of benefit to power resources and still enhance native fish populations. This program also is one of the EIS common elements.

7. Reclamation shall develop an adaptive management program that will afford flexibility to provide for adequate studies to review impacts to endangered and native fish species and recommend actions to further their conservation. Reclamation will ensure that agencies with trust responsibilities for endangered and native fish species shall be afforded a equitable decision role pursuant to Grand Canyon Protection Act. The Service will review the studies, analyses, and the recommended actions and provide comments as to the need for further consultation or inclusion of discretionary recovery actions.

The Adaptive Management Program, an EIS common element, was being described as the Service prepared the draft biological opinion. The Service supports adaptive management as an iterative approach to resource management. No ecosystem is fixed in time and the aquatic and terrestrial ecosystems below Glen Canyon Dam are still adjusting to impacts from operations which will continue into the future. Adaptive management will compel an integration of resources because periodic reports of the status of those resources will be found in a common document allowing comparison of condition and trends. Adaptive management should be, as discussed by Hilborn (1992), an active rather than a passive learning system and should include deliberate experimental design.

Because this biological opinion has found jeopardy to the existence of the humpback chub and razorback sucker, Reclamation is required to notify the Service of its final decision on the implementation of the reasonable and prudent alternative.

ATTACHMENT 5

Programmatic Agreement on Cultural Resources

PROGRAMMATIC AGREEMENT
AMONG
THE BUREAU OF RECLAMATION, THE ADVISORY COUNCIL ON HISTORIC PRESERVATION, THE NATIONAL PARK SERVICE,
THE ARIZONA STATE HISTORIC PRESERVATION OFFICER, HAVASUPAI TRIBE, HOPI TRIBE, HUALAPAI TRIBE, KAIBAB PAIUTE TRIBE, NAVAJO NATION, SAN JUAN SOUTHERN PAIUTE TRIBE, SHIVWITS PAIUTE TRIBE AND ZUNI PUEBLO
REGARDING
OPERATIONS OF THE GLEN CANYON DAM

WHEREAS, the Secretary of Interior has directed the preparation of an Environmental Impact Statement (EIS) on the effects of the operation of the Glen Canyon Dam on the downstream environmental and ecological resources, and historic properties of Glen Canyon and Grand Canyon; and

WHEREAS, the Grand Canyon Protection Act of 1992 (PL 102-575 Title XVIII) mandates the continued monitoring and management of resources located within the area of impact covered by this agreement and requires completion of the EIS by October 1994; and

WHEREAS, the purpose of the EIS is to ". . . reevaluate the operation of the Glen Canyon Dam to determine specific options that could be implemented to minimize - consistent with law - adverse impacts on the downstream environmental and cultural resources and Native American interests in Glen and Grand Canyons." (Interim Preliminary Draft EIS 7/92); and

WHEREAS, the Bureau of Reclamation (Reclamation), Upper Colorado Regional Office, administers the releases of water from the Glen Canyon Dam and has determined that the operation of the Dam (the Program) may have effects upon properties included in or eligible for inclusion in the National Register of Historic Places and has consulted with the Advisory Council on Historic Preservation (Council), the National Park Service (NPS), and the Arizona State Historic Preservation Officer (SHPO) pursuant to 36 CFR § 800.13 of the regulations (36 CFR Part 800) implementing Section 106 of the National Historic Preservation Act (ACT) (16 U.S.C. 470f); and

WHEREAS, Reclamation is the lead Federal agency for the Program for purposes of Section 106; and

WHEREAS, the NPS is responsible for the administration and management of historic properties within the boundaries of the Glen Canyon National Recreation Area and the Grand Canyon National Park pursuant to Section 110 of the Act; and

WHEREAS, given their mutual responsibilities, Reclamation and the NPS have determined to coordinate their respective roles in the management and consideration of historic properties which may be affected by the Program; and

WHEREAS, the Hualapai Tribe is responsible for the administration and management of historic properties within the boundaries of its reservation lands affected by the Program; and WHEREAS, prior to performing any work required under the terms of this Agreement within the boundaries of the Hualapai Indian Reservation, Reclamation or the NPS shall notify the Hualapai Tribe of such work and obtain appropriate Tribal permits before entering the boundaries of the Hualapai Indian Reservation. The Tribe will require that a Hualapai Tribe member monitor be present when necessary for any culturally sensitive work, as determined by the Tribe.

WHEREAS, the Navajo Nation is responsible for the administration and management of historic properties within the boundaries of the Navajo Nation pursuant to the Cultural Resources Protection Act (CMY-19-88); and

WHEREAS, the Navajo Nation agrees to NPS administration and management of any Navajo Nation historic properties which may be included under the terms of this agreement until such time as the Navajo Nation assumes such responsibility; and

WHEREAS, the Havasupai Tribe, Hopi Tribe, Hualapai Tribe, Kaibab Paiute Tribe, Navajo Nation, San Juan Southern Paiute Tribe, Shivwits Paiute Tribe and the Zuni Pueblo (the Tribes) participated in consultation and are signatories to this Programmatic Agreement;

NOW, THEREFORE, Reclamation, the Council, NPS, SHPO, and the Tribes agree that the Program shall be administered in accordance with the following stipulations to satisfy Reclamation's Section 106 responsibilities for all individual aspects of the Program.

Stipulations

Reclamation, as lead Federal agency for purposes of the Program, shall ensure that the following stipulations are carried out.

1. IDENTIFICATION AND EVALUATION

a. The NPS has identified a total of 313 contributing properties, referred to as the Grand Canyon River Corridor District (District), within the Area of Potential Effects (APE). Nine additional properties within the boundaries of the District remain unevaluated. The NPS shall assist Reclamation in obtaining the necessary information to complete the evaluation of these nine sites for determining their eligibility for listing on the National Register as contributing properties to the District or as eligible on their own merits. Reclamation shall submit such evaluations to the SHPO for determinations of eligibility. In the event that Reclamation and SHPO do not agree on the eligibility of any property, or if the Council or Keeper so request, Reclamation shall obtain a formal determination of eligibility from the Keeper of the National Register in accordance with 36 CFR § 800.4(c). Determinations of eligibility for the remaining nine properties shall be completed by August 1993.

b. Reclamation and the NPS, in consultation with SHPO, shall identify and evaluate historic properties in the remaining 37 miles of the APE not previously intensively inventoried (Attachment A). Properties identified within the 37 mile corridor shall be evaluated on their own merits and as contributing elements to the District pursuant to 36 CFR § 800.4(c). An intensive inventory of the entire APE shall be completed by August 1993. Ongoing identification and evaluation efforts shall be a part of the management program identified at Stipulations 2 and 3.

c. In consultation with the Tribes and SHPO, Reclamation and the NPS shall identify and evaluate properties within the APE which retain traditional cultural values. Such properties shall be evaluated under criteria A, B, C, and D of the National Register Criteria pursuant to 36 CFR Part 60, and taking into consideration "National Register Bulletin 38, Guidelines for Evaluating and Documenting Traditional Cultural Properties".

(1) Traditional Cultural Properties shall be identified by Reclamation and the NPS through the conduct of ethnographic studies. Ethnographic studies shall solicit and include the participation of and consultation with the Tribes to collaborate in the identification and evaluation of traditional cultural properties.

(2) Reclamation shall submit such evaluations to the SHPO for determinations of eligibility. In the event that Reclamation and SHPO do not agree on the eligibility of any property, or if the Council or Keeper so request, Reclamation shall obtain a formal determination of eligibility from the Keeper of the National Register in accordance with 36 CFR § 800.4(c). Such study and evaluations shall be completed by October 1994.

2. MONITORING AND REMEDIAL ACTION

a. Within three months of the execution of this Programmatic Agreement, Reclamation and the NPS, in consultation with the SHPO and Tribes, shall develop a Plan for monitoring the effects of the Glen Canyon Dam operations on historic properties within the APE and for carrying out remedial actions to address the effects of ongoing damage to historic properties. The purpose of the Monitoring and Remedial Action Plan shall be to generate data regarding the effects of Dam operations on historic properties, identify ongoing impacts to historic properties within the APE, and develop and implement remedial measures for treating historic properties subject to damage. Such data shall be incorporated into Reclamation's Long-Term Operating and Monitoring Plans governing dam releases identified in the EIS, The EIS is scheduled for completion in October 1994.

b. The Monitoring and Remedial Action Plan (Plan) shall provide for the identification and evaluation of previously unrecorded properties overlooked by previous surveys or exposed subsequent to the surveys, and include measures by which any adverse effects identified during the monitoring effort shall be avoided or minimized. Remedial measures shall be implemented to mitigate ongoing adverse effects and may include, but not be limited necessarily to, bank stabilization, check dam construction and data recovery, as appropriate. The Plan shall specify an expedited consultation process among the parties to this agreement to accommodate situations requiring remedial actions.

c. Reclamation shall submit a draft of the Plan to the parties in this agreement for review and comment. Each party shall have 60 days from receipt of the Plan to comment. Reclamation may assume the concurrence of any party which does not issue comments within 60 days of their receipt of the Plan.

(1) Reclamation shall take into consideration all comments received in their development of a final draft Plan, and submit the final draft Plan to the reviewing parties for a second review opportunity. Each reviewing party shall have 20 days from receipt to review the final draft Plan and issue comments to Reclamation.

(2) If any reviewing party objects to the adequacy of the final draft Plan, Reclamation shall consult with the objecting party, and the other parties to this Programmatic Agreement as necessary to resolve the objection pursuant to Stipulation.

(3) When all objections are resolved, Reclamation shall implement the Monitoring and Remedial Action Plan.

3. MANAGEMENT

a. Reclamation and the NPS shall incorporate the results of the identification, evaluation, and monitoring and remedial action efforts into a Historic Preservation Plan (HPP) for the long-term management of the Grand Canyon River Corridor District and any other historic properties within the APE. The HPP shall be developed in consultation with the parties to this Programmatic Agreement. The HPP shall integrate Reclamation's lead agency role pursuant to Section 106 of the Act and the NPS's stewardship role pursuant to Section 110 of the Act. Specifically, the HPP shall provide management direction responsive to the NPS's responsibilities under Sections 110(a)(1) and 110(a)(2); and NPS's and Reclamation's responsibilities under Sections 110(b) and 110(d).

b. The HPP shall establish consultation and coordination procedures, long term monitoring and mitigation strategies, management mechanisms and goals for long term management of historic properties within the APE.

c. Reclamation and the NPS shall submit a draft of the HPP to the parties to this agreement for 60 days review. The parties to this agreement shall have 60 days from receipt to issue comments to Reclamation and the NPS regarding the adequacy of the HPP. Reclamation and the NPS may assume the concurrence of any party which does not issue comments within 60 days of receipt of the HPP.

(1) Reclamation and the NPS shall take into consideration all comments received in their development of a final draft HPP, and submit the final draft HPP to the reviewing parties for a second review opportunity. Each reviewing party shall have 30 days from receipt to review the final draft HPP and issue comments to Reclamation and the NPS.

(2) If any reviewing party objects to the adequacy of the final draft HPP, Reclamation and the NPS shall consult with the objecting party, and the other parties to this agreement as necessary to resolve the objection pursuant to Stipulation 4. When all objections have been resolved, Reclamation and the NPS shall implement the HPP.

d. The development, and review of the HPP shall be completed prior to the issuance of a Record of Decision for the GCD-EIS, or December 1994, whichever comes first. Upon issuance of a Record of Decision, the HPP shall be reviewed by the parties to this agreement and revised, if necessary, based on the decision. The review of a revised HPP shall be conducted in accordance with the procedures of Stipulation 3.C.1. and 2.

4. DISPUTE RESOLUTION

a. Should any party to this agreement object within 30 days to any plans, specifications, or actions proposed pursuant to this agreement, Reclamation and the NPS shall consult with the objecting party to resolve the objection. If any party involved in the dispute determines that the dispute cannot be resolved, Reclamation shall forward all documentation relevant to the dispute to the Council. Within 30 days after receipt of all pertinent documentation, the Council will either:

(1) Provide Reclamation and the NPS with recommendations, which Reclamation will take into account in reaching a final decision regarding the dispute; or

(2) Notify Reclamation and the NPS that it will comment pursuant to 36 CFR § 800.6(c)(2) with reference to the subject of the dispute.

Any recommendation or comment provided by the Council will be understood to pertain only to the subject of the dispute; Reclamation's responsibility to carry out all actions under this agreement that are not the subjects of the dispute shall remain unchanged.

b. At any time during implementation of the measures stipulated in this agreement should an objection to any such measure or its manner of implementation be raised by a member of the public, Reclamation and the NPS shall take the objection into account and consult as needed with the objecting party, SHPO, the Tribes, or the Council to resolve the objection.

5. REVIEW OF THE AGREEMENT

a. The Council, SHPO, NPS and Tribes may review activities carried out pursuant to this Programmatic Agreement, and the Council will review such activities if so requested. Reclamation will cooperate with the Council, SHPO, NPS and Tribes in carrying out their reviewing activities.

b. Reclamation and the NPS shall cooperatively provide bi-annual summary reports of their progress toward completing the terms of this agreement to each of the parties to this agreement. The biannual reports shall identify accomplishments and actions completed and provide schedules for completion of all remaining tasks. The first biannual report shall be submitted to the parties of this agreement six (6) months after the date of the Council's signature on this agreement and every six months thereafter until the HPP has been implemented.

c. A yearly meeting will be held among the signatories to review the agreement and the results of the monitoring and remedial actions.

6. AMENDMENT

Any party to this Programmatic Agreement may request that it be amended, whereupon the parties will consult in accordance with 36 CFR § 800.13 to consider such amendment.

7. TERMINATION

Any party to this Programmatic Agreement may terminate this agreement by providing 30 days written notice to the other parties, provided that the parties will consult during the period prior to termination to seek agreement on amendments or other actions that would avoid termination. In the event of termination, Reclamation will comply with 36 CFR §§ 800.4 through 800.6 with regard to individual undertakings covered by this Programmatic Agreement.

8. FAILURE TO CARRY OUT TERMS

In the event Reclamation and the NPS do not carry out the terms of this Programmatic Agreement, Reclamation will comply with 36 CFR §§ 800.4 through 800.6 with regard to individual undertakings covered by this Programmatic Agreement.

Execution and implementation of this Programmatic Agreement evidences that Reclamation has afforded the Council a reasonable opportunity to comment on the Program and that Reclamation has taken into account the effects of the Program on historic properties.

At press time, signatures were not available.

ADVISORY COUNCIL ON HISTORIC PRESERVATION

BY:______________________________ Date:______________

Title: ____

BUREAU OF RECLAMATION

BY:______________________________ Date:______________

Title: ____

ARIZONA STATE HISTORIC PRESERVATION OFFICER

BY:______________________________ Date:______________

Title: ____

NATIONAL PARK SERVICE, WESTERN REGION

BY:______________________________ DATE:______________

Title: ____

NATIONAL PARK SERVICE, ROCKY MOUNTAIN REGION

BY:______________________________ DATE:______________

Title: ____

HAVASUPAI TRIBE

BY:______________________________ Date:______________

Title: ____

HOPI TRIBE

BY:______________________________ Date:______________

Title: ____

HUALAPAI TRIBE

BY:______________________________ Date:____________

Title: ____

KAIBAB PAIUTE TRIBE

BY:______________________________ Date:____________

Title: ____

NAVAJO NATION

BY:______________________________ Date:____________

Title: ____

SAN JUAN SOUTHERN PAIUTE TRIBE

BY:______________________________ Date:____________

Title: ____

SHIVWITS PAIUTE TRIBE

BY:______________________________ Date:____________

Title: ____

ZUNI PUEBLO

BY:______________________________ Date:____________

Title: ____

ATTACHMENT 6

Supporting Data on Alternatives

A. Formula for determining minimum and maximum flows under the Moderate and Seasonally Adjusted Fluctuating Flow Alternatives (October-May). Minimum and maximum flow restrictions would be determined from the mean release for the month (Qmean). Qmean would be determined from the scheduled monthly release volume using the following equation.

$$\text{Qmean} = \frac{\text{Volume}}{\text{No. days per month}} \times \frac{43{,}560\ \text{ft}^2 \bullet \text{day}}{86{,}400\ \text{acre} \bullet \text{sec}}$$

Where volume is the scheduled monthly release volume in acre-feet per month and Qmean is the equivalent release in cfs.

The minimum (Qmin) and maximum (Qmax) flows would be determined by the following equations.

for $\text{Qmean} \leq 9{,}091$ cfs $\quad \text{Qmin} = 5.000$ cfs
for $\text{Qmean} \geq 9{,}091$ cfs $\quad \text{Qmax} = \text{Qmean} - C$

for $\text{Qmean} \leq 25{,}500$ cfs $\quad \text{Qmax} = \text{Qmean} + C$
for $\text{Qmean} \geq 25{,}500$ cfs $\quad \text{Qmax} = 31{,}500$ cfs

where

for $\text{Qmean} \leq 13{,}333$ cfs $\quad C = 0.45 \times \text{Qmean}$
for $\text{Qmean} \geq 13{,}333$ cfs $\quad C = 6{,}000$ cfs

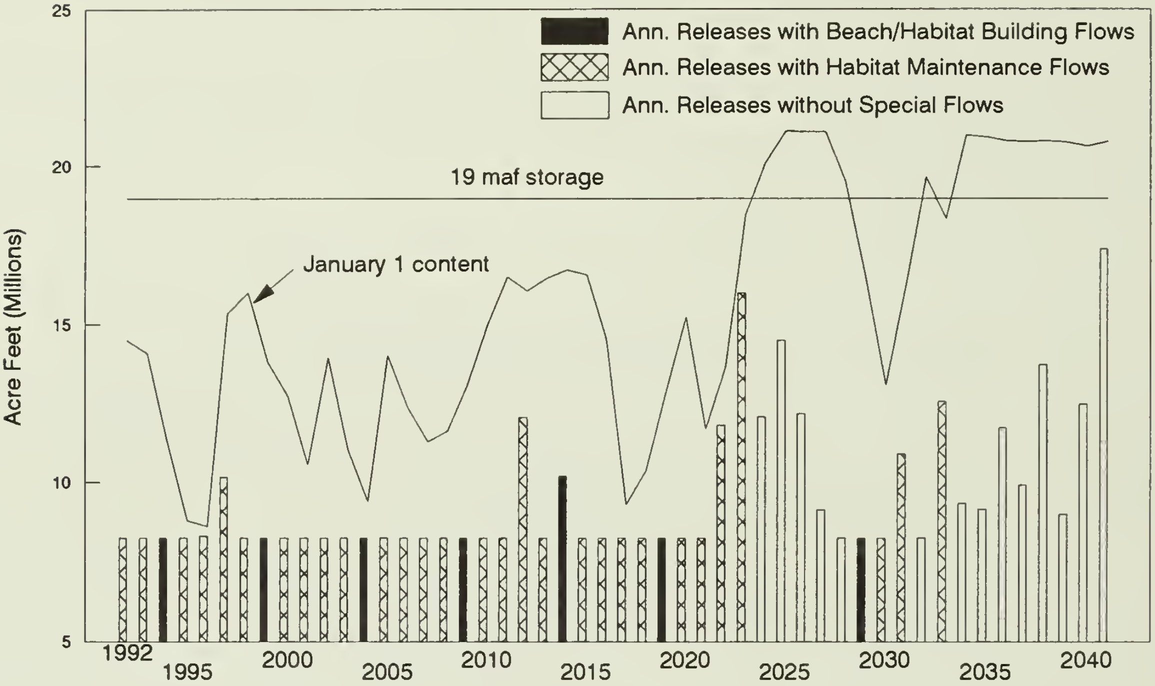
Releases rates would be allowed to fluctuate daily and hourly between the minimum and maximum limits.

B. Monthly release volumes for alternatives incorporating the habitat maintenance flow, example water year 1989 (8.2 million acre-feet) in thousand acre-feet

Month	No Action	Moderate and Modified Low Fluctuating Flow	Seasonally Adjusted Steady Flow
Oct	520	484	499
Nov	616	580	477
Dec	644	608	500
Jan	760	724	655
Feb	671	635	587
Mar	607	1,006	1,086
Apr	548	512	723
May	540	504	1,073
Jun	763	727	1,037
Jul	841	805	682
Aug	884	848	474
Sep	823	787	449

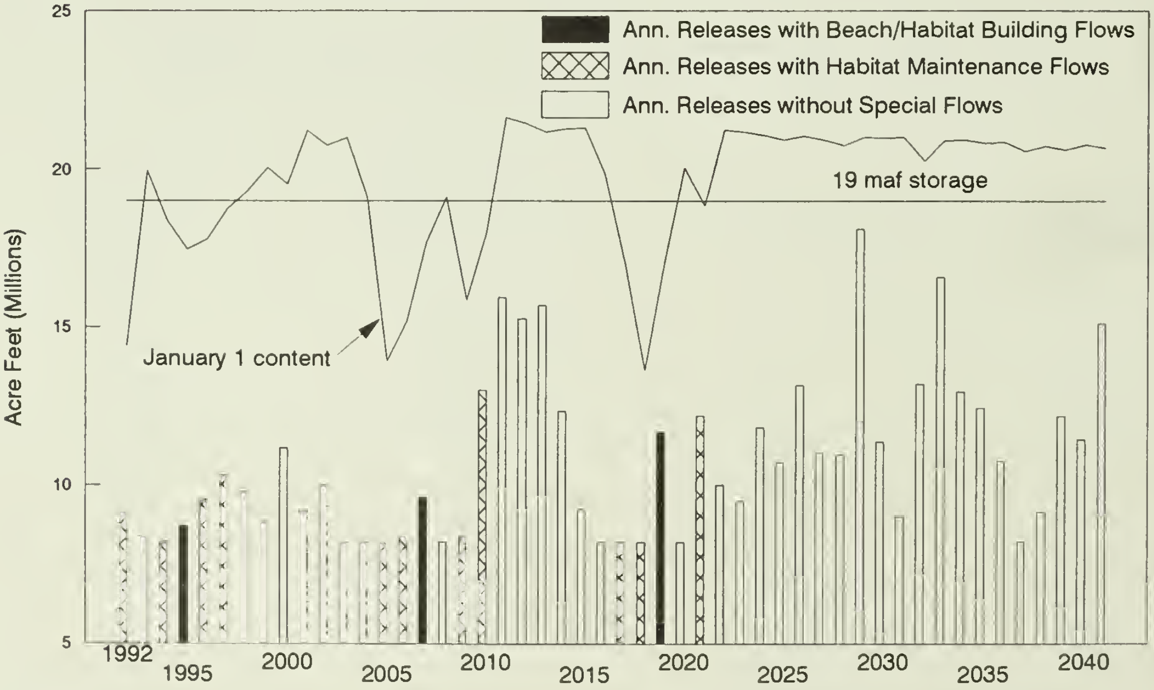
Example Scheduling of Special Flows

Modified LFF - CRSS Hydrologic Trace No. 48



Example Scheduling of Special Flows

Modified LFF - CRSS Hydrologic Trace No. 60



Emergency Operations Guidelines

Inflow Forecasting

National Weather Service inflow projections, received twice a month, are used to project a 3- to 4-month period. This data comes from a satellite telemetered network of more than 100 Upper Colorado River Basin data collection points. These points gather snow water content, precipitation, temperature, and streamflow information. The water year begins in October, with later adjustments made for anticipated targets such as annual volumes and flood control elevations. Starting on January 1, forecasts are made for the April through July inflow, the peak runoff period. These early forecasts may contain large errors due to climatic variability as well as modeling and data uncertainties. Uncertainty decreases as the snow accumulation period progresses into the runoff season. As the runoff season progresses, monthly scheduled releases are modified to accommodate projected runoff changes.

Operational Emergencies

The North American Electrical Reliability Council (NERC) has established guidelines for emergency operations of interconnected systems. These guidelines apply to Glen Canyon Dam operations and may account for operational changes outside of those identified in descriptions of the alternatives. These changes in operations are intended to be of short duration as a result of emergencies at the dam or within the transmission network. NERC provides the following guidelines for system emergencies. Because of the technical nature of the descriptions, only examples are given here.

Insufficient Generation Capacity. When a control area has an operating capacity emergency, it must promptly balance its generation and interchange schedules to its load, without regard to financial cost, to avoid prolonged use of the assistance provided by interconnection frequency bias. The emergency reserve inherent in frequency deviation is intended to be used only as a temporary source of emergency energy and must be promptly restored so the interconnected systems can withstand the next contingency. A control area unable to balance its generation and interchange schedules to its load must remove sufficient load to permit correction of its Area County Error.

If a control area anticipates an operating capacity emergency, it must bring on all available generation, postpone equipment maintenance, schedule interchange purchases well in advance, and prepare to reduce load.

An example of insufficient generation capacity and the appropriate response would be as follows: if any coal-fired powerplant in Western's load control area were unexpectedly lost, the response would be an increase in Colorado River Storage Project (CRSP) generation or imports to cover the change in anticipated generation within the control area.

Transmission (Overload, Voltage Control). If a transmission facility becomes overloaded or if voltage levels are outside of established limits and the condition cannot be relieved by normal means (such as adjusting generation or interconnection schedules) and a credible contingency under these conditions would adversely impact the interconnection, appropriate relief measures, including load shedding, shall be implemented promptly to return the transmission facility to within established limits. This action shall be taken by the system, control area, or pool causing the problem if it can be identified; or by other systems or control areas, as appropriate, if identification; cannot be readily determined.

An example of a response to an overloaded transmission system would be automatic relay tripping and taking a transmission line, such as the Glen Canyon-Flagstaff 345-kilovolt line, out of service. This action would cause Glen Canyon powerplant generation to be reduced instantaneously to a predetermined level based on the capacity of the line taken out of service.

Load Shedding. After taking all other steps, a system or control area whose integrity is in jeopardy due to insufficient generation or transmission capacity shall shed customer load rather than risk an uncontrolled failure of interconnection components.

An example requiring the extreme step of load shedding could occur if there were an interruption of the transmission capacity between the heavy load areas of Southern California and Arizona and the heavy generation areas of the Pacific Northwest, Colorado, Wyoming, and Montana. In this situation, Glen Canyon would be isolated with the heavy load areas. The response would be for Glen Canyon to swing from existing generation levels to maximum powerplant capacity. Then the automatic relay protection would open the transmission lines to the heavy load area, reducing the generation at Glen Canyon.

System Restoration. After a system collapse, restoration shall begin when it can proceed in an orderly and secure manner. Systems and control areas shall coordinate their restoration actions. Restoration priority shall be given to the station supply of powerplants and the transmission system. Even though the restoration should be expeditious, system operators should avoid premature action to prevent a recollapse of the system.

Customer load shall be restored as generation and transmission equipment becomes available, while keeping load and generation in balance at normal frequency as the system is restored.

Emergency Information Exchange. A system control area or pool experiencing or anticipating an operating emergency should communicate its current and future status to neighboring systems, control areas, or pools and throughout the interconnection. Systems able to provide emergency assistance must make known their capabilities.

Special System or Control Area. Because the facilities of each system may be vital to the interconnection's secure operation, systems and control areas shall make every effort to remain connected. However, if a system or control area determines that it is endangered by remaining interconnected, it may take action as necessary to protect its system.

If a portion of the interconnection becomes separated from the remainder of the interconnection, abnormal frequency and voltage deviations may occur. To permit resynchronizing, relief measures should be applied by those separated systems contributing to the frequency and voltage deviations.

An example of when Western might choose to disconnect the Glen Canyon Powerplant from the interconnected system would be in the case of a search and rescue operation in the canyon when there would be a need to control the releases.

Although the situations are infrequent, they do occur and require immediate, short-term changes in dam operation. In general, changes resulting from emergencies at Glen Canyon would result in decreases in flows. Emergencies in the system away from the dam would result in increases in flows.

Humanitarian Situations

There are occasions when managing agencies and local authorities, such as the police, request that the flows from the dam be reduced so that search and rescue procedures can be conducted or fatalities can be recovered from the river. In these situations, flows will be reduced for an agreed upon period of time. When returning to normal operations, flows will be brought up quickly to the minimum flow identified in the alternative and then may be increased at the ramping rate identified in the alternative.

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As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering sound use of our land and water resources, protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. Administration.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.