United States General Accounting Office

GAO

Report to Congressional Committees

October 1996

# BUREAU OF RECLAMATION

# An Assessment of the Environmental Impact Statement on the Operations of the Glen Canyon Dam

GAO/RCED-97-12

GAO

**United States**
**General Accounting Office**
**Washington, D.C. 20548**

**Resources, Community, and**
**Economic Development Division**

B-272927

October 2, 1996

The Honorable Frank Murkowski
Chairman
The Honorable J. Bennett Johnston
Ranking Minority Member
Committee on Energy and Natural Resources
United States Senate

The Honorable Don Young
Chairman
The Honorable George Miller
Ranking Minority Member
Committee on Resources
House of Representatives

This report responds to subsection 1804(b) of the Grand Canyon Protection Act of 1992 (title XVIII of P.L. 102-575), which required GAO to audit the Bureau of Reclamation's final environmental impact statement on the operations of the Glen Canyon Dam. The report discusses (1) whether Reclamation's determination of the impact of various dam-operating alternatives on selected resources was reasonable and (2) what, if any, concerns still exist on the part of key interested parties about the final impact statement.

We are providing a copy of this report to the Secretary of the Interior, the Assistant Secretary for Water and Power, and the Commissioner of the Bureau of Reclamation. We will also make copies available to others upon request.

This report was prepared under the direction of Victor S. Rezendes, Director, Energy, Resources, and Science Issues, who can be reached at (202) 512-3841 if you or your staff have any questions. Major contributors to this report are listed in appendix XIII.

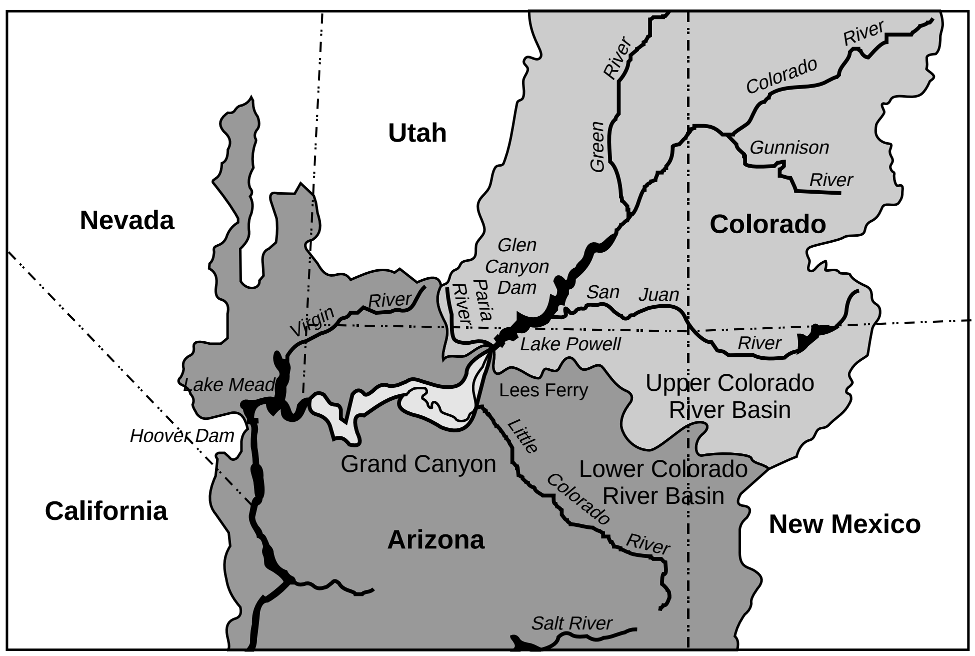
Keith O. Fultz
Assistant Comptroller General

# Executive Summary

## Purpose

Since the Glen Canyon Dam, located in Page, Arizona, was completed by the Bureau of Reclamation in 1963, it has been used to generate power during periods of high demand, commonly known as peaking power. The fluctuating releases of water associated with the dam's peaking power operations have caused concerns about the detrimental effects such flows have on downstream resources, particularly those located in the Grand Canyon. In response to these concerns, the Secretary of the Interior, in July 1989, directed the Bureau of Reclamation to prepare an environmental impact statement that would reevaluate the Glen Canyon Dam's operations. The purpose of the reevaluation was to determine specific options for operating the dam that could minimize the adverse impacts on the downstream environmental and recreational resources, as well as on Native American interests in the Glen and Grand canyons, while still producing hydropower.

**Figure 1: Location of the Glen Canyon Dam**




Source: Bureau of Reclamation.

In October 1992, the Congress enacted the Grand Canyon Protection Act of 1992 (title XVIII of P.L. 102-575), which required the Secretary of the Interior to complete the environmental impact statement by October 30, 1994. The act also required that GAO audit the costs and benefits of the various operating alternatives identified in the final environmental impact statement. In preparing the statement, Reclamation studied the potential impact of various flow alternatives on selected resources. Reclamation reported the results of these studies in the final environmental impact statement on March 21, 1995. As discussed with the responsible congressional committees, for the purpose of this audit, GAO examined (1) whether Reclamation's impact determinations were reasonable and (2) what, if any, concerns still exist about the Glen Canyon Dam's final environmental impact statement. The act also requires that on the basis of the findings, conclusions, and recommendations made in the environmental impact statement and the GAO audit report, the Secretary is to adopt criteria and operating plans for the dam.

## Background

Before the construction of the Glen Canyon Dam, the Colorado River's sediment-laden flows fluctuated dramatically during different seasons of the year. Annual daily flows of greater than 80,000 cubic feet per second were common during the spring runoff. In contrast, flows of less than 3,000 cubic feet per second were typical throughout the late summer, fall, and winter. Water temperatures ranged from near freezing in the winter to more than 80 degrees Fahrenheit in the summer. The construction of the Glen Canyon Dam altered the natural dynamics of the Colorado River corridor through the Glen and Grand canyons. The dam replaced the dramatic seasonal flow variations with significant daily fluctuations, greatly reduced the amount of sediment in the water, and resulted in nearly constant water release temperatures of about 46 degrees Fahrenheit.

As early as 1982, the Secretary of the Interior initiated the Glen Canyon Environmental Studies of the effects of the dam. These studies were led by Reclamation and conducted by a number of different agencies. In 1989, the Secretary designated Reclamation as the lead agency in preparing an environmental impact statement. Other agencies and individuals participated in these efforts, including federal and state resource agencies, Indian tribes, private consultants, universities, and river guides. To protect the downstream resources until the completion of the impact statement and the adoption of a new operating plan for the dam, in November 1991 Reclamation implemented interim operating criteria. The interim operating criteria reduced the maximum peak releases and daily fluctuations. With the passage of the Grand Canyon Protection Act of 1992, the Congress required that the Glen Canyon Dam be operated to protect and restore the downstream resources of the Grand Canyon National Park and the Glen Canyon National Recreational Area.

The National Environmental Policy Act of 1969 (42 U.S.C. 4321 et seq.) requires that a detailed environmental impact statement be prepared for every major federal action that may significantly affect the quality of the human environment. The act and its implementing regulations set forth the requirements for preparing an impact statement. Among other things, a statement must (1) address the purpose of and need for the action, (2) describe the environment that will be affected, (3) identify alternatives to the proposed action, (4) present the environmental impacts of the proposed action (including the direct, indirect, and cumulative impacts), and (5) identify the agency's preferred alternative. The act does not require, and Reclamation did not perform, a cost and benefit analysis of the proposed action.

In preparing the environmental impact statement for the operation of the Glen Canyon Dam, Reclamation identified 11 resources affected by the dam's operations to be analyzed in detail: water, sediment, fish, vegetation, wildlife and habitat, endangered and other special-status species, cultural resources, air quality, recreation, hydropower, and non-use value. (Non-use values have been defined as those values that people may receive from the knowledge that such things as rare plants and unspoiled natural environments exist, even if people do not consume or use these goods directly.)

In addition, the impact statement identified nine alternative operational scenarios to be studied in detail. These alternatives can be divided into three descriptive categories: unrestricted fluctuating flows (two alternatives, including the no-action alternative); restricted fluctuating flows (four alternatives); and steady flows (three alternatives).

In the final impact statement, Reclamation recommended the Modified Low Fluctuating Flow as the preferred alternative. This alternative was developed to reduce daily flow fluctuations well below the dam's previous operating levels and to provide periodic high, steady releases of short duration; the goal of this alternative was to protect or enhance downstream resources while allowing limited flexibility for power operations.

## Results in Brief

In general, Reclamation used appropriate methodologies and the best available information in determining the potential impact of the dam's various flow alternatives on selected resources. GAO identified some shortcomings and controversy in Reclamation's application of certain methodologies, and some of the data that Reclamation used in making its impact determinations were dated, preliminary, or incomplete. These limitations, combined with the inherent uncertainty associated with making forecasts, reduces the precision of the impacts contained in the statement, and some uncertainty, such as the impact of steady flows on fish resources, remains. Nonetheless, according to GAO's analysis and the opinions of experts, these limitations are not significant enough to alter the relative ranking of the flow alternatives nor render the final environmental impact statement unusable as a decision-making document. Furthermore, Reclamation recognizes that uncertainties still exist. To address these concerns, Reclamation intends to initiate a process of "adaptive management" that would provide for long-term monitoring and research to measure the actual effects of the selected alternative. The results of this effort would form the basis for possible future modifications of the dam's operations.

Many of the key interested parties affected by the Glen Canyon Dam's environmental impact statement support the process used by Reclamation to develop the impact statement as well as the implementation of the preferred alternative. However, while expressing their support, some interested parties raised specific concerns that still exist about the final environmental impact statement, including (1) the manner in which compliance with the Endangered Species Act will be achieved, (2) the economic impact of reducing the Glen Canyon Dam's hydroelectric power capacity, (3) the consideration of other possible causes of adverse downstream impacts, (4) the difficulties in measuring the impact of changes in the dam's operations, (5) the adequacy of the measures for reducing the frequency of unscheduled floods, (6) the need for installing multilevel water intake structures (selective withdrawal structures) on the dam to raise the downstream water temperature, and (7) the implementation of the Adaptive Management Program.

# Principal Findings

## Impact Determinations Are Usable for Decision-Making

In preparing the environmental impact statement, Reclamation used a variety of methodologies and data sources to study the impact of the various dam flow alternatives on hydropower, non-use values and other resources located below the dam. Generally, GAO found the methodologies used to be reasonable and appropriate. For example, the power analysis was conducted by a committee of specialists representing the federal government, the utility industry, private contractors, and the environmental community. This committee used utility-specific data and state-of-the-art simulation models to estimate the economic impact of the alternative dam flows on large regional utilities.

In assessing Reclamation's implementation of the various methodologies, GAO did note several shortcomings and controversy over the methodology used to estimate non-use values. For example, in the hydropower analysis, Reclamation's assumptions do not explicitly include the mitigating effect of higher electricity prices on electricity demand (price elasticity). GAO also found that Reclamation's assumptions about future natural gas prices were relatively high and that two computational errors were made during the third phase of the power analysis. These limitations suggest that the estimated economic impacts for power are subject to uncertainty. However, Reclamation and many experts associated with the process do not believe that these limitations make the results of the analysis unusable. For example, an association that represents the affected power utilities, which has maintained throughout the power studies process that the impact statement understates the costs to the power system, does not believe that Reclamation's cost estimate is understated by a large magnitude. To quantify the impact of various dam flow alternatives on recreation and non-use value, Reclamation used a methodology called contingent valuation. The use of contingent valuation studies, which rely on surveys to elicit information from consumers to estimate how much they would be willing to pay for something is controversial. Although contingent valuation is currently the only known approach for estimating non-use values, some prominent economists question whether this methodology can accurately elicit the value consumers place on non-use goods. However, many economists and survey researchers working in the natural resource and environmental areas have developed and used this methodology. Although these shortcomings affect the estimates for the alternatives, it is unlikely that they would alter the relative ranking of the fluctuating and steady flow alternatives.

GAO also found that Reclamation generally used the best available data in making its impact determinations. For example, for information on cultural resources and properties, Reclamation went beyond the federal requirements for the development of an impact statement by performing assessments of all previously identified archeological sites within the Colorado River corridor in the Glen and Grand canyons. According to many experts, when completed, this effort generated the best and most current scientific information available. However, GAO also found some limitations in the data used in the development of the impact statement. Specifically, some of the information was dated, some was preliminary, and some was incomplete. For example, to assess the economic impact of the alternative flows on recreational activities, Reclamation used a 1985 survey of a sample of anglers, day-rafters, and white-water boaters that asked about their experiences on the Colorado River and what effect, if any, different streamflows would have on their recreational experiences. Although Reclamation updated some of the data to 1991, it acknowledges that the survey information is generally dated. The National Research Council generally found the analysis to be adequate.

Many of the results of the sediment studies at Glen Canyon were preliminary, were in draft form, and had not been published at the time that the draft or even the final impact statement was written. However, according to the researchers that GAO interviewed, no new or additional information on sediment impacts has been obtained that would alter the information or conclusions presented in the final impact statement.

Finally, the information on some resources is incomplete, as is the knowledge of how changes in the Glen Canyon Dam's operations will affect those resources. For example, in part because of incomplete data, the experts' opinions vary on the interactions between native and nonnative fish and how operational changes would affect these interactions and, ultimately, fish populations. In its final biological opinion, the U. S. Fish and Wildlife Service stated that Reclamation's preferred alternative for the dam's future operations, the Modified Low Fluctuating Flow alternative, is likely to jeopardize the existence of two native endangered fish species (the humpback chub and the razorback sucker). The Service identified actions that would modify the preferred alternative with seasonally adjusted steady flows. The Service and Reclamation agreed to categorize these flows as experimental, or research flows. The purpose of this research is to study the effects of steady flows on endangered and native fish.

Reclamation recognizes that many uncertainties about the actual impact of the various flow alternatives still exist. To address such concerns, Reclamation intends to initiate a process of “adaptive management” that would provide for long-term monitoring, research, and measurement of the effects of the selected alternative. The results of this effort would form the basis for future modifications of the dam’s operations.

## Most Key Parties Support the Preferred Alternative, but Some Concerns Remain

The process for selecting a preferred alternative for the future operations of the Glen Canyon Dam considered many factors, such as protecting natural and cultural resources and maintaining hydropower generating capability, and involved many parties with diverse interests. Reclamation’s goal was to select an alternative dam-operating plan that would permit downstream resources to recover to acceptable long-term management levels while maintaining some level of hydropower flexibility. Reclamation believes that it accomplished this goal by selecting the Modified Low Fluctuating Flow as the preferred alternative. According to Reclamation, this flow alternative was developed to reduce daily flow fluctuations well below the dam’s historic operations and to provide periodic high, steady water releases of short duration with the goal of protecting or enhancing the downstream resources while allowing limited flexibility for power operations. This alternative has the same annual and essentially the same monthly water releases as the dam’s historic operations but would restrict daily and hourly water releases more than previously.

GAO judgmentally selected 37 key interested parties and surveyed them on whether they supported Reclamation’s preferred alternative and whether they have any remaining concerns about implementing this alternative as the future operating plan for the Glen Canyon Dam. GAO’s judgmental sample consisted of all of the organizations and individuals that Reclamation identified as providing significant comments on the draft impact statement, any organizations that were considered cooperating agencies in the impact statement’s development process, and other key interested parties. Over 83 percent (25 of 30) of the respondents to GAO’s survey supported the preferred alternative, and many expressed support for the process used by Reclamation to develop the impact statement. Of the five remaining respondents, three stated that they had no position on the issue, while two, the San Juan Southern Paiute Tribe and the Grand Canyon River Guides, believed that the current interim operating criteria would be more protective of resources and, therefore, more consistent with the intent of the Grand Canyon Protection Act.

Other interested parties, although supporting the preferred alternative, believed that several areas of concern still remain. For example, one organization stated that the final impact statement assumes that the dam's operations are the only cause of the impacts on downstream resources and, therefore, that changing the dam's operations is the only technique available for managing and enhancing those resources. The organization noted other causes of downstream impacts, including the introduction of nonnative fish and human usage. Still other organizations believed that there is a potential for negative impacts that will be difficult to measure because, between the draft and the final impact statement, Reclamation revised the preferred alternative to simultaneously increase two of the dam's operating parameters: the maximum daily peak releases and the upramp rate (the hourly rate of increase). Others stated that they were concerned about flood protection measures. Also, concerns were expressed about the future implementation of Reclamation's Adaptive Management Program, including its continued monitoring and research efforts.

## Recommendations

GAO is making no recommendations in this report.

## Agency Comments

GAO provided copies of a draft of this report to the Department of the Interior for its review and comment. Interior generally agreed with the information presented in the report and stated that they were impressed with the quality of the product developed by the audit team. Interior also provided several technical clarifications to the draft, which have been incorporated into the report as appropriate. Interior's comments and GAO's responses are included in appendix XII.

# Contents

## Tables

# Figures



## Abbreviations

| | |
|---|---|
| ABT | Aquatic Biology Team |
| cfs | cubic feet per second |
| CROD | Contract Rate of Delivery |
| CRSP | Colorado River Storage Project |
| CRSS | Colorado River Simulation System |
| CVM | contingent valuation method |
| EGEAS | Electronic Generation Expansion Analysis System |
| EIS | environmental impact statement |
| Elfin | Electric Utility Financial and Production Cost Model |
| EPA | U.S. Environmental Protection Agency |
| FWCA | Fish and Wildlife Coordination Act |
| FWS | U.S. Fish and Wildlife Service |
| GCES | Glen Canyon Environmental Studies |
| NEPA | National Environmental Policy Act |
| NOAA | National Oceanic and Atmospheric Administration |
| SLCA/IP | Salt Lake City Area/Integrated Projects |
| WAPA | Western Area Power Administration |

Chapter 1

# Introduction

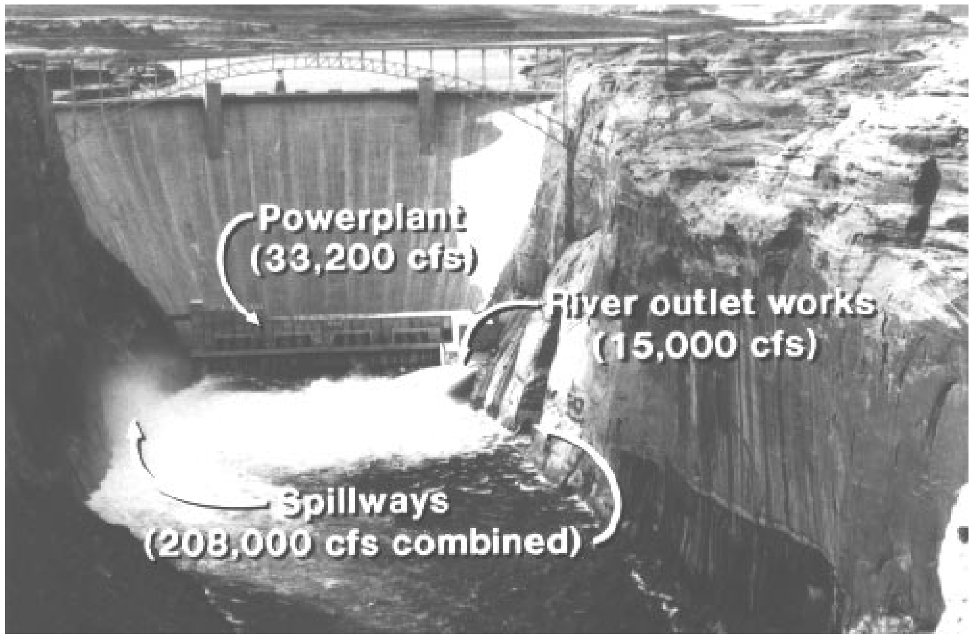
The Glen Canyon Dam was completed by the Bureau of Reclamation in 1963 as a multipurpose facility. It is the key feature and major storage unit of the Colorado River Storage Project. The Colorado River Storage Project was authorized in 1956 to develop and use the water resources in the Upper Colorado River Basin. The operations of the Glen Canyon Dam and its reservoir, Lake Powell, enable the Colorado River Storage Project to fulfill the downstream water release requirements while the runoff from the Upper Basin is stored and used for irrigation, recreation, and municipal and industrial purposes.

The powerplant at the Glen Canyon Dam has been used primarily for generating power during high-demand periods (peaking power). The fluctuating releases of water associated with peaking power operations have caused concern among federal, state, and tribal resource management agencies; river users who fish in Glen Canyon or take white-water raft trips in the Grand Canyon; and Native American and environmental groups, in connection with the detrimental effects that such water releases have on the cultural resources and the downstream plants, animals, and their habitats.

## Operation of the Glen Canyon Dam's Powerplant

The Glen Canyon Dam powerplant has eight generators with a maximum combined capacity of 1,288,000 kilowatts at a 95-percent power factor. The maximum combined discharge capacity of the eight turbines is approximately 33,200 cubic feet per second (cfs) when Lake Powell is full; however, Reclamation has limited such releases to 31,500 cfs. Fluctuations within a day have typically ranged from 12,000 cfs in October to about 16,000 cfs in January and August. Although water can be released from the dam through the powerplant, the outlet works, or the spillways, discharging water through the powerplant's turbines is the preferred method because electricity and its associated revenue can be produced. The power generated by the Glen Canyon Dam is marketed principally in a six-state area—Arizona, Colorado, Nevada, New Mexico, Utah, and Wyoming. Figure 1.1 shows the various release capacities for the Glen Canyon Dam.

**Figure 1.1: Water Release Capacities of the Glen Canyon Dam's Powerplant, Outlet Works, and Spillways**




Source: Bureau of Reclamation.

Historically, the Glen Canyon Dam, as part of the Colorado River Storage Project, was operated to produce the greatest amount of firm capacity and energy practicable while adhering to the releases required under the "Law of the River." The Law of the River—a collection of federal and state statutes, compacts, court decisions and decrees, federal contracts, a treaty with Mexico, and formally determined long-range operating criteria—defines the operation and management of the Colorado River. The operating criteria for the dam were established under the "Criteria for Coordinated Long-Range Operation of Colorado River Reservoirs" (Long-Range Operating Criteria), which include the criteria for annual operations. The Annual Operating Plan, which is prepared under the Long-Range Operating Criteria, addresses monthly operations while interagency agreements control the dam's hourly operations.

The annual volume of releases from the dam is based on the water inflow to Lake Powell and the remaining space in Lake Powell and Lake Mead. The annual release volumes vary greatly, but all adhere to the Long-Range

Operating Criteria's objectives of an 8.23-million-acre-feet[1] minimum annual release and equalized storage between the two reservoirs. From 1968 to 1989, the annual releases ranged from 8.23 million acre-feet to 20.4 million acre-feet. Annual releases greater than the minimum were permitted to avoid anticipated spills (excess annual releases that cannot be used for project purposes) and to equalize storage. The minimum release occurred in about half the years.

The volume of water released from Lake Powell each month depends on the forecasted inflow, existing storage level, monthly storage targets, and annual release requirements. Demands for electrical energy, fish and wildlife needs, and recreation needs are also 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 the winter and summer months, and recreation needs are highest during the summer. Therefore, higher-volume releases are scheduled during these months whenever possible. 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 on the basis of updated streamflow forecast information. The Scheduled releases for the remaining months are adjusted to avoid anticipated spills and maintain conservation storage in accordance with the Long-Range Operating Criteria.

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

To the extent possible, the Glen Canyon Dam follows these guidelines in producing hydropower:

- Maximize water releases during the peak energy demand periods, generally Monday through Saturday between 7 a.m. and 11 p.m.,

[1]An acre-foot is the amount of water needed to cover 1 acre of land to a depth of 1 foot—or about 326,000 gallons.

- Maximize water releases during peak energy demand months and minimize during low demand months,
- Minimize and, to the extent possible, eliminate powerplant bypasses.

## Glen Canyon's Environmental Studies and Environmental Impact Statement

Before the construction of the Glen Canyon Dam, the Colorado River's sediment-laden flows fluctuated dramatically during different seasons of the year. Flows of greater than 80,000 cfs were common during the spring runoff. In contrast, flows of less than 3,000 cfs were typical throughout the late summer, fall, and winter. Water temperatures ranged from near freezing in the winter to more than 80 degrees Fahrenheit in the summer. The construction of the Glen Canyon Dam altered the natural dynamics of the Colorado River. The dam replaced seasonal flow variations with daily fluctuations, greatly reduced the amount of sediment in the river, and resulted in nearly constant water release temperatures of about 46 degrees Fahrenheit.

In response to the concerns of federal, state, and tribal agencies and the public about the negative effects of the dam's operations, in December 1982 the Secretary of the Interior directed Reclamation to initiate a series of interagency scientific studies. These studies were to examine the short- and long-term effects of the dam's historic, current, and alternative operations on the environmental and recreational resources of the Glen and Grand canyons. The studies became known as phase I of the Glen Canyon Environmental Studies. From 1982 through 1987, 39 technical reports were prepared evaluating terrestrial biology, aquatic biology, sediment and hydrology, recreation, and the dam's operations. However, no studies were conducted on the economic impact to hydropower from changes in the dam's operations. According to Reclamation, of primary importance in the Glen Canyon Environmental Studies was the research connected with endangered fish. The existence and operations of the dam were believed to be important factors involved in the extinction of two fish species (the Colorado squawfish and bonytails) from the river corridor. The dam and its operations were also considered to present survival problems for the existing populations of the humpback chub and razorback sucker as well as other native fish species. Therefore, according to Reclamation, the biological opinion issued by the U.S. Fish and Wildlife Service in 1994 was an important factor in the ultimate formulation of the preferred alternative in the environmental impact statement (EIS).

The Glen Canyon Environmental Studies technical reports were concurrently reviewed by the National Research Council and the

Executive Review Committee. The Executive Review Committee was made up of policy-level representatives from Reclamation, the National Park Service, the U.S. Fish and Wildlife Service, the Department of the Interior's Office of Environmental Policy and Compliance, and the Western Area Power Administration. This Committee then prepared a report[2] in January 1988 on the findings and conclusions of phase I of the Glen Canyon Environmental Studies and made recommendations and suggested options for revising the dam's operations.

In June 1988, phase II of the Glen Canyon Environmental Studies was initiated to gather additional data over a 4- to 5-year period on the dam's specific operational elements. Phase II was to further define the impacts on the natural environment, public uses associated with recreation, cultural resources, and power-generation economics. At the urging of the National Research Council, an entity of the National Academy of Sciences, non-use values were incorporated into the studies. "Non-use value" is the term used to describe the monetary value that non-users place on the status of the environment. For example, the values that people may receive from the knowledge that such things as rare plants, animals, and unspoiled natural environments exist are defined as non-use values. A number of federal and state resource agencies, Indian tribes, private consultants, universities, and river guides participated in phase II of the Glen Canyon Environmental Studies.[3] Funding for these studies was provided mainly from the revenue derived from the sale of electricity generated by the Glen Canyon Dam.

In July 1989, the Secretary of the Interior decided that Reclamation should prepare an environmental impact statement to reevaluate the operations of the Glen Canyon Dam. The purpose of the EIS was to determine specific options for operating the dam that could minimize the adverse impacts on the downstream environmental and cultural resources, as well as on the Native American interests in the Glen and Grand canyons, while still producing hydropower. Reclamation was designated by the Secretary to be the lead agency responsible for preparing the EIS; other participants were the following cooperating agencies: the Bureau of Indian Affairs, the National Park Service, the U.S. Fish and Wildlife Service, the Western Area Power Administration, and the Arizona Game and Fish Department. In

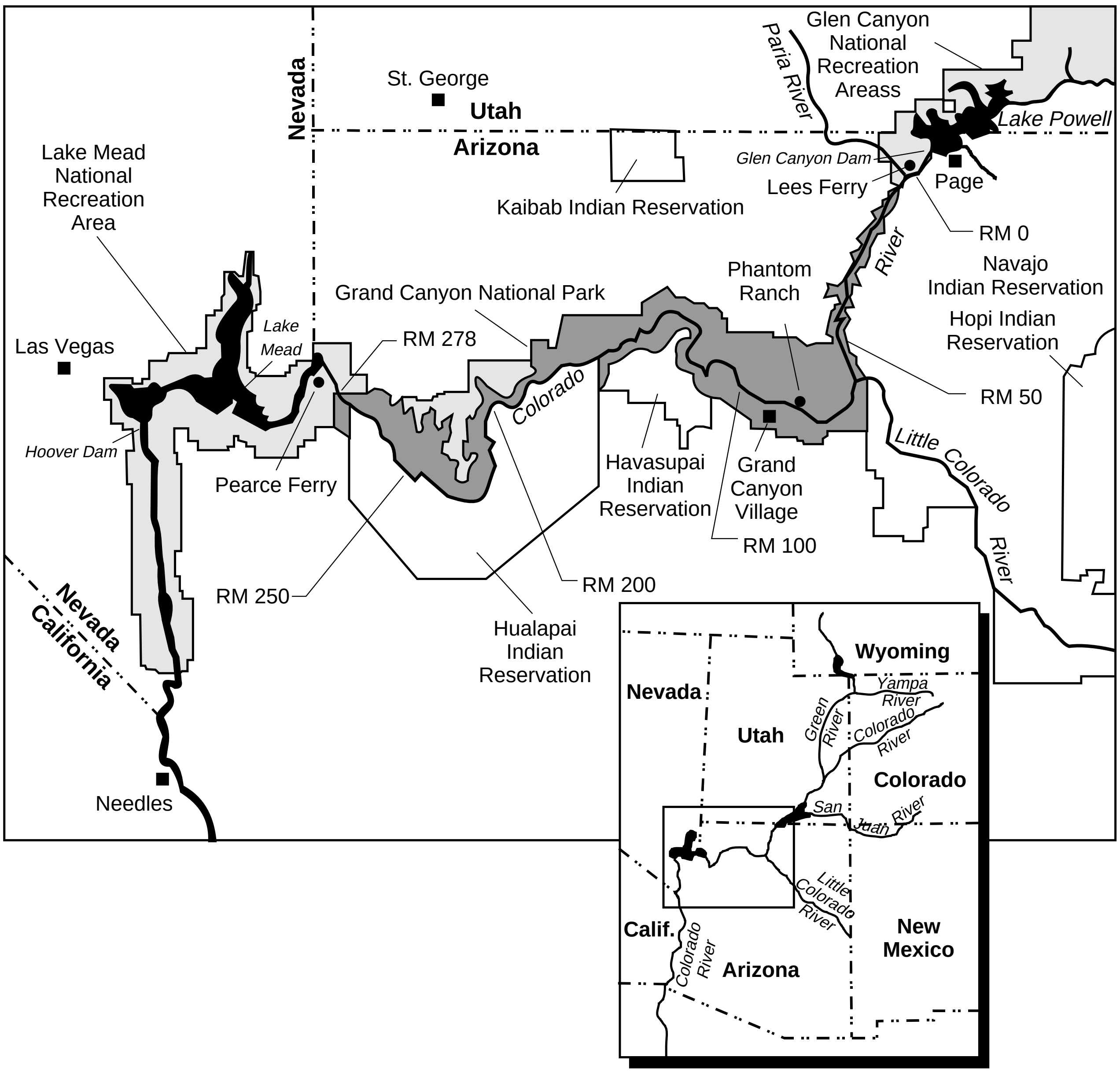
[2]The Glen Canyon Environmental Studies Final Report, U.S. Department of the Interior, 1988.

[3]Agencies participating in phase II of the Glen Canyon Environmental Studies included Reclamation, the National Park Service, the Western Area Power Administration, the U.S. Geological Survey, the U.S. Fish and Wildlife Service, the Hopi Tribe, the Hualapai Tribe, the Navajo Nation, the Pueblo of Zuni, the San Juan Southern Paiute Tribe, the Southern Paiute Consortium, and the Arizona Game and Fish Department.

1989, after the EIS process started, Reclamation also made the following Native American tribes cooperating agencies: the Hopi Tribe, the Hualapai Tribe, the Navajo Nation, the Pueblo of Zuni, the San Juan Southern Paiute Tribe, and the Southern Paiute Consortium. Officials from many of these same agencies and tribes participated in the Glen Canyon Environmental Studies, which formed the basis for the analyses of alternatives for the EIS.

The EIS was designed primarily to focus on the Colorado River corridor from the Glen Canyon Dam in northwestern Arizona, southward through the Glen and Marble canyons and westward through the Grand Canyon to Lake Mead. The map in figure 1.2 shows the area of study under the Glen Canyon Environmental Studies and the EIS for the Glen Canyon Dam.

**Figure 1.2: Map of the Study Area of the Glen Canyon Dam's Environmental Studies and Environmental Impact Statement**




Note: RM - River Mile.

Source: Bureau of Reclamation.

The requirement to prepare an EIS accelerated the scheduled completion of the research studies in phase II of the Glen Canyon Environmental Studies to provide more timely data for the EIS. This acceleration was accomplished by designing special "research flows," a series of carefully designed discharges of water and data collection programs conducted in June 1990 through July 1991. Each research flow lasted 14 days and included 3 days of steady 5,000 cfs flows and 11 days of either steady or fluctuating flows. The research flows provided a means to evaluate the short-term responses of certain resources to a variety of discharge parameters, including minimum and maximum flows, the rate of change in flow, and the range of daily fluctuations.

To protect downstream resources until the completion of the EIS and the formal adoption of new operating criteria for the Glen Canyon Dam, Reclamation implemented the interim dam operations on November 1, 1991. The interim operating criteria were purposely designed to be conservative for the protection of natural and cultural resources. Specifically, the interim criteria reduced peak water releases from the approved maximum of 31,500 cfs to 20,000 cfs; restricted daily fluctuations in releases to between 5,000 cfs and 8,000 cfs; and restricted the rate of change in releases (ramp rates) to 2,500 cfs per hour when increasing and to 1,500 cfs per hour when decreasing. While these limitations were imposed, the interim criteria met the minimum annual release of 8.23 million acre-feet in accordance with the 1970 Long-Range Operating Criteria. Although the interim operating criteria could be modified on the basis of new information, they were to remain in effect until the EIS and the Secretary's Record of Decision for new operating criteria for the dam were completed.

## Grand Canyon Protection Act of 1992

Subsequent to Reclamation's initiation of the EIS process, on October 30, 1992, the Congress enacted the Grand Canyon Protection Act of 1992 (title XVIII of P.L. 102-575). The act addresses the protection of the Grand Canyon National Park, the Glen Canyon National Recreational Area, the interim operating criteria for the dam until the EIS is completed, long-term monitoring and research, and the replacement of lost power from any changes to the dam's operation. The act requires that the Glen Canyon Dam be operated to protect, mitigate adverse impacts to, and improve the downstream resources of the Grand Canyon National Park and the Glen Canyon National Recreational Area. The act also required the Secretary of the Interior to complete a final environmental impact statement for the Glen Canyon Dam's operations by October 30, 1994. Furthermore, the act required GAO to audit the costs and benefits of the various operating alternatives identified in the final environmental impact statement. On the basis of the findings, conclusions, and recommendations made in the EIS, other relevant information, and our audit report, the Secretary is to issue a Record of Decision adopting future operating criteria and operating plans for the Glen Canyon Dam.

## National Environmental Policy Act

The National Environmental Policy Act of 1969 (NEPA) (42 U.S.C. 4321 et seq.) establishes the national environmental policy and goals for protecting, maintaining, and enhancing the environment, and it provides a process for implementing these goals within federal agencies. The act requires, among other things, that the applicable federal agency prepare a detailed EIS for every major federal action that may significantly affect the quality of the human environment. The EIS is designed to ensure that important environmental impacts will not be overlooked or underestimated before the government commits to a proposed action. The act also established the Council on Environmental Quality, which oversees the NEPA process.

The Council on Environmental Quality's Regulations for Implementing the Procedural Provisions of the National Environmental Policy Act (40 C.F.R. 1502.4) provide federal agencies with a process for determining whether or not to prepare an EIS. If it is determined that an EIS is necessary, regulations require, among other things, that the EIS must (1) address the purpose of and need for the action, (2) describe the environment that will be affected, (3) identify alternatives to the proposed action, (4) present the environmental impacts of the proposed action (including the direct, indirect, and cumulative impacts), (5) identify any adverse environmental impacts that cannot be avoided should the proposed action be implemented, and (6) identify any irreversible and irretrievable commitment of resources that would occur should the proposed action be implemented. The regulations also require each federal agency to identify the agency's preferred alternative or alternatives, if one or more exists, in the draft and the final EIS. In addition, before making a decision, the responsible agency must solicit comments from the public and from other government agencies that may have jurisdiction by law or expertise with respect to any environmental impacts.

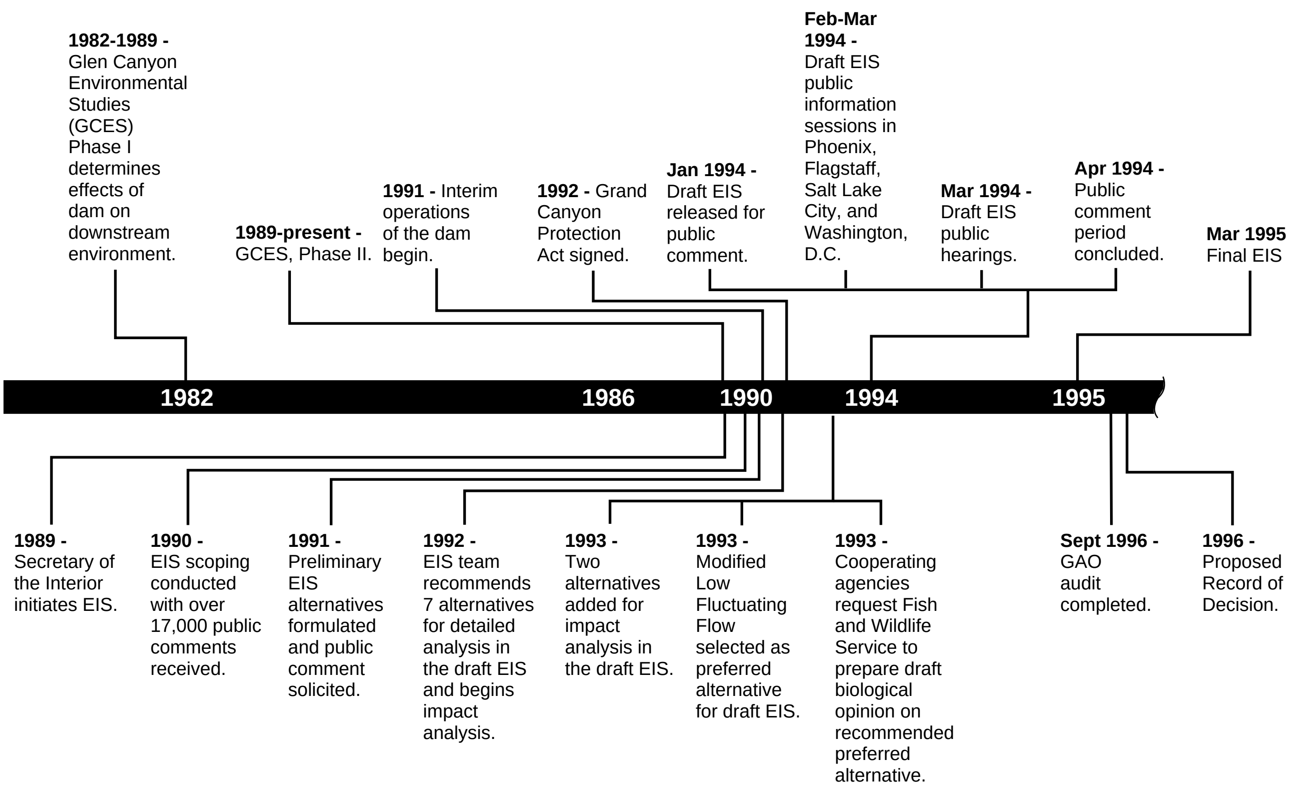
Under section 309 of the Clean Air Act, the Environmental Protection Agency (EPA) is required to review and publicly comment on the environmental impacts of major federal actions, including actions that are the subject of a draft or final EIS. EPA reviews and comments on both the adequacy of the analyses and the environmental impacts of the proposed action. If the Administrator, EPA, determines that the action is environmentally unsatisfactory from the standpoint of the public's health or welfare or environmental quality, this determination shall be published and the matter will be referred to the Council on Environmental Quality. If the action involves a federal project located at a specific site, the appropriate EPA regional office has the jurisdiction and delegated responsibility for carrying out the section 309 review and working with the proposing federal agency to resolve any problems. EPA's Region IX in San Francisco, California, was the region responsible for reviewing the draft and final EIS for the operation of the Glen Canyon Dam.

## Reclamation's Process for Completing the Glen Canyon Dam's EIS

The preparation of the Operation of Glen Canyon Dam Final Environmental Impact Statement was a cooperative effort involving Reclamation, the cooperating agencies, the participants in the Glen Canyon Environmental Studies program, and the representatives of an interagency EIS team. Although Reclamation was designated to be the lead agency responsible for preparing the EIS, its objective was to obtain substantial input from these organizations during the decision-making process, and its goal was to build a consensus for the ultimate decision of recommending a preferred alternative in the EIS.

The group of cooperating agencies, which prior to the development of the formal EIS included only federal agencies, was established in July 1989. This group ultimately included representatives from Reclamation, the Bureau of Indian Affairs, the Environmental Protection Agency, the National Park Service, the U.S. Fish and Wildlife Service, the Western Area Power Administration, the Arizona Game and Fish Department, the Hopi Tribe, the Hualapai Tribe, the Navajo Nation, the San Juan Southern Paiute Tribe, the Southern Paiute Consortium, and the Pueblo of Zuni. The EIS team was established in mid-1990 and included representatives from Reclamation, the National Park Service, the U.S. Fish and Wildlife Service, the Western Area Power Administration, the U.S. Geological Survey, the Arizona Game and Fish Department, the Hopi and Hualapai Tribes, the Navajo Nation, and a private consulting firm. Reclamation charged the EIS team with formulating alternatives for operating the dam and assessing their impacts on the environment. For resources that were to be studied in detail, subteams were formed to make the impact determinations, document their findings, and draft that particular section of the EIS. For the other resources, individuals with expertise in a particular field were assigned the responsibility for determining the impacts and preparing the documentation. Figure 1.3 shows some of the key dates in the preparation of the Glen Canyon Environmental Studies and the EIS.

**Figure 1.3: Key Dates in the Environmental Studies and the Environmental Impact Statement Processes for the Glen Canyon Dam**




Source: GAO's presentation of the Bureau of Reclamation's data.

## Scoping Phase

The initial step in preparing an EIS involves a scoping phase that provides for the early identification and consideration of environmental issues and alternatives. In February 1990, Reclamation published a notice in the Federal Register announcing the opening of the scoping phase of the Glen Canyon Dam's EIS. This phase included environmental scoping meetings to obtain public comments and determine the appropriate scope of the EIS. The comment period, initially established for March 12 through April 16, 1990, was extended to May 4, 1990, in response to comments by the public. Reclamation provided opportunities for public participation in the scoping phase through news releases, mailings, legal notices, and contacts with media, organizations, and individuals. Throughout the process, the EIS team periodically reported the results of its analyses to the cooperating agencies and the public. The cooperating agencies acted as a steering committee and provided input to Reclamation on both the EIS process and the EIS document after a period of review and discussion.

More than 17,000 comments were received during the scoping period. Numerous comments were received about suggested alternatives and factors to be considered in the development of alternatives. These comments ranged from general suggestions about the management of the dam to specific flow release recommendations. As a result of the analyses and the categorization of the oral and written scoping comments by a Reclamation contractor, the EIS team consolidated and refined the public's issues of concern. The following resources were identified to be analyzed in detail in the EIS: water, sediment, fish, vegetation, wildlife and their habitat, endangered and other special-status species, cultural resources, air quality, recreation, hydropower, and non-use value.

In July 1990, representatives from the cooperating agencies and various interest groups participated in a "brainstorming" workshop to fully consider all concepts and suggestions in formulating alternatives for the dam's operations. On the basis of the results of the workshop, scoping comments, and the Glen Canyon Environmental Studies phase I report, the interdisciplinary EIS team formulated 10 preliminary alternative flow scenarios. Some of these alternatives would provide for warmer water release temperatures in the summer, add sediment to the river below the dam, or reregulate releases to provide steady flows downstream. The EIS team presented these alternatives to the cooperating agencies and, following their approval, presented them to the public in March 1991.

The public was asked to comment on the range of preliminary alternatives as part of the EIS scoping process. The predominant public comment was the need to separately consider alternatives that deal with the operations of the dam from those considering changes to the structure of the dam. Using the additional input received from the public, professional judgment, and analysis of interim flows, the EIS team reviewed and revised the preliminary alternatives. Seven alternatives were then identified for detailed analysis. Later, to present a full range of reasonable operations for study in the EIS, two more alternatives were formulated. These included the Maximum Powerplant Capacity alternative, which was developed to allow use of the powerplant's maximum discharge capacity of 33,200 cfs, and the eventual preferred alternative—the Modified Low Fluctuating Flow alternative. The Modified Low Fluctuating Flow alternative was similar to the Interim Flow but included a habitat maintenance flow. Habitat maintenance flows are high, steady releases of water within the powerplant's capacity for 1 or 2 weeks in the spring. The purpose of these flows is to reform and rejuvenate backwaters and maintain sandbars, which are important for native fish habitat. Table 1.1 presents the nine alternative flows studied in detail in the Glen Canyon Dam's environmental impact statement. These alternatives can be categorized as follows: unrestricted fluctuating flows, restricted fluctuating flows, and steady flows.

**Table 1.1: Alternative Operating Procedures Studied in the Glen Canyon Dam's EIS**

| | |
|---|---|
| **Unrestricted fluctuating flows** | The two unrestricted fluctuating flow alternatives would allow flows to vary, as necessary, for power generation purposes. |
| No-Action | Maintain historic fluctuating releases the same as they were from 1964, when the dam was placed in hydropower operation, until the research flows began in June 1990. The maximum allowable discharge during these fluctuations would be 31,500 cfs. |
| Maximum Powerplant Capacity | Permits use of full powerplant capacity (33,200 cfs). |
| **Restricted fluctuating flows** | The four restricted fluctuating flow alternatives would provide a range of downstream resource-protection measures, while offering varying amounts of flexibility for power operations. |
| High | Slightly reduce daily fluctuations from historic no-action levels. |
| Moderate | Moderately reduce daily fluctuations from historic no-action levels; includes habitat maintenance flows, which are short-duration high releases during the spring that allow sand to be transported and deposited for maintaining camping beaches and fish and wildlife habitat. |
| Modified Low (preferred alternative) | Substantially reduce daily fluctuations from historic no-action levels; includes habitat maintenance flows. |
| Interim Low | Substantially reduce daily fluctuations from historic no-action levels; same as interim operations. |
| **Steady flows** | The three steady flow alternatives would 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. |
| 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. |

## Resource Protection Measures (Common Elements)

All of the restricted fluctuating flow and steady flow alternatives include elements designed to provide additional resource protection or enhancement. Since these elements were common to all such alternatives, they became known as the "common elements." Each impact analysis includes these common elements. The common elements include adaptive management, monitoring and protecting cultural resources, flood frequency reduction measures, beach/habitat-building flows, further study of selective withdrawal structures, measures to increase populations of an endangered fish—the humpback chub,[4] and emergency operating exception criteria.

### Adaptive Management

The concept of adaptive management is based on the recognized need for operational flexibility to respond to future monitoring and research findings and varying resource conditions. The purpose of the Adaptive Management Program would be to develop future modifications to the dam's operating criteria if monitoring and/or research results indicate a need for change. Long-term monitoring and research would measure how well the selected alternative meets the resource management objectives. The basis for any decision would be linked to the response of the resources to the operations of the dam. (Further details on the Adaptive Management Program are provided in ch. 2.)

### 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 the Glen and Grand canyons. These properties include prehistoric and historic archeological sites and Native American traditional cultural properties and resources. Impacts are likely to occur to some of these historic properties regardless of the EIS alternative chosen for implementation. The National Historic Preservation Act, as amended in 1992, instructs federal agencies to develop measures to avoid or minimize the loss of historic properties resulting from their actions.

### Flood Frequency Reduction Measures

Under this common element, the frequency of unscheduled flood flows greater than 45,000 cfs would be reduced to no more than once in 100 years as a long-term average. This would allow management of certain other common elements—habitat maintenance flows and beach/habitat-building flows.

The two separate methods of reducing flood frequency that were identified include (1) increasing the capacity of Lake Powell by raising the

[4]Measures to provide protection for, or enhancement of, populations of the razorback sucker are not specifically included as a common element because currently very few of the species exist in the mainstream Colorado River and no reproduction is known to occur.

height of the spillway gates by 4.5 feet and (2) reducing the volume of the lake by 1 million acre-feet from its current capacity in the spring until the runoff peak has clearly passed.

### Beach/Habitat-Building Flows

Sandbars above the river's normal peak stage will continue to erode, and backwater habitat within the river's flow will tend to fill with sediment under any EIS alternative. Beach/habitat-building flows involve controlled high releases of water greater than the powerplant's capacity for a short duration; they are designed to rebuild high-elevation sandbars, recycle nutrients, restore backwater channels, and provide some of the dynamics of a natural system.

### Further Study of Selective Withdrawal Structures

Reclamation would perform a study to determine if structures that would allow the withdrawal of water from various depths of the reservoir should be installed at the Glen Canyon Dam. Currently, water released from the dam to produce hydropower is withdrawn from the cold depths of Lake Powell, averaging 230 feet below the water's surface when the reservoir is full. This withdrawal process is accomplished by a series of eight 15-foot-diameter intake pipes that provide the water directly to the dam's eight turbines. This water withdrawal process results in the river water temperature downstream of the dam being a nearly constant year-round average of about 46 degrees Fahrenheit. Many native fish species cannot reproduce and survive in these constant cold temperature conditions. Increasing mainstream water temperatures by means of selective withdrawal structures offers the greatest potential for creating new spawning populations of humpback chub and other native fish in the Grand Canyon. Multilevel intake structures (a means of selective withdrawal) could be built at Glen Canyon Dam to provide seasonal variation in the water temperature. A structure would be attached to each of the eight existing intake pipes to withdraw warmer water from the upper levels of the reservoir. However, the cost of installing multilevel intake structures at the Glen Canyon Dam has been estimated at $60 million.

### New Population of Humpback Chub

With the assistance of the U.S. Fish and Wildlife Service, the National Park Service, the Arizona Game and Fish Department, and other land management entities, such as the Havasupai Tribe, Reclamation would make every effort—through funding, facilitating, and technical support—to establish a new population of humpback chub within the Grand Canyon. The humpback chub is currently a listed species under the federal Endangered Species Act of 1973 (16 U.S.C. 1532 et seq.) and is one of the native fish species that faces continued ecological health problems due to the cold water temperatures of the Colorado River. Such cold temperatures are not conducive to the humpback chubs' spawning or the survival of eggs and young.

### Emergency Exception Criteria

Normal operations described under any alternative could be altered temporarily to respond to power and water emergencies, such as insufficient generating capacity, the restoration of the electrical system, or search and rescue operations. These changes in operations would be of short duration (usually less than 4 hours) and would be the result of emergencies at the dam, downstream, or within the interconnected electrical system.

## Draft EIS and Public Comments

On January 4, 1994, Reclamation filed a draft EIS with EPA. The Draft EIS presented the impacts of the nine flow alternatives, including the No-Action alternative (historic operations) that provided a baseline for comparison, on the 11 resources that could be affected by the various dam-operating regimes. Over 33,000 written comments were received on the draft EIS. More than 2,300 separate issues and concerns were extracted from an analysis of the comments.

EPA's Region IX supported the preferred alternative (Modified Low Fluctuating Flow) selected by Reclamation in the draft EIS. However, EPA gave the draft EIS a qualified rating based on insufficient information on two issues. First, EPA expressed concern about the lack of information on the impacts of raising the dam's spillway gates as a flood frequency reduction measure and recommended that the final EIS include a more thorough evaluation of the flood frequency reduction options. Second, EPA recommended that the final EIS contain further discussion of Reclamation's Adaptive Management Program and how it plans to implement beach/habitat-building flows.

## Preliminary Final EIS

Reclamation issued a preliminary final EIS for the operations of the Glen Canyon Dam in December 1994. The preliminary final EIS also took into consideration the discussions with the U.S. Fish and Wildlife Service (FWS) in connection with the consultation requirements of the Endangered Species Act and with the provisions of the Fish and Wildlife Coordination Act. Section 7 of the Endangered Species Act, as amended (16 U.S.C. 1536), requires federal agencies to consult with FWS to ensure that the actions they authorize, fund, or carry out are not likely to jeopardize the continued existence of a species listed under the act as endangered or threatened. If the action would jeopardize a listed species, FWS suggests a reasonable and prudent alternative that the federal agency can implement to minimize and/or mitigate the activity's impact on the species or their critical habitat. The Fish and Wildlife Coordination Act of 1958 (16 U.S.C. 661 et seq.) was enacted to ensure that fish and wildlife receive equal consideration during the planning and construction of federal water projects. FWS prepares a Fish and Wildlife Coordination Act report that contains nonbinding recommendations for actions that would be beneficial to fish and wildlife. The cooperating agencies and the EIS team reviewed the preliminary final EIS, and additional changes were made to the EIS on the basis of that review.

## Final EIS

On March 21, 1995, Reclamation filed the final EIS with EPA. In June 1995, EPA informed Reclamation that it continues to support the preferred alternative and was pleased that Reclamation had addressed EPA's concerns about the draft EIS. Specifically, the final EIS states that Reclamation will conduct a detailed evaluation of the flood frequency reduction measures before a decision is made and provides more information on the approach that Reclamation will use to implement an Adaptive Management Program and conduct beach/habitat-building flows. EPA applauded the efforts made by all of the agencies, tribes, organizations, and individuals involved in the research, scoping, and preparation of the EIS. EPA summarized that the dedication to sound science and cooperative relations was critical to developing a preferred alternative (including adaptive management), which it believes will protect and enhance the environmental and cultural resources downstream from the Glen Canyon Dam.

## Reclamation's Preferred Alternative for Future Operations of the Glen Canyon Dam

In the Glen Canyon Dam's final environmental impact statement, Reclamation recommends the Modified Low Fluctuating Flow as the preferred method for the future operations of the Glen Canyon Dam. According to the final EIS, the Modified Low Fluctuating Flow alternative was developed to reduce daily flow fluctuations well below no-action levels and to provide periodic 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 under the No-Action alternative but would restrict daily and hourly water releases. Specifically, minimum flows would be no less than 8,000 cfs between 7 a.m. and 7 p.m. and 5,000 cfs at night. The maximum rate of release would be limited to 25,000 cfs during fluctuating hourly releases. Ramp rates would be limited to 4,000 cfs per hour for increasing flows and 1,500 cfs per hour for decreasing flows. Daily fluctuations would be limited to 5,000, 6,000, or 8,000 cfs depending on the monthly release volume.

The preferred alternative also included periodic habitat maintenance flows, which are steady high releases within the powerplant's capacity for 1 to 2 weeks in the spring. The purpose of these flows is to rejuvenate backwater channels that are important to fish habitat and maintain sandbars that are important for camping. Habitat maintenance flows differ from beach/habitat-building flows in that they would be within the powerplant's capacity and would occur nearly every year when the reservoir's volume is low. According to Reclamation, when the reservoir is low, water flows normally would not exceed about 22,000 cfs, and the probability of an unscheduled spill is small. Therefore, the habitat maintenance flows would be scheduled in those years. Habitat maintenance flows would not occur in years when a beach/habitat-building flow is scheduled. Beach/habitat-building flows are controlled floods with scheduled high releases of water greater than the powerplant's capacity for a short duration, designed to rebuild high elevation sandbars, deposit nutrients, restore backwater channels, and provide some of the dynamics of a natural river system.

According to Reclamation, instead of conducting the beach/habitat building flows in years in which Lake Powell storage is low on January 1, it has been agreed to modify the preferred alternative in the Record of Decision to accomplish the flows in high reservoir years when bypassing the powerplant would be necessary for safety purposes at the dam. In the spring of 1996, Reclamation conducted its first experiment of the controlled flood concept. The controlled experiment commenced with 4 days of constant flows at 8,000 cfs. Flows began to increase incrementally on March 26, 1996, until they reached a maximum of 45,000 cfs, where they remained for 7 days. After 7 days of high flows, the releases were reduced, gradually, to a constant flow of 8,000 cfs for 4 days of evaluation. According to Reclamation, the preliminary results indicate that the release increased sandbars in the Glen and the Grand canyons by as much as 30 percent and also created numerous backwaters for fish.

## Objectives, Scope, and Methodology

Subsection 1804(b) of the Grand Canyon Protection Act states that the Comptroller General shall (1) audit the costs and benefits to water and power users and to natural, recreational, and cultural resources resulting from the management policies and dam operations identified pursuant to the environmental impact statement and (2) report the results of the audit to the Secretary of the Interior and the Congress.

While the act states that GAO should audit the "costs and benefits" of various alternative dam operations identified in the EIS, the National Environmental Policy Act does not require, and Reclamation did not perform, a cost and benefit analysis. In preparing the impact statement, Reclamation studied the impact of nine dam-operating alternatives on 11 resources. In the absence of a cost and benefit analysis, we determined that the statute does not require us to conduct our own cost and benefit analysis. As discussed with the staff of the Majority and Ranking Minority members of the Senate and House committees having jurisdiction over these matters, to fulfill the requirements of the act, we examined

- whether Reclamation's determination of the impact of various flow alternatives on selected resources was reasonable and
- what, if any, concerns still exist on the part of key interested parties about the final EIS.

To assess whether Reclamation's impact determinations were reasonable, we assessed for each resource, the methodologies and data used to make the impact determinations, how the methodologies were implemented, and the results achieved. The details of our analysis, and a comprehensive list of individuals contacted and key studies identified, are contained in appendixes I through X of this report. The title of each appendix is the designation (name) of the resource, and they are numbered in alphabetical order. We combined our analysis of the vegetation and wildlife/habitat impact determinations into one appendix—appendix IX. We made this choice because (1) similar indicators were studied in making the impact determinations for these resources, (2) the riparian vegetation that developed along the Colorado River corridor plays an important role as habitat to support the diversity of wildlife within the Glen and the Grand canyons, and (3) the same EIS team member was responsible for the impact determinations of both resources.

For three resources—hydropower, recreation, and non-use values—Reclamation quantified the economic impact of the cost or benefit that the various flow alternatives would have on the resource. For these resources, we also reviewed the documentation on the modeling techniques and economic assumptions used to make the impact determinations. For example, for Reclamation's power methodology, we reviewed key economic assumptions, results, and documentation, including reports entitled Power System Impacts of Potential Changes in Glen Canyon Power Plant Operations, [Phase II] Final Report, October 1993, and Power System Impacts of Potential Changes in Glen Canyon Power Plant Operations, Phase III Final Report, July 1995. These reports were prepared by the Power Resources Committee, a subgroup of the EIS team which included experts from the federal government, the utility industry, and the environmental community. This committee was charged with determining the impact of the nine flow alternatives on hydropower.

We interviewed members of the Power Resources Committee, including the Reclamation officials who served as Chairman and economist, and representatives from the Western Area Power Administration, the Colorado River Energy Distributors Association, the Environmental Defense Fund, and the Reclamation contractor that conducted the studies.

In addition, to assess the methodology used, economic assumptions, and results, we reviewed federal guidance on water resource projects entitled Economic and Environmental Principles and Guidelines for Water and Related Land Resources Implementation Studies, U.S. Water Resources Council, March 10, 1983; public comments on the draft and final EIS, and comments provided by three energy consultants retained by HBRS, Inc. to review the power analysis. HBRS, Inc. (now called Hagler Bailly Consulting), was Reclamation's primary contractor for conducting the power analysis. Also, we reviewed the comments provided by the National Research Council on the power analyses in the draft and final EIS. We used standard microeconomic principles to assess the reasonableness of key economic assumptions. Our assessment of the reasonableness of Reclamation's methodology was limited to a review of the general analytical framework and an assessment of the reasonableness of the key assumptions and data. We did not evaluate the Power Resources Committee's calibration of the power simulation models used or the spreadsheet models used, nor did we verify the accuracy of all data inputs.

For both the recreation and non-use methodologies, we reviewed the literature and research principles on the contingent valuation method to assess the reasonableness of the methodology, assumptions used, and results in conjunction with standard economic principles. Economists and survey researchers working in the natural resource and environmental areas have developed the theory and practice of contingent valuation to estimate non-use values.

To gain an understanding of Reclamation's recreational methodology, key assumptions, and results, we reviewed documentation that describes these in detail, including the EIS. We also interviewed members of the Recreation subgroup, including Reclamation officials and their contractors, as well as representatives from the National Park Service and the Arizona Game and Fish Department. In addition, we interviewed academic experts in the field and a member of the National Academy of Sciences' team that reviewed the EIS.

To gain an understanding of Reclamation's non-use value study methodology and results, we reviewed the final report entitled GCES Non-Use Value Study, dated September 8, 1995. We interviewed Reclamation officials responsible for the preparation of the report, and a Senior Associate at Hagler Bailly Consulting, who was a primary contributor to the development of the report. To evaluate Reclamation's non-use study, we made use of some general guidelines that focus on the quality of a contingent valuation study and on the underlying survey research. Specifically, to assess the contingent valuation study, we relied on general guidelines developed by a panel of prominent researchers convened by the National Oceanic and Atmospheric Administration. The panel's report was published in the Federal Register on January 15, 1993. To assess the total design method for conducting mail surveys used by Reclamation in the non-use study we used the most widely accepted written standards for mail questionnaires published by Don A. Dillman in 1978. We also interviewed a number of the Non-Use Value Committee members to obtain their opinion of the methodologies and data used and the results achieved. The Committee included members from the power industry, environmental groups, Native American tribes, and federal agencies. The Committee was tasked to consider interim study results and provide input to the study process.

For the eight resources whose impact determinations were not economically quantified, to determine the methodology and data used to make an impact determination, we obtained and reviewed the following documents: the draft EIS and associated appendixes, the preliminary final EIS, the final EIS, public comments on the draft EIS, Reclamation's analysis of and responses to these comments, copies of the minutes of EIS team meetings, summaries of the cooperating agency meetings, and Reclamation's newsletters on the EIS process. We also obtained and reviewed the U.S. Fish and Wildlife Service's draft biological opinion and final biological opinion on the Glen Canyon Dam's EIS, Reclamation's comments and responses to the biological opinions, and the U.S. Fish and

Wildlife Service's report required by the Fish and Wildlife Coordination Act. Also, we reviewed numerous scientific studies related to each of the resources that were identified by EIS team members as the most useful in developing the impact determinations for the respective resources.

To obtain a better understanding of other issues related to the EIS process, we also reviewed the Colorado River Simulation System Overview, the Final Analysis Report on Scoping Comments, and the Glen Canyon Dam EIS Preliminary Alternatives Report. Other documents reviewed included the draft and final environmental assessment of the spring 1996 beach/habitat-building test flow and papers presented at a 1991 National Research Council Symposium on the Glen Canyon Environmental Studies.

Because certain parameters included in the preferred alternative were changed, we reviewed a document entitled "Assessment of Changes to the Glen Canyon Dam Environmental Impact Statement Preferred Alternative from Draft to Final EIS," issued by Reclamation in October 1995. This paper explained the background and scientific basis of the changes to the preferred alternative between the draft and final EIS. A comprehensive list of the documents we reviewed is contained in the discussion of each of the 11 resources in appendixes I through X (vegetation and wildlife/habitat are both discussed in appendix IX).

To assess the reasonableness of the impact determinations for the eight resources that were not economically quantified, we interviewed the EIS team members and/or subgroup members who had the primary responsibility for making the impact determinations, writing sections of the draft EIS, and revising the EIS following the receipt of public comments. We also spoke with scientists identified by EIS team members and members of EIS subgroups who commented on issues in their area of expertise. Finally, we interviewed other agency officials with information on the EIS and Glen Canyon Environmental Studies processes. For each of these resources, we obtained his or her views on the reasonableness of the methodology and data used in making the impact determinations, how well the methodologies were implemented, and the reasonableness of the results achieved.

To obtain information on what, if any, concerns still exist on the part of key interested parties about the final impact statement, including how many supported the preferred alternative, we surveyed 37 key organizations and individuals knowledgeable about the EIS and its development. Our judgmental sample included officials of federal agencies, state agencies, Indian tribes, environmental organizations, water and power suppliers and users, and individuals involved in the development of the EIS. Specifically, among the 37 organizations and individuals we asked to respond to our survey, 23 were organizations and individuals that provided what Reclamation considered to be the most substantive comments on the draft EIS. These agencies and individuals include the Navajo Nation, Hualapai Tribe, Hopi Tribe, Bureau of Indian Affairs, National Park Service, Arizona Game and Fish Department, U.S. Fish and Wildlife Service, Western Area Power Administration, Plains Electric Generation and Transmission Coop, Inc., Environmental Protection Agency, Environmental Defense Fund, National Research Council, Upper Colorado River Commission, Department of the Interior's Office of Environmental Policy and Compliance, Salt River Project, Colorado River Energy Distributors Association, Grand Canyon Trust, American Rivers, Sierra Club Legal Defense Fund, American Fisheries Society, Grand Canyon River Guides, and Dr. Larry Stevens. Dr. Stevens is considered by many to be the leading authority on vegetation in the Grand Canyon region. He was a major contributor of research on both the vegetation and wildlife/habitat resources for the EIS. We also contacted Mr. David Marcus, whom Reclamation stated also provided substantive comments on the draft EIS. However, Mr. Marcus stated that he worked as a consultant for American Rivers and that he preferred to provide us with his comments through that organization, not as an individual. As such, we did not include Mr. Marcus as part of our survey universe.

We also contacted the three cooperating agencies (Pueblo of Zuni, Southern Paiute Tribe, and Southern Paiute Consortium) that were not among the 22 above. Furthermore, the seven Colorado River Basin states (Arizona, California, Colorado, Nevada, New Mexico, Utah, and Wyoming) were asked to respond to our survey. In addition, another five environmental groups with interests in the Glen Canyon Dam area (Sierra Club, Arizona Flycasters, Friends of the River, America Outdoors, and Trout Unlimited) were also contacted. We received responses from 30 of the 37 (81 percent) organizations and individuals we contacted. The seven nonrespondents did not represent any particular interest group. Specifics on how the 37 organizations and individuals responded to our survey are provided in chapter 3 of this report.

We conducted our work from January 1995 through September 1996 in accordance with generally accepted government auditing standards.

We provided copies of a draft of this report to the Department of the Interior for its review and comment. Interior generally agreed with the information presented in the report and stated that they were impressed with the quality of the product developed by the audit team. Interior also provided several technical clarifications to the draft, which have been incorporated into the report as appropriate. Interior's comments and our responses are included in appendix XII.

# Reclamation's Impact Determinations Are Usable for Decision-Making

In preparing the Glen Canyon Dam's environmental impact statement, Reclamation studied the impact of the dam's various flow alternatives on hydropower, non-use values, and other selected resources located below the dam. To make these impact determinations, Reclamation used a variety of methodologies and data sources. Generally, we believe the methodologies used to be reasonable and appropriate and the data used to be the best available at the time. Some prominent economists, however, question the credibility of results obtained from the methodology Reclamation used to derive non-use values. We also noted some shortcomings in some of Reclamation's economic assumptions and its application of certain methodologies. In addition, we found that some of the data used in the resource analyses were dated, preliminary, or incomplete. Overall, these limitations reduce the precision of the estimated impacts contained in the EIS. In addition, there is general agreement that as a result of incomplete information, the impact of steady flow alternatives on fish resources remains uncertain. Nonetheless, our work disclosed no evidence that these limitations would alter the relative ranking of the fluctuating and steady flow alternatives. Therefore, we believe that these limitations are not significant enough to render the final impact statement unusable to the Secretary of the Interior as a decision-making document.

Generally, Reclamation and other experts associated with the development of the Glen Canyon Dam's environmental impact statement believe that the impact determinations are reasonable. At the same time, they recognize that there are limitations to the EIS. However, they believe that these limitations are not significant enough to make the results unusable. Furthermore, Reclamation recognizes that many uncertainties still exist. To address these uncertainties, Reclamation intends to initiate a process of "adaptive management" that would provide for long-term monitoring and research to measure the actual effects of the selected alternative. The results of this effort would form the basis for possible future modifications of the dam's operations.

## Methodologies Used to Make Impact Determinations Were Generally Reasonable

We found that, in general, the variety of methodologies and research techniques used by Reclamation to make impact determinations were reasonable and appropriate. For most resource assessments, Reclamation relied on multidisciplinary subteams consisting of experts representing federal and state governments, tribal interests, academic and scientific communities, the electric utility industry, environmental organizations, and the recreation industry. The exact makeup of each team depended on the resource and the area of concern. In addition, for each resource, the subteam assessed, either quantitatively, qualitatively or both, how alternative flows would affect the resource relative to a No-Action (base case) flow. The EIS teams generally used state-of-the-art modeling techniques and/or the latest scientific research to make the impact determinations. Furthermore, the methods used and results achieved were reviewed by peers and outside experts, including the Glen Canyon Environmental Studies Review Team and the National Academy of Sciences.

To conduct the impact analyses of various flows on hydropower, Reclamation established the Power Resources Committee—a group of electricity and modeling experts from Reclamation, the Western Area Power Administration, the electric utility industry, private contractors, and the environmental community. Using a 50-year analysis period (1991-2040) and the No-Action Flow alternative (historic operations) as the base case, the Committee assessed how various flow alternatives would affect hydropower production and then projected the subsequent economic costs that would be incurred by regional utilities and end-users to replace the dam's forgone power production. The Committee considered the fixed costs associated with the existing generating capacity in the region to be "sunk" costs and, hence, excluded them from the economic cost calculations. The Committee also used two state-of-the-art modeling techniques and detailed utility-specific data to quantify the economic impacts. In addition, the Committee used sensitivity analysis to test the impact of changes in key economic assumptions. The results of the power study were then incorporated into the draft EIS for public comment. The Committee solicited and received an independent review of the power study from three energy experts. On the basis of the comments received from the public and outside experts, the Committee partially revised its initial power study. For example, the Committee updated the projected costs of building gas-combustion powerplants, revised its retail rate analysis, and conducted additional sensitivity analyses. The results of both power studies were incorporated into the final EIS. (See app. V for details on the results of the power study.)

For fish resources, numerous public comments were received by Reclamation expressing concern about the impact determinations presented in the draft EIS. To respond to these concerns, Reclamation formed an Aquatic Biology Team workgroup. This work group consisted of EIS team members representing Reclamation, the U.S. Fish and Wildlife Service, the Arizona Game and Fish Department, and two Indian tribes.

The workgroup was tasked to respond to comments and to reorganize and rewrite the fish section of the final EIS. Individual workgroup members were given specific assignments, interactive discussions were held, and decisions were made through consensus. As a result of this effort, several major changes were made to the final EIS, including more explicit recognition of the uncertainty and disagreement that exist among scientists about the response of fish to the steady flow alternatives. (See app. IV for details on the results of the fish impact determinations.)

To assess the impact of various flow alternatives on water and sediment, Reclamation's EIS team used the Colorado River Simulation System (CRSS) to project the long-term (50 years) and short-term (20 years) impacts on annual and monthly streamflows, floodflows and other water spills, water storage, water allocation deliveries, and Upper Colorado River Basin yields. CRSS is a package of computer programs and databases designed to assist water resource managers in performing comprehensive long-range planning and operations studies that arise from proposed changes in the Colorado River's operations, proposed development of the Colorado River Basin, or changes in present water use throughout the basin. The development of CRSS took place over a 10-year period and stemmed from the need for a comprehensive model of the Colorado River Basin that would incorporate all areas of interest, including legislative requirements. According to Reclamation and other experts, CRSS is the most comprehensive and detailed simulation of the Colorado River system that exists. (See app. VIII and app. X for details on the results of the sediment and water analyses, respectively.)

To quantify the economic impact of the dam's various flow alternatives on non-use values and recreation, Reclamation primarily relied on a methodology called contingent valuation. Social scientists and economists have long acknowledged the existence of non-use values—the monetary value placed on the status of the environment by people who never visit or otherwise use these features. Contingent valuation relies on public surveys to elicit information from consumers and estimate how much they would be willing to pay for a non-use good. For valuing most goods and services, economists are able to rely on people's actual purchases of goods in markets. However, by definition people do not purchase non-use goods, and some prominent economists question whether the contingent valuation method can accurately elicit the values consumers place on non-use goods. For example, Peter A. Diamond and Jerry A. Hausman state, "We believe that contingent valuation is a deeply flawed methodology for measuring non-use values, one that does not estimate what its proponents claim to be estimating."[1] Still many economists and survey researchers working in the natural resource and environmental areas have developed and used this methodology, and it is currently the only known approach for estimating non-use values. (See app. VI for details on the results of the non-use value study.) Economists generally have fewer questions about the application of the contingent valuation methodology in measuring the value of goods and services that consumers actually purchase. Therefore, there are fewer questions about the usefulness of this approach for measuring the values associated with recreational activities. (See app. VII for details on the results of the recreation studies.)

## Shortcomings Noted in Reclamation's Economic Assumptions and Implementation of Certain Methodologies

In light of the results of our work and the opinions of the experts we contacted, we believe the methodologies used by Reclamation and its EIS teams to make impact determinations were generally reasonable. We did note, however, some shortcomings in the economic assumptions used in the hydropower analysis and in Reclamation's implementation of certain methodologies. Specifically, in the hydropower analysis, the assumptions used do not explicitly include the mitigating effect that higher electricity prices would have in reducing the demand for electricity (that is, price elasticity). For example, the Power Resources Committee assumed that both the demand for and price of electricity would continue to rise over the planning period. However, we believe the rise in the price of electricity would likely induce some electricity consumers (both wholesalers and end-users) to consume less electricity or switch to cheaper alternative suppliers, which is not taken into account in the analysis. Consequently, fewer resources would be needed to replace forgone power at the Glen Canyon Dam, and the subsequent economic impacts would be lower than estimated (all else being the same).

In addition, the Committee's assumptions about future natural gas prices are relatively high. The Committee assumed that the average gas price would increase annually by 8 percent from 1991 through 2010. In 1994, industry forecasters projected that the price of natural gas would increase by about 6 percent for the same time period, and in 1995, forecasts assumed that prices will rise by only 5 percent. The higher escalation rates could affect the power analysis by overstating the economic cost of replacing the Glen Canyon Dam's power.

[1]Peter A. Diamond and Jerry A. Hausman, "Contingent Valuation: Is Some Number Better than No Number?" Journal of Economic Perspectives, 8(4), Fall 1994, pp. 45-64. (quotation on p. 62).

We also found that Reclamation's staff made two computational errors during the revision of the initial power analysis. The Power Resources Committee acknowledged these errors in its final report and stated that the errors affected the results in opposite directions, that is, one error may have overstated costs while the other error may have understated costs. The Committee was unable to correct the errors in the report because of time and funding constraints.

These shortcomings, combined with the inherent uncertainty in making economic forecasts, reduce the precision of the estimated economic impacts. However, an association that represents the affected power utilities, while maintaining that the costs to the power system are understated, does not believe that Reclamation's analysis is inaccurate by a large magnitude. Furthermore, because these shortcomings affect the estimated economic impact of all alternatives equally, we believe that addressing these shortcomings would not alter the relative ranking of the fluctuating and steady flow alternatives.

Although we believe the recreation impacts methodology is generally reasonable, we noted several limitations. For example, the survey data used as the basis of the analysis were gathered during an unusually high-water year; therefore, some respondents may not have actually experienced how various alternative flows would have affected their recreational experience, which is what they were being asked to value. In addition, the survey was designed well before the flow alternatives to be studied in the Glen Canyon Dam's EIS were finalized. As a result, the survey scenarios do not systematically correspond to the flow alternatives presented in the EIS. Finally, although researchers tested proposed questions to determine which ones offered the highest response rate, they did not adequately pretest some survey instruments to detect wording, construction, and presentation defects or other inadequacies. Because the recreation economic model used the results of these survey instruments as a basis for the analysis, the estimated dollar value of the benefits may not be very precise. Reclamation and National Park Service officials involved in the process acknowledged that the recreation analysis has limitations but stated that these limitations would not affect the ranking of the alternatives. They also noted that the estimated recreation benefits identified by this research were not a key element in the selection of the preferred alternative.

In addition to the shortcomings in the hydropower and recreation analyses, we also noted that there was no formal opportunity for affected parties as well as the general public to offer comments on the Glen Canyon non-use value study. Although the final EIS notes that the non-use value is positive and significant, the actual quantified results are not included in the final EIS. Reclamation did not include the non-use value study results because they were not available when the final EIS was published. The non-use study was completed as a separate Glen Canyon Environmental Studies report and, according to Reclamation, will be attached to the Record of Decision package sent to the Secretary of the Interior. In that way, it will become part of the final decision-making process. Reclamation noted that although the non-use study did not go through the public comment process, the study team solicited and received peer review at various key decision points and that the final results of the non-use value study received a positive review by the National Academy of Sciences and the Office of Management and Budget. Reclamation also noted that interests likely to be affected by any changes in the operations of the Glen Canyon Dam, such as power groups and environmental groups, were involved in the non-use value study process. In addition, there were scoping sessions and focus groups that were derived from members of the general public. The results of these sessions were used to assist in the development of the content of the survey and the relevant issues to be addressed.

## Data Used in Impact Determinations Were the Best Available

Reclamation's National Environmental Policy Act Handbook requires that all EIS analyses be based on the best reasonably obtainable scientific information. According to Reclamation and other experts who developed the Glen Canyon Dam's environmental impact statement, the data used to make the impact determinations were the best available at the time. For example, for the impact of various flow alternatives on nonfish endangered species, one researcher said the terrestrial and bird-related research used as a basis for making impact determinations was "top notch." Another researcher who worked on endangered species stated that when they were clarifying information or needed data to fill gaps, the EIS team contacted researchers directly to get the latest available data. For information on cultural resources and properties, members of that resource team believe that Reclamation went beyond federal requirements for the development of an impact statement by performing assessments of all previously identified archeological sites within the Colorado River corridor in the Glen and Grand canyons. According to many experts, when completed, this effort generated the best and most current scientific information available.

For some resources, we found that although the data were the best available, they had limitations. Some of the data used in making the impact determinations were dated, preliminary, or incomplete. For example, Reclamation used survey data collected in 1985 to assess the economic impact of alternative dam flows on recreational activities. Reclamation's contractor surveyed a sample of anglers, day-rafters, and white-water boaters about their recreational experiences on the Colorado River and what effect, if any, different streamflows would have on their recreational experiences. However, because the survey was undertaken in 1985, it may not represent more recent trends in recreational experiences. For example, the number of angling trips on the Colorado River more than doubled between 1985 and 1991 (the base year used by Reclamation in preparing the draft EIS), which may influence the value of each trip. Reclamation updated some of the data to 1991 but acknowledges that the survey data were generally dated. Reclamation stated, however, that the recreation analysis was adequate to present a good picture of the potential impact of alternative flows on various recreational experiences and that because of the limited impact of alternative flows on recreation, limited research funds could be better used to improve other analyses. The National Research Council generally found the recreation analysis to be adequate.

In addition, the estimated non-use values for the steady flow alternatives could be overstated because of new information that was not available at the time the survey instruments were developed. The non-use value surveys described the environmental impacts based on information that was the best available at the time. This information indicated that improvements would be obtained for fish resources under fluctuating and steady flow alternatives. However, after the development of the survey instruments, the fish section of the EIS was revised to recognize the uncertainty that exists about the impact of steady flow alternatives. To the extent that the non-use value surveys did not capture this degree of uncertainty, the precision of the non-use value estimates could be reduced.

Many of the results of the Glen Canyon sediment studies were preliminary, in draft form, and had not been published at the time that the draft impact statement or the final impact statement was written. In addition, in some cases definitive information on the impact of a specific flow alternative was not available. Therefore, the EIS team had to extrapolate from the existing data using their professional judgment to estimate the potential impact of a specific alternative. The EIS team told us that they always verified the reasonableness of their conclusions and extrapolations with the researchers. However, they believed that if finalized data had been available, the reasons for the selection of the preferred alternative would have been more clearly supported. These researchers added that no new or additional information on sediment impacts has been obtained that would alter the information or conclusions presented in the final impact statement.

Finally, information on some resources is incomplete, as is the knowledge of how changes in the Glen Canyon Dam's operations will affect those resources. For example, the experts' opinions vary, in part because of incomplete data, on how native and nonnative fish interact and how changes to the dam's operations would affect these interactions. Many researchers and EIS team members we interviewed expressed regret about the lack of coordinated time frames between the completion of the Glen Canyon Environmental Studies and the development of the Glen Canyon Dam EIS. The leader of the workgroup responsible for developing the EIS impact determinations for fish stated that this difference in time frames was especially problematic when the preferred alternative was selected. At that point, decisions had to be made, but data and analyses were not complete.

Reclamation explicitly acknowledges the uncertainty that exists about the impact of the steady flow alternatives on fish resources in the final EIS. In its final biological opinion, the U.S. Fish and Wildlife Service stated that Reclamation's preferred alternative is likely to jeopardize the existence of two native endangered fish species (the humpback chub and the razorback sucker). In general, the biological opinion's "reasonable and prudent alternative" would modify the preferred alternative by including seasonally adjusted steady flows. The U.S. Fish and Wildlife Service and Reclamation have agreed to categorize these flows as experimental and include them as part of the Adaptive Management Program.

## The Results of the Glen Canyon Dam's EIS Are Generally Reasonable, but Future Studies Will Be Needed

Reclamation and other experts associated with the development of the Glen Canyon Dam's EIS generally believe that the impact determinations presented in the final EIS are reasonable. (A summary of Reclamation's comparison of alternatives and impacts is presented in app. XI of this report.) They recognize that there are limitations to the results, but they believe that these limitations are not significant enough to make the impact determinations unusable for the Secretary's decision-making. For example, one EIS team member stressed that in the process of scientific decision-making and economic forecasting, complete and certain information is never available. Furthermore, Reclamation noted that the Congress had mandated that the final EIS be issued within a certain time frame; therefore, decisions had to be made on the basis of the best information available at the time.

Reclamation recognizes that uncertainties still exist about the impact of the various flow alternatives on resources. To address these uncertainties, Reclamation intends to initiate a process of "adaptive management."

## Impact Determinations in the Glen Canyon Dam's EIS Are Generally Reasonable

We discussed the results of the impact determinations for each resource with Reclamation and other experts involved in the development of the Glen Canyon Dam's EIS. Although these individuals recognized that there were some shortcomings in the analyses, they generally agreed that the results of the impact determinations as presented in the Glen Canyon Dam's final EIS were reasonable. For example, although some researchers described the model used (the sand-mass balance model) to determine the impact of various flows on sediment as "simplistic" compared with models that are currently being developed by U.S. Geological Survey researchers, none of the preliminary results from the new models contradict the conclusions reached by the sand-mass balance model. Another researcher who worked on the vegetation and wildlife resources told us that although the EIS may have been based on incomplete information, subsequent science supports it. The researcher further added that the results of the EIS were right on track with the best scientific evidence available at the time.

The results of some impacts, however, such as how steady flows will affect fish, are still uncertain. The individual responsible for leading the fish impact determinations process stated that the lack of final results from the fish research studies was frustrating and that the limited data allowed differences of opinion and scientific interpretation to arise about the impacts on fish resources. However, he added that he believed that if final data had been available, they would have refined the EIS team's conclusions but would not have changed the impact determinations or the preferred alternative.

Although there is general agreement that the results of the Glen Canyon Dam's EIS are reasonable, there is also general agreement that additional research is needed to further refine or, in the case of fish resources, define the impact on resources of changes to the dam's operations. For example, impacts to some archeological and cultural properties are bound to occur regardless of the flow alternative chosen. To avoid or minimize the loss of historic properties and comply with the requirements of the National Historic Preservation Act, Reclamation developed a programmatic agreement between federal and state agencies as well as affected Native American tribes. Implemented in 1994, the agreement led to numerous monitoring trips and site-stabilization efforts, but all parties involved believe that more research is needed to understand how water flow affects cultural resources. Furthermore, several sediment researchers we interviewed stated that they supported the impact determinations and the preferred alternative. However, one stated that as more information is obtained about the various systems in the canyon, the preferred alternative may become less restrictive in terms of the allowed water releases for hydropower use.

## Reclamation's Proposed Adaptive Management Program

Reclamation recognizes that uncertainties exist about the downstream impacts of water releases from the Glen Canyon Dam. To address these uncertainties, Reclamation plans to initiate an Adaptive Management Program. The concept of adaptive management is based on the recognized need for ongoing operational flexibility to respond to future monitoring and research findings and varying resource conditions. The objective of the Adaptive Management Program is to establish and implement long-term monitoring programs that will ensure that the Glen Canyon Dam is operated, consistent with existing law, in a manner that will protect, mitigate adverse impacts to, and improve the values for which the Glen Canyon National Recreational Area and the Grand Canyon National Park were established. According to Reclamation, long-term monitoring and research are essential to adaptive management. Reclamation believes that such an effort is needed to measure the performance of any selected EIS alternative. In this way, managers can determine whether the alternative is actually meeting resource management objectives and obtain an additional understanding of the resources' responses to the dam's operations.

Under Reclamation's current proposal, the Adaptive Management Program, which would be under the direction of the Secretary of the Interior, would be facilitated through an Adaptive Management Work Group. The Adaptive Management Work Group, chartered under the Federal Advisory Committee Act, would include representatives from each of the EIS cooperating agencies, the basin states,[2] contractors for the purchase of federal power, recreation interests, and environmental organizations. The work group would:

[2]The basin states consist of Arizona, California, Colorado, Nevada, New Mexico, Utah, and Wyoming.

- develop proposals for (1) modifying the operating criteria, (2)research under the long-term monitoring program, and (3) other mitigation actions as appropriate and
- facilitate technical coordination and input from interested parties.

The Adaptive Management Work Group would be supported by a monitoring and research center and a technical work group. The Monitoring and Research Center would manage and coordinate monitoring activities, research, and inventory programs and maintain a scientific information database. The technical work group would include technical representatives from federal, state, and tribal governments and their contractors. This work group would translate the policy and goals of the Adaptive Management Work Group into resource management objectives and establish criteria and standards for long-term monitoring and research. The independent scientific review panel would include scientific experts not otherwise participating in the long-term monitoring and research studies. The responsibilities of this review panel would include reviewing scientific study plans, resource reports, and scientific logic and protocols.

# Most Key Interested Parties Support Reclamation's Preferred Alternative for the Dam's Operations, but Some Concerns Remain

Since December 1982, Reclamation has been studying the effects of the Glen Canyon Dam on various resources within the Glen and the Grand canyons. According to Reclamation, during this 14-year period, over $75 million was spent initially on the Glen Canyon Environmental Studies and then on the Glen Canyon Dam's EIS. This research and analysis was aimed at providing sufficient information to recommend an operating plan for the dam that would permit the recovery of downstream resources while maintaining some level of hydropower flexibility. Still, after all this time and money, the process of selecting a preferred alternative involved not only scientific evidence but also trade-offs and compromise. This occurred because no one alternative could maximize benefits to all resources and because the impacts of some of the flow alternatives remain uncertain. Nevertheless, over 83 percent of the key interested parties who responded to our survey support Reclamation's preferred alternative as a good starting point for the future operations of the Glen Canyon Dam. In addition, many respondents supported the process used to develop the Glen Canyon Dam's EIS. However, while expressing their support, some organizations still had concerns about the final EIS.

## Reclamation's Process for Selecting a Preferred Alternative

The selection of a preferred alternative for the future operation of the Glen Canyon Dam involved a repetitive sequence of comparisons of the effects that each of the nine flow alternatives would have on the 11 resources studied in the EIS. All resources were evaluated in terms of whether each flow alternative had a positive or an adverse effect. Reclamation's goal was to find an alternative dam-operating plan that would permit downstream resources to be maintained and if possible recover to acceptable long-term management levels while maintaining some flexibility in hydroelectric power capability. The EIS team, which included up to 25 individuals representing 11 of the cooperating agencies, the U.S. Geological Survey, and a private consultant, was primarily responsible for initially recommending a preferred alternative to the cooperating agencies. This team, which also had been responsible for the scientific and technical development of the resource impact determinations, realized very early in the process that they would have to make trade-offs in the selection of a preferred alternative. None of the alternatives could maximize potential benefits to all of the resources. The Grand Canyon Trust environmental organization told us that

"The Glen Canyon Dam EIS was a lengthy, complex process with many individuals and interests involved. It is safe to say that the preferred alternative will not completely satisfy any one group, however it represents a balance of interests and a reasonable starting point for future dam operations."

Another factor that the EIS team considered was that some affected resources were renewable, while others were viewed as nonrenewable. They avoided recommending an alternative dam-operating procedure that would result in significant loss of any existing nonrenewable resource and tried to minimize the adverse impacts to most renewable resources. They eliminated the No-Action, Maximum Powerplant Capacity, and High Fluctuating Flow alternatives from consideration as a preferred alternative because the data indicated that while these alternatives were beneficial to hydropower, they would either increase or maintain conditions that result in adverse impacts to nonrenewable downstream resources.

The EIS team also eliminated the Year-Round Steady Flow alternative from consideration as the preferred alternative. This alternative exhibited the highest probability for net gain in riverbed sand, had the largest potential for expanding riparian vegetation, and received the highest ranking among all alternatives for white-water boating safety benefits. However, the EIS team believed that the alternative probably exceeded sediment protection requirements for long-term management and would result in the lowest-elevation sandbars. The team was also concerned that a completely stable flow alternative would permit vegetation to adversely affect camping beaches and over time reduce the value of wildlife habitat. In addition, a stable flow may increase the negative interaction between native fish and predator and competitor nonnative fish. Finally, the team eliminated this alternative because they believed that it did not provide benefits that could not be provided by other alternatives, yet it would cause large adverse effects to hydroelectric power generation.

Of the remaining alternatives, the Existing Monthly Volume Steady Flow alternative was eliminated for reasons similar to those discussed for the Year-Round Steady Flow alternative. The Low Fluctuating Flow alternative was eliminated to reduce redundancy—Reclamation considered the Modified Low Fluctuating Flow alternative an improved version of the Low Fluctuating Flow alternative.

The EIS team considered the impacts associated with the three remaining alternatives (Moderate Fluctuating Flow, Modified Low Fluctuating Flow, and Seasonally Adjusted Steady Flow), although they were substantially different from the effect of the No-Action alternative, to be very similar in their assumed benefits to most downstream resources. Reclamation's former NEPA Manager for the Glen Canyon Dam's EIS advised us that from an ecosystem perspective, sediment was identified as the key resource in the selection of a preferred alternative. Riverbed sand and sandbars were the sediment resources of primary interest affected by riverflows below the dam. For sandbars to exist, sufficient amounts of sand must be stored on the riverbed. Because the dam traps 90 percent of the sediment, the sand supply is currently limited to whatever is contributed by downstream tributaries and hundreds of side canyons. Of equal concern is the river's capacity to transport sediment. Riverflows must be large enough to move and deposit sediment but not so large as to carry the sediment out of the canyon ecosystem. Frequent high flows, either from floods or large daily fluctuations, can transport greater amounts of sand than are contributed, causing a net decrease in both the amount of stored riverbed sand and the size of sandbars. Water release patterns modify the natural process of sandbar deposition and erosion. Rapid drops in the level of the river drain groundwater from sandbars, thus accelerating sandbar erosion. The EIS team concluded that any of these three alternatives were very similar in their assumed benefits to most downstream resources.

The effects on native fish did, however, vary among the three remaining alternatives. The Moderate Fluctuating Flow alternative provides potential minor benefits to native fish over no-action conditions. The benefits from the Seasonally Adjusted Steady Flow alternative were uncertain given the improvement in habitat conditions that this alternative would provide for predator and competitor nonnative fish. The team also determined that seasonally adjusted steady flows would create conditions significantly different from those under which the current aquatic ecosystem had developed since the construction of the dam. Finally, for hydropower, the team determined that the Seasonally Adjusted Steady Flow alternative would have the highest economic cost of any alternative, estimated at about $124 million annually. Ultimately, the EIS team decided to recommend the Modified Low Fluctuating Flow for the preferred alternative in the draft EIS. The members believed that this alternative would create conditions that permit the recovery of downstream resources to acceptable management levels while maintaining a level of hydroelectric power flexibility. The EIS team presented this recommendation to the cooperating agencies. Most cooperating agencies concurred, and the group recommended that this alternative be adopted by Reclamation. The draft EIS was issued by Reclamation in January 1994 with the Modified Low Fluctuating Flow identified as the preferred alternative.

After the draft EIS was provided for public comment but before the issuance of the final EIS, Reclamation changed two parameters of the preferred alternative. Specifically, the draft EIS' preferred alternative had a maximum release level of 20,000 cfs and a maximum upramp rate of 2,500 cfs per hour. In the final EIS, Reclamation modified the preferred alternative to provide a maximum release level of 25,000 cfs and a maximum upramp rate of 4,000 cfs per hour. The primary reason for these changes was to benefit hydropower. The preferred alternative presented in the draft EIS had the same maximum release rate and upramp rate as the interim operating criteria. Reclamation stated that the interim operating criteria were based on the results of phase I of the Glen Canyon Environmental Studies and professional judgment and were designed to be environmentally conservative over the interim period. With the benefit of the additional phase II results of the Glen Canyon Environmental Studies and EIS impact analyses, Reclamation stated that the upramp rate and maximum flow criteria were found to be overly conservative for the long term and that the two changes would not cause adverse impacts to downstream resources. As a result, with the concurrence of the cooperating agencies, the preferred alternative was modified in the final EIS.

In July 1995, Reclamation issued a document entitled Flow Modifications to the Glen Canyon Dam Environmental Impact Statement Preferred Alternative. Those who commented on that document expressed concern that no studies on the specific upramp and maximum flow criteria had been conducted. In October 1995, Reclamation issued a new report entitled Assessment of Changes to the Glen Canyon Dam Environmental Impact Statement Preferred Alternative from Draft to Final EIS. This report provided a more detailed and focused assessment of the impacts associated with the increased upramp rate and maximum flow criteria. While acknowledging that no new studies were conducted, Reclamation pointed out that the same was true for the parameters of the interim flows when they were selected and implemented. Furthermore, Reclamation stated it was possible to determine the effects of these changes by using the extensive amount of knowledge gained from both phase I and phase II of the Glen Canyon Environmental Studies. Reclamation concluded that the analyses were fully adequate to justify the change.

## Support for Preferred Alternative Is Significant

The respondents to our survey of key parties interested in the Glen Canyon Dam's EIS overwhelmingly supported Reclamation's preferred alternative—the Modified Low Fluctuating Flow operating regime. We surveyed 37 key organizations and individuals about whether they support the preferred alternative and what, if any, remaining concerns they may have about implementing this alternative as the future operating plan for the Glen Canyon Dam. Our judgmental sample included federal and state resource agencies, American Indian tribes, water and power suppliers and users, and environmental groups. Specifically, Reclamation identified 23 of these organizations and individuals as providing the most substantive comments on the draft EIS. We excluded David Marcus from our survey analysis because he had commented on the draft EIS as a consultant to American Rivers and preferred to provide us with his comments through that organization. In addition, we surveyed any other organizations that were considered to be cooperating agencies in the development of the impact statement as well as other key interested parties. We also queried the seven Colorado River Basin states: Arizona, California, Colorado, Nevada, New Mexico, Utah, and Wyoming.

Over 83 percent (25 of 30) of the respondents to our survey supported the preferred alternative. Of the five remaining respondents, three organizations stated that they had no position on the issue, while two, the San Juan Southern Paiute Tribe and the Grand Canyon River Guides, believe that the current interim flows would be more protective of resources and, as such, consistent with the intent of the Grand Canyon Protection Act. Table 3.1 provides details on whom we surveyed and their response, if any.

**Table 3.1: Key Interested Parties' Responses on Support of the Preferred Alternative**

| Respondents | Support preferred alternative | Other alternative supported |
|---|---|---|
| **Federal agencies** | | |
| U.S. Fish and Wildlife Service | Yes | Modified Low Fluctuating Flow as modified by the reasonable and prudent alternative |
| Environmental Protection Agency | Yes | None |
| National Park Service | Yes | None |
| Department of the Interior - Office of Environmental Policy and Compliance | No position | |
| Bureau of Indian Affairs | Yes | Interim Low Fluctuating Flow and Seasonally Adjusted Steady Flow |
| National Research Council | Nonrespondent | |
| Western Area Power Administration | Yes | None |
| **State agencies** | | |
| Arizona Game and Fish Department | Yes | None |
| Colorado River Board of California | No position | |
| Colorado River Commission of Nevada | Nonrespondent | |

(continued)

| Respondents | Support preferred alternative | Other alternative supported |
| --- | --- | --- |
| Arizona Department of Water Resources | Yes | None |
| New Mexico Interstate Stream Commission | Yes | Modified Low Fluctuating Flow as modified by adaptive management |
| Colorado Department of Natural Resources | No position | |
| Utah Division of Water Resources | Yes | None |
| Wyoming State Engineer's Office | Yes | None |
| **Indian tribes** | | |
| Hopi Tribe | Yes | None |
| Hualapai Tribe | Nonrespondent | |
| Navajo Nation | Yes | None |
| San Juan Southern Paiute Tribe | No | Interim Low Fluctuating Flow |
| Pueblo of Zuni | Yes | None |
| Southern Paiute Consortium | Yes | None |
| **Water and power suppliers, users, associations, etc.** | | |
| Colorado River Energy Distributors Association | Yes | None |
| Plains Electric Generation and Transmission Coop, Inc. | Nonrespondent | |
| Salt River Project | Yes | None |
| Upper Colorado River Commission | Yes | Modified Low Fluctuating Flow as modified by adaptive management |
| **Interest groups** | | |
| America Outdoors | Yes | Seasonally Adjusted Steady Flow |
| American Fisheries Society | Nonrespondent | |
| Arizona Flycasters | Nonrespondent | |
| American Rivers | Yes | None |
| Environmental Defense Fund | Yes | None |
| Trout Unlimited (Arizona Council) | Yes | None |
| Friends of the River | Nonrespondent | |
| Grand Canyon River Guides | No | Interim Low Fluctuating Flow |
| Grand Canyon Trust | Yes | None |
| Sierra Club Legal Defense Fund | Yes | None |
| Sierra Club | Yes | None |
| **Individual** | | |
| Dr. Larry Stevens | Yes | None |

## Respondents Also Support Reclamation's EIS Process

Many respondents to our survey supported the process used by Reclamation to complete the EIS. In fact, many respondents commended Reclamation for its efforts to produce a comprehensive EIS. For example, the National Park Service stated that the EIS process was directed very well by Reclamation and that alternatives for the operation of the dam were fully explored. American Rivers, an environmental interest group, stated that the EIS is a high-quality document that reflects a process that was exemplary in its scope, thoroughness, and overall achievement. The Grand Canyon Trust stated that the EIS represents a significant and productive effort to understand the complexities of the river's ecosystem below Glen Canyon Dam and to include broad participation by the public and parties vitally interested in the issue. They further stated that in addition to increasing the scientific understanding of the Colorado River system, a great deal of trust and good faith were created between traditionally contentious interest groups. The Navajo Nation stated that overall, they were very pleased with the EIS process, citing that Native American concerns were taken into account by Reclamation and that the affected tribes had real input into the development of the EIS.

## Several Concerns Remain About the Implementation of the Dam's New Operating Procedures

While respondents to our survey were generally positive about the selection of a preferred alternative and the process used by Reclamation to develop the EIS, some were still concerned about the preferred alternative and the Glen Canyon Dam's final environmental impact statement. These concerns focus on the manner in which compliance with the Endangered Species Act will be achieved, the economic impact of reducing the Glen Canyon Dam's hydroelectric power capacity, the lack of consideration in the EIS of other causes of downstream adverse impacts other than water releases from Glen Canyon Dam, the simultaneous changing of two of the dam's operating parameters very late in the EIS process, the adequacy of the flood frequency reduction measures, the need for selective withdrawal structures, and issues related to adaptive management, including future research and monitoring.

The U.S. Fish and Wildlife Service supports the preferred alternative as modified by its reasonable and prudent alternative. FWS's biological opinion expressed concern that the preferred alternative recommended flows would likely jeopardize the continued existence of two endangered species, the humpback chub and the razorback sucker. The biological opinion's reasonable and prudent alternative would modify the preferred alternative with seasonally adjusted steady flows about 25 percent of the time. FWS and Reclamation agreed to categorize these flows as experimental, or research flows, so that studies could be conducted to verify an effective dam-operating plan and to include those flows with another element of the reasonable and prudent alternative, adaptive management. However, there are concerns on the part of the Colorado River Energy Distributors Association, which represents over 140 nonprofit utilities that purchase power from the Western Area Power Administration (WAPA), that the implementation of endangered fish research flows will proceed regardless of the outcome of the Adaptive Management Program. The association strongly supports the EIS preferred alternative as a reasonable point to begin modified dam operations and adaptive management. However, the association also believes that an important part of the adaptive management process is that if an analysis of a research proposal indicates an inappropriate risk to the endangered fish or other resource, the Secretary could decide not to pursue this element of the preferred alternative. As such, the association objects to the language in the final EIS and the final biological opinion that indicates that the research flows will go forward regardless of the outcome of the adaptive management research design and risk assessment.

The Colorado River Energy Distributors Association and the Salt River Project, an agricultural improvement district that provides electrical service to various counties in the state of Arizona, are concerned that the economic cost of reducing the hydroelectric power capacity of the Glen Canyon Dam is understated in the EIS. Both the association and the Salt River Project believe that the preferred alternative does not adequately address the economic cost to power users of research flows. In addition, the Salt River Project believes that the EIS does not analyze the full economic impact of the preferred alternative on Salt River and its customers and on WAPA and its customers, resulting from WAPA's being unable to fulfill its obligations under an exchange agreement. The exchange agreement obligated Salt River to build and operate power generation facilities near customers in Colorado and New Mexico and to deliver the power produced by those facilities to WAPA to serve those customers. In exchange, WAPA was obligated to deliver a like amount of power to the Salt River Project from the Glen Canyon Dam.

WAPA stated that the EIS assumes that the dam's operations (water releases) are the only cause of the adverse impacts on the downstream resources and that, therefore, changing the dam's operations is the only technique or method available for managing and enhancing those resources. WAPA believes that other causes of downstream impacts include lack of sediment, cold water temperatures, nonnative fish species, and human usage. Accordingly, they believe that changing the operations at Glen Canyon Dam is not the only, or necessarily the best or lowest-cost, means of achieving positive resource changes. WAPA believes that a more holistic approach to the management of the downstream resources should be taken and supports the investigation of both operational and nonoperational management techniques, practices, and programs. Although WAPA supports the preferred alternative, it stated that the concepts of pumping sand, protecting beaches with native materials, augmenting sediment, managing vegetation, restricting human use, restricting raft moorings, reducing the competition for native fish, developing new tributary habitats for native fish, and using a reregulation dam (build another dam below the Glen Canyon Dam to regulate river flow) are all valid management techniques that merit detailed investigation and consideration.

Several environmental and recreational organizations, although supporting the preferred alternative, were concerned that Reclamation changed certain parameters of the preferred alternative very late in the EIS process. Specifically, the draft EIS' preferred alternative had a maximum release level of 20,000 cfs and a maximum rate of increase (upramp rate) of 2,500 cfs per hour. In the final EIS, Reclamation modified the preferred alternative to allow for a maximum release level of 25,000 cfs and a maximum upramp rate of 4,000 cfs per hour. Two basic concerns exist about this change: (1) the higher parameters were substituted in the final EIS without adequate scientific evidence that such flows would not negatively affect the downstream resources of the Glen and Grand canyons and (2) two parameters were changed simultaneously, which could compromise the ability to scientifically monitor and assess the future impacts of these flow parameters in the proposed adaptive management framework. Reclamation believes that it has adequately addressed both of these concerns by conducting an assessment of the proposed changes. Some agencies, including the Wyoming State Engineer's Office, America Outdoors, American Rivers, and the Sierra Club Legal Defense Fund still believe that adequate specific scientific testing was not done to fully evaluate the effect of changing these flow parameters. However, these groups still support the preferred alternative at this time because of Reclamation's proposed Adaptive Management Program.

The New Mexico Interstate Stream Commission believes that the spillway gates on the Glen Canyon Dam must be increased in height by about 4.5 feet to add the flexibility to accomplish flood protection without reducing the water supply available to the Upper Colorado Basin. The Commission, which supports the preferred alternative, also believes that the selective withdrawal outlet proposal for Glen Canyon Dam has not been adequately justified; the estimated cost of $60 million needs to be arrayed against the resulting benefits; and an assessment needs to be made of the potential adverse impacts associated with increasing water temperature.

Future monitoring and research efforts were a concern of several groups, including federal agencies, Native American tribes, and an environmental group. For example, American Rivers urged Reclamation to do everything in its power to ensure that an effective Adaptive Management Program be in place or sufficiently delineated in scope and substance and that a specific long-term monitoring program be identified that will quantify any impacts before the proposed flow changes are implemented.

# Air Quality

In the Glen Canyon Dam's environmental impact statement (EIS), air quality is identified as an issue for both the immediate vicinity of the Grand Canyon and the surrounding six-state area, including parts or all of Utah, Wyoming, Colorado, Arizona, New Mexico, and Nevada. The power needs of this area are served by the Salt Lake City Area Integrated Projects, a group of power generation facilities that include the Glen Canyon Dam. Although the Glen Canyon Dam's hydroelectric powerplant does not cause air pollution, a change in its operations would affect the regional electrical power system. The Glen Canyon Dam has historically been used to generate power during periods of high demand for electricity, commonly known as peaking power. The loss or reduction of that capability would mean that another source of peaking power would be required. If that alternative source of power used fossil fuel, there would be a net change in the power system's emissions. Fossil fuels contain hydrocarbons, whose combustion can result in emissions of such atmospheric pollutants as sulfur dioxide and nitrogen oxides.

Reclamation found that the region's air quality would improve under all restricted fluctuating and steady flow alternatives for operating the dam. Generally, this would occur because the sources of replacement power would produce less emissions than the sources of power used by the current Integrated Projects System. According to Reclamation and the EIS team member who was responsible for the air quality impact determination, the process used to come to this conclusion was appropriate, the data used were the best scientific information available at the time, and the results were reasonable.

## Description of the Resource

While the Grand Canyon region enjoys some of the cleanest air in the lower 48 states, the visual range is affected by haze. This haze is generally at its worse during the summer months. Air is carried into the Grand Canyon area from the south and west, where it picks up pollutants from urban and industrial areas. As a result, during the summer, the average visibility is only 100 miles, and it drops below 68 miles 10 percent of the time. Sulfates, which are produced from sulfur dioxide, are the major contributors to haze in the Grand Canyon. The Navajo Generating Station near Page, Arizona, has been identified as a major source of sulfates in the vicinity of the Grand Canyon.

During the winter, strong cold fronts bring in clean air from sparsely populated areas. The average visibility during these months is 158 miles, but it reaches more than 211 miles 10 percent of the time. Between the passages of cold fronts, however, the air stagnates, and pollution from local sources sinks into the canyon. The pollution can be trapped by strong inversions until another cold front again brings in clean air.

## Effects of Pre- and Postdam Conditions on Air Quality

Although power production at the Glen Canyon Dam has had no direct effect on air quality at the Grand Canyon or in the region, an analysis of the impacts on air quality was included in the EIS because the Glen Canyon hydroelectric facility is part of a regional utility system that has some sulfate-producing facilities. The region's air quality is affected by the operation of these interconnected powerplants. For example, the National Park Service identified the Navajo Generating Station as a major source of sulfates in the Grand Canyon's air. In response to the Park Service's findings, the Environmental Protection Agency mandated modifications to reduce the plant's emissions. Although the Navajo Generating Station is independent of the Glen Canyon Dam's operations and modifications will be made to it regardless of which EIS operating alternative is selected, the air quality in the Grand Canyon would likely improve because of the modifications.

The changes in the operations at the Glen Canyon Dam might indirectly affect the region's air quality by forcing reliance on other types of power-generating facilities. For example, if power generated in the marketing area served by the Salt Lake City Area Integrated Projects were changed from older existing powerplants to new, cleaner-burning facilities, there would be less emissions, all else being the same. Conversely, if the reductions in power production from hydroelectric plants are replaced with power from existing powerplants that burn coal, there would be an increase in the amount of sulfur dioxide and nitrogen oxide emissions in the region.

## Issue

The final EIS considers how the dam's operations affect other electricity-producing facilities in the area, including those that have impacts on air quality.

## Indicators

The resource indicators considered in the EIS were the amount of sulfates in the Grand Canyon's air and the tons of sulfur dioxide and nitrogen oxides in the region's air.

## Methodology Used to Make Impact Determination

Reclamation assigned the responsibility for the development of the air quality section of the EIS to a member of the National Park Service, who at the time was assigned to the Grand Canyon National Park. The impacts on the air quality in the Grand Canyon's immediate vicinity and across the region served by Salt Lake City Area Integrated Projects' power-marketing system were evaluated for each of the dam's operating alternatives. Reclamation used the same power-modeling data used to analyze hydropower impacts to determine the amount of sulfur dioxide and nitrogen oxide emissions that may occur under the dam's various operating scenarios. (See app. V of this report for details on Reclamation's hydropower analysis). For the final EIS, these studies indicate that the region's air quality will improve under the four restricted fluctuating and three steady flow alternatives. Because these emissions analyses included assumptions for long-term (50-year) power system expansion plans, some of the impacts are based on specific assumptions about power generation technology, demand for power, public attitudes, and political and economic climates.

In making the air quality impact determinations, Reclamation made a number of key assumptions. For example, the analysis assumes that any loss of power generation at the Glen Canyon Dam will be partly absorbed by currently available generation at other plants in the region. The analysis further assumes that, over time, gas combustion turbines will be added to the system to replace older, inefficient facilities. Because natural gas is a cleaner-burning energy source than coal, emissions will be reduced over the short term. However, as the demand for electric power increases in the future, new powerplants will be needed. These newer plants, it is assumed, will produce less emissions than the existing plants because existing clean air standards are more stringent than those in effect when the older plants were constructed. There would have to be a relaxing of current environmental laws and regulations to invalidate these assumptions.

The air quality impact analyses determined that any one of the steady or restricted fluctuating flow alternatives was acceptable. However, the EIS air quality team leader favors the preferred alternative because, in his opinion, it has the least detrimental impact when the entire ecosystem of the Glen and Grand canyons is considered.

## Effects of the Flow Alternatives on Air Quality

According to the final EIS, the amount of Glen Canyon Dam hydropower that would need to be replaced varies under each of the dam-operating alternatives in the EIS. The net effect on the region's air quality under each alternative would be a slight reduction in emissions. Under the No-Action alternative, it was anticipated that gas combustion turbines, which are cleaner burning than coal-burning systems, will soon be added to the regional power system to replace older and more inefficient coal facilities. These additions should reduce the system's emissions over the first 5 years of operation. The assumptions under the Maximum Powerplant Capacity alternative would be essentially the same as those under the No-Action alternative.

Under the restricted fluctuating and steady flow alternatives, the amount of electrical energy produced at the dam during the day would be reduced, whereas the amount of energy produced at night would increase. Under this scenario, as the demand for electrical energy increases, especially during daytime hours, additional powerplants would be needed sooner than under the No-Action alternative. These new powerplants would produce less emissions than older, less-efficient existing plants because of today's more stringent emissions standards and because some of these plants would burn natural gas.

## Assessment of Impact Determinations

During our review, we did not receive any negative comments about Reclamation's air quality impact determinations. However, the draft EIS generated 29 public comments related to concerns about air quality. The comments varied from observations and concerns about the analysis methods used, to the need for further details and support for some statements. For example, there was some concern that the EIS did not do a good job of identifying as speculative its projections of the potential developments in power generation technologies, future demand for power, public attitudes, and political and economic climates. Reclamation agrees that forecasts over a 50-year period are speculative, but it also believes that the results of the hydropower-modeling studies provide the best available information on the powerplants' impacts on air quality.

Another concern expressed was that the lost generating capacity at the Glen Canyon Dam would have to be replaced by the use of fossil-fueled powerplants or other sources that are more expensive, nonrenewable, and polluting. Reclamation told us that the hydropower studies, which looked at all affected utilities, concluded that there would be a decline in emissions under several alternatives, including the preferred alternative.

The individual who was responsible for the air quality section of the EIS told us that he believed that

- the process used in making the air quality impact determinations was reasonable,
- the methodologies employed in this process were adequate for the decision-making process, and
- the results of the analysis were reasonable.

However, he stated that he could not judge the overall quality of the data used in the analysis because it was proprietary and he did not have access.

## Scope and Methodology

To identify how Reclamation determined the impact of various flow alternatives on air quality, we reviewed the scientific studies and research materials that were used by Reclamation in making its impact determinations.

## Key Studies Identified

We identified the following studies as the primary scientific sources of the data included in the air quality section of the EIS:

- Electric Utility Financial and Production Cost Model (prepared by the Environmental Defense Fund).
- Material prepared by Mike Roluti, Bureau of Reclamation.
- Preliminary Research Findings - Glen Canyon Environmental Studies, by Duncan Patten and Dave Wegner, dated September 11, 1992.
- Stone and Webster Power Modeling Reports (prepared for the Western Area Power Administration).

In addition, to determine what, if any, concerns were expressed about the air quality analysis presented in the draft EIS, we reviewed the Bureau of Reclamation's Operation of Glen Canyon Dam Draft Environmental Impact Statement: Public Comments Analysis Report prepared by the Bear West Consulting Team for the Bureau of Reclamation. To determine other concerns that were expressed about air quality issues in the preparation of the EIS, we also reviewed the Final Analysis Report on Scoping Comments, Bureau of Reclamation, dated March 12-May 4, 1990, Bear West Consulting Team.

## Officials Interviewed

In order to assess the methodology used, how well it was implemented, the quality of the data used, and the reasonableness of the results of the air quality segment of the EIS, we obtained the views of Mr. Jerry Mitchell, the official responsible for developing the air quality impact determination.

We also spoke with members of the Power Resource Committee who performed the hydropower analysis, which was the basis for the air quality analysis. The names of these individuals and details on the hydropower analysis are contained in appendix V of this report.

# Cultural Resources

Cultural resources include archeological sites and Native American traditional cultural properties and resources. The affected area containing these sites and properties includes a 255-mile section of the Colorado River corridor within the Glen and the Grand canyons and lands adjacent to the Navajo Nation, the Havasupai and Hualapai Reservations, and the Lake Mead National Recreation Area. The tribes that have ancestral claims to the Grand Canyon and that continue to use the area today include the Havasupai, the Hopi, the Hualapai, the Navajo, the Southern Paiute, and the Zuni.

The Glen Canyon Dam changed the pattern of sediment deposition, erosion, and flooding through the Glen and Grand canyons. As a result, archeological sites that were once protected by sandbars and terraces have become increasingly exposed, making them vulnerable to erosion, deterioration, and ultimate destruction. While erosion will continue to occur under any operating alternative selected, some flow alternatives are more favorable for enhancing the long-term preservation of cultural resources than others.

According to representatives of Native American groups, the information used to analyze cultural resources issues was the best and most up to date available. In addition, many researchers and representatives of Indian tribes believe that Reclamation went beyond the requirements of the National Environmental Policy Act (NEPA) in preparing the cultural resource impact determination. Those involved in the process were also highly complimentary of Reclamation's efforts to include Native American tribes in making the impact determinations. As a result of the cooperation of all parties involved, the cultural resources team was able to reach a consensus on the impacts that various flow alternatives would have on the resources. Also, although not tasked to reach a consensus on a preferred alternative, the individual cultural resource team members each agreed on the Modified Low Fluctuating Flow alternative as the preferred dam operating regime.

## Description of the Resource

All natural resources are considered sacred by Indian tribes, and some resources are considered vital for the continuation of traditional cultural practices. The cultural resources in the EIS study area include prehistoric and historic archeological sites, traditional cultural properties, and other resources that are important to Native Americans in maintaining their cultural heritage, lifeways, and practices. A variety of archeological sites were identified—for example, pueblos (habitation sites of four or more contiguous rooms); storage sites (granaries or cists); sherd and lithic scatter (scatter or concentration of ceramic sherds and debris from making stone tools); rock art (pecked, incised, scratched, or painted designs, symbols, or figures on rock); and burial sites. Many of these sites were determined to be eligible for inclusion on the National Register of Historic Places.

Also, many properties and resources within the Colorado River corridor, despite not being archaeologically significant, are culturally significant to Native American beliefs and practices. The culturally significant sites include plant-gathering areas, landforms, springs, prayer-offering sites (shrines), and mineral deposits. Also significant to some Native American tribes are willows, giant reeds, and many birds, including yellow warblers and yellow throats.

## Effects of Pre- and Postdam Conditions on Cultural Resources

Until the mid-1980s, it was generally thought that cultural resources were not affected by the operation of the Glen Canyon Dam. The belief was that archeological remains would not be found below the historic high-water mark in the river corridor. This belief was based on two assumptions: (1) that prehistoric people were aware of the river's flood potential and would thus build above the floodplain and (2) that any cultural remains close to the river would have been washed away over the past thousands of years.

In 1989, the National Park Service and the U.S. Geological Survey conducted a pilot research project to evaluate erosion at archeological sites in the Grand Canyon. The project's results suggested that the operation of the Glen Canyon Dam contributed to ongoing site erosion. The dam affected sediment deposition, erosion, and flooding through the Glen and Grand canyons. As a result, river-deposited sandbars and high terraces (the surface form of a high sediment deposit having a relatively flat surface and a steep slope facing the river) have been eroded and, in some cases, destroyed. The archeological sites once protected by these sediment deposits have become increasingly exposed to erosion and ultimate destruction.

## Issue

The issue presented in the final EIS for cultural resources is how do the dam's operations affect the continued existence of cultural resources in the Glen and Grand canyons?

## Indicators

The indicators studied for cultural resources and listed in the final EIS were

- the number of archeological sites directly, indirectly, or potentially affected and
- the number of Native American traditional cultural properties and resources directly, indirectly, or potentially affected.

## Methodology Used to Make Impact Determinations

To provide baseline cultural resource information for inclusion in the Glen Canyon Dam's EIS, Reclamation contracted with the National Park Service to conduct an archeological inventory in August 1990. The inventory, which was conducted by staff from the National Park Service and Northern Arizona University, was completed in May 1991. The inventory gathered basic information on the numbers, types, locations, National Register eligibility, and physical conditions of all cultural resources within the area that have been or could be affected by the operations of the Glen Canyon Dam. The inventory identified 475 sites in the Colorado River corridor, 336 of which had been or could be affected by the existence and operation of the dam. The remaining 139 sites did not exhibit any effects from the dam's operations and were excluded from further study. The EIS summarized these impacts, as shown in table II.1.

**Table II.1: Glen Canyon Dam's Impacts on Archeological Sites**

| Type of impact | Number of sites |
|---|---|
| Direct—site erosion immediately caused by river flows | 33 |
| Indirect—sediment loss at the site or arroyo cutting near the site | 124 |
| Potential—loss of site due to catastrophic event such as unexpectedly high flows | 179 |

In addition to the 336 sites, many Native American cultural properties and resources, especially plant and animal species that depend on sandbars and high terraces, have been adversely affected by the flows from the Glen Canyon Dam. According to the cultural resource writing team leader, the information on cultural resources and properties was obtained from research conducted by the following Native American tribes: Hopi, Hualapai, Southern Paiutes, Navajo, and Zuni.

The National Historic Preservation Act requires that an impact determination be made when any action by a federal agency could affect sites included in or eligible for the National Register of Historic Places.

The process for such determinations is spelled out in 36 C.F.R. 800 and requires that a determination of "effect" or "no effect" be made. When there is an effect, a "finding of no adverse effect" or "finding of adverse effect" is required. Mitigating measures must be taken when there is a "finding of adverse effect."

Because dam-related impacts to archaeological sites would continue regardless of the alternative flow patterns, the operations of the Glen Canyon Dam were considered to have an adverse effect on cultural resources located on the terraces that have formed along the river corridor. However, the rate at which impacts would occur could be affected by alternative operations, principally through flood frequency reduction measures.

To assess the impacts of various alternatives on cultural resources, Reclamation established a cultural resource team. The team leader was an archeologist with the National Park Service. The team leader was primarily responsible for cultural resource analysis, including archeological and tribal issues and compliance with the National Historic Preservation Act. The team members included representatives of the Hualapai Tribe, the Navajo Nation, and the Hopi Tribe.

The team was asked to analyze the archeological data and cultural resource issues and determine how various flow alternatives for the dam affected these resources. The team was not required to arrive at one specific preferred alternative.

In addition, tribal representatives from other interested tribes would periodically attend various EIS meetings to discuss the cultural resources issues. The cultural resource information for tribes that did not have representation on the team was prepared for them by the cultural resource team.

## Effects of the Flow Alternatives on Cultural Resources

According to the final EIS, the dam's operations influence the rate at which archeological sites and cultural resources are affected. Flow alternatives that maintain the sand balance and allow for its distribution along the river corridor would enhance the long-term preservation of cultural resources. The most favorable operation alternatives are those which produce a positive net sand balance in the river system while maintaining a higher elevation of sand deposits. Of the nine alternatives, six (Moderate Fluctuating, Modified Low Fluctuating, Interim Low Fluctuating, Existing

Monthly Volume Steady, Seasonally Adjusted Steady, and Year-Round Steady flows) cause moderate impacts on the sites but nevertheless allow for a net positive sediment balance in the system and potential sediment redeposition in areas that would protect cultural resources. The No-Action and the Maximum Powerplant alternatives were shown to have major impacts affecting all of the archeological sites, and the High Fluctuating Flow alternative was found to have the potential to have major adverse impacts on 263 sites.

## Need for Continued Studies of Cultural Resources

The assessment of impacts on cultural resources will be an ongoing endeavor. The National Historic Preservation Act, as amended in 1992, requires federal agencies to develop measures to avoid or minimize the loss of historic properties resulting from their actions and recommends a long-term monitoring program to assess the changing conditions of cultural resources. In addition, long-term monitoring is required by the Grand Canyon Protection Act of 1992.

To comply with these requirements, Reclamation and the National Park Service developed a programmatic agreement for the continued monitoring of cultural resources and for the mitigation of the adverse effects of the dam on threatened cultural resources. The programmatic agreement stipulates that these long-term responsibilities will be outlined in a Historic Preservation Plan to be developed for cultural resources along the river corridor. The following are signatories to the programmatic agreement.

Advisory Council on Historic Preservation
Arizona State Historic Preservation Officer
Bureau of Reclamation
Hopi Tribe
Hualapai Tribe
Kaibab Paiute Tribe
National Park Service
Navajo Nation
Paiute Indian Tribe of Utah for the Shivwits Paiute Tribe
San Juan Southern Paiute Tribe
Zuni Pueblo

At the time of our review, the Havasupai Tribe was also expected to be a signatory to the programmatic agreement. The agreement was officially implemented in February 1994, and numerous river-monitoring trips, site-stabilization efforts, and periodic meetings among the signatories have already been held. The agreement calls for continued monitoring within the river corridor.

## Assessment of Impact Determinations

The cultural resource writing team members and several of the representatives from the cooperating agencies who were concerned about the cultural resource issues were complimentary of Reclamation's effort to solicit information from and include Native American tribes in the EIS process. There was a consensus that the data used to address the impacts on the cultural/archeological resources were the best and most up to date that were available.

Several comments commended Reclamation for conducting an open and well-researched and well-documented EIS process. For example, one commenter stated that Reclamation went beyond the requirements of NEPA by funding new research used to make impact determinations.

According to the leader and other members of the cultural resource team, there was consensus among the members on how to present cultural resource issues. The tribes also presented a unified position. A representative from the Bureau of Indian Affairs noted that he was not aware of any disagreement from any tribes about the EIS process. According to most representatives of the Native American groups we interviewed, the scientific data used in the archeological and cultural resource sections of the EIS were the most recent data available. Furthermore, many representatives stated that all relevant information available at the time was sought out and used and that the data presented in the EIS are factual and do not contradict historical tribal information or other known data. While most of the information used in the cultural resources section of the EIS was in draft form, no new or additional data have emerged that would change or contradict the information in the EIS.

The cultural resource team members, as well as most representatives from the Native American tribes, support the preferred alternative (the Modified Low Fluctuating Flow).

The cultural resources team leader's overall position was that

- the process used in making cultural resource impact determinations was reasonable,
- the methodologies employed in this process were appropriate,

- the data used were the best available, and
- new information that had been obtained at the time of our audit work did not alter the facts used in arriving at the impact determinations in the final EIS.

## Scope and Methodology

In addition to identifying how Reclamation determined the impact of various flow alternatives on cultural resources, we evaluated the scientific foundations, the study review process, the EIS work groups, and the impact determinations. We also gathered studies and research materials that were instrumental to Reclamation in making the EIS decisions.

## Key Studies Identified

We identified the following studies as the primary scientific foundations for the data included in the cultural resources section of the EIS:

- Big River Canyon: Southern Paiute Ethnographic Resource Inventory and Assessment for Colorado River Corridor, Glen Canyon National Recreation Area, Utah and Arizona, and Grand Canyon National Park, Arizona, June 1994, and Storied Rocks: Southern Paiute Rock Art in the Colorado River Corridor, September 1995. These reports were prepared by the Southern Paiute Consortium and the University of Arizona. According to the consortium, research data collected for the studies were used in preparing the EIS. The fieldwork for the ethnographic resource study began in July 1992. We did not obtain data on a peer review of the reports.
- The Grand Canyon River Corridor Survey Project: Archeological Survey Along the Colorado River Between Glen Canyon Dam and Separation Canyon prepared in cooperation with the Glen Canyon Environmental Studies Cooperative Agreement No. 9AA-40-07920. Although this study was not published until December 1994, research conducted for it was used in preparing the EIS. The researchers for the study included professional staff from the National Park Service and Northern Arizona University. The fieldwork commenced August 30, 1990, and was completed May 10, 1991. Peer review was performed by the Arizona State Historical Office, the University of Cincinnati, the University of Arizona, the National Park Service regional archeological staff in Denver and San Francisco, and affected Native American tribes.
- The River of Neverending Life: Navajo History and Cultural Resources of the Grand Canyon and the Colorado River. Navajo Nation Historic Preservation Department. August 9, 1995. A draft version of the report as well as basic research were used in preparing the EIS. The fieldwork for

this report was begun in May 1992. We did not obtain information on a peer review of the report.

- Surficial Geology, Geomorphology, and Erosion of Archaeologic Sites along the Colorado River, Eastern Grand Canyon, Grand Canyon National Park, Arizona. U.S. Geological Survey, Open-File Report 93-517, prepared in cooperation with the Bureau of Reclamation-Glen Canyon Environmental Studies. This report, released in 1993, acknowledges a number of individuals for critical review and comments.
- Zuni and the Grand Canyon: A Glen Canyon Environmental Studies Report, July 21, 1995, Zuni GCES Ethnohistorical Report prepared by the Institute of the North American West. The research data on which this report is based were used in the EIS. The research was initiated in 1993. We did not obtain information on a peer review of the report.

In addition to these studies, which dealt specifically with cultural resources, we examined other relevant documents to determine the significance of cultural resource concerns expressed or addressed prior to the preparation of the EIS. These other documents included the following:

- Final Analysis Report on Scoping Comments, prepared by Bear West Consulting Team, March 12-May 4, 1990, and
- Preliminary Research Findings, Glen Canyon Environmental Studies, presented to the Bureau of Reclamation and Western Area Power Administration in Denver by Duncan Patten and David Wegner, September 11, 1992.

## Officials Interviewed

To assess the procedures followed and obtain views on the quality of the data used in preparing the cultural resource issues, we interviewed the four members of the cultural resource writing team. We asked the team leader for the cultural resources workgroup to review our description of the resource impact determination process for factual accuracy. She agreed that the information presented is a good summary of the process, methodology, and scientific basis used to determine the impacts on the cultural resources from the Glen Canyon Dam's operations. We also contacted representatives of several cooperating agencies, primarily Native American tribes, to obtain their perspectives on and concerns about the archeological/cultural resources addressed in the EIS. The following officials were contacted.

Roger Anyon, Pueblo of Zuni
Janet Balsom, National Park Service - Grand Canyon

Clay Bravo, Hualapai Tribe
Angelita Bulletts, Southern Paiute Consortium
Gary Cantley, Bureau of Indian Affairs
Kurt Dongoske, Hopi Tribe
Alan Downer, Navajo Nation
Loretta Jackson, Hualapai Tribe
Leigh Jenkins, Hopi Tribe
Signa Larralde, Bureau of Reclamation
Johnny Lehi, San Juan Southern Paiute Tribe
Alexa Roberts, Navajo Nation
John Thomas, Navajo Nation
Michael Yeats, Hopi Tribe

Also, members of the following cooperating agencies were involved in the analysis and development of the cultural resource issues addressed in the EIS: Bureau of Indian Affairs, National Park Service, Hopi Tribe, Hualapai Tribe, Navajo Nation, Pueblo of Zuni, San Juan Southern Paiute Tribe, and Southern Paiute Consortium.

# Endangered Species

The historic operations of the Glen Canyon Dam have negatively affected some wildlife resources while enhancing others. Among the wildlife that inhabit the Glen and Grand canyon river corridor, there are seven nonfish endangered species.[6] The impacts of the various flow alternatives on these endangered species are mostly indirect and were analyzed through linkages to other resources, such as fish and vegetation. The U.S. Fish and Wildlife Service (FWS) determined that the proposed operation of the Glen Canyon Dam under the Modified Low Fluctuating Flow preferred alternative, is not likely to jeopardize the continued existence of the bald eagle, Kanab ambersnail, or peregrine falcon. The FWS addressed only species that were listed as endangered by the federal government. When the final EIS was issued, the southwestern willow flycatcher was only a candidate for listing. It has subsequently been listed as an endangered species. In addition, the bald eagle has been reclassified from endangered to threatened. The belted kingfisher, osprey, and southwestern river otter are Arizona species of concern. Therefore, they were addressed in the EIS but not by the FWS. In general, nonfish endangered species issues were not controversial in the preparation of the Glen Canyon Dam's EIS, and few concerns exist about the process used or the data relied upon for making the endangered species impact determinations.

## Description of the Resource

Wildlife is diverse and abundant along the river corridor through the Glen and the Grand canyons. Riparian (near water) vegetation, which developed along the river after the construction of the Glen Canyon Dam, plays an important role as habitat to support this diversity and abundance. The variety of animals present in the river corridor, their habitats, and how they use their habitats form a complex system that is difficult to evaluate in detail. However, like other resources, this system is linked to the river and ultimately to the operations of the Glen Canyon Dam.

Both aquatic and terrestrial endangered species occupy or use the river corridor. The seven nonfish endangered species considered in this appendix include five birds, one terrestrial snail, and one mammal now presumed extinct. Specifically, these species are the bald eagle, peregrine falcon, southwestern willow flycatcher, belted kingfisher, osprey, Kanab ambersnail, and southwestern river otter. A brief description of each of these species follows.

[6]In this appendix, the term "endangered species" is used for all special-status species addressed in the final EIS, including endangered species, candidate species, and Arizona species of concern. In the final EIS, Reclamation revised the fish section to include the discussion of endangered fish species. This appendix follows the same approach. That is, only nonfish endangered species are discussed in this appendix. Endangered fish species are discussed in app. IV.

## Bald Eagle

The bald eagle was listed as endangered in 1978 but has since been reclassified as threatened. The Colorado River corridor through the 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 those of the Colorado River before the construction of the Glen Canyon Dam, they were not often observed in the Grand Canyon until after the rainbow trout fishery was established.

The bald eagle's use of the river corridor is opportunistic and currently concentrated around Nankoweap Creek, where they use winter-spawning trout as a food source. The 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 Little Colorado River and occur around Lake Powell.

## Peregrine Falcon

Peregrine falcons were listed as endangered in 1970 but have generally increased nationwide since the prohibition on the use of certain pesticides. The Grand Canyon and the surrounding areas support the largest known breeding population of peregrine falcons in the contiguous United States. The birds using the Grand Canyon appear to be part of an increasing peregrine falcon population on the Colorado Plateau.

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 abundance of birds and bats. These 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 refute or confirm the above relationships, and no data are available on the activities of peregrine falcons in the Grand Canyon before the construction of the Glen Canyon Dam.

## Southwestern Willow Flycatcher

The southwestern willow flycatcher is a riparian bird found in Arizona, New Mexico, and southern California. At the time the final EIS was released, this species was a candidate for listing. It has since been listed as an endangered species.

Southwestern willow flycatchers have always occupied the river corridor. Nesting pairs of this species increased in the Grand Canyon following the completion of the Glen Canyon Dam. Researchers attribute this response to increases in riparian vegetation following reduced flood discharges. However, a 1991 survey found only two pairs of nesting birds. The most probable reason for this apparent decline is the brown-headed cowbird. These birds lay their eggs in other species' nests, usually at the expense of their hosts' young.

One researcher speculated that a possible reason for the decline in the numbers of this species is habitat fragmentation caused by floods and fluctuating river flows. Fluctuating flows contribute to the erosion of terrestrial habitats, resulting in a decrease in the size of contiguous vegetation patches. However, the required patch size for nesting southwestern willow flycatchers is not known. Although the southwestern willow flycatcher has traditionally been associated with willows and other native vegetation, all of the nests located in the Grand Canyon have been located in tamarisk, even though native vegetation was available.

## Belted Kingfisher

The belted kingfisher is considered a candidate species for listing by the state of Arizona. This bird is found in low numbers year-round in the Grand Canyon and its tributaries. This species is restricted to habitats with permanent, fish-inhabited waters.

## Osprey

The osprey is a fall, spring, or accidental transient in the Grand Canyon and is listed by the state of Arizona as a "state threatened" bird species. Osprey are primarily found in coniferous forests around lakes, and it is assumed that they use the river as a travel lane to other habitat.

## Kanab Ambersnail

Only three populations of this snail are known to exist—two near Kanab, Utah, and one in the Grand Canyon. Since the listing of this species as endangered in 1992, one of the Utah populations is now believed to be extirpated (extinct in that area). The Grand Canyon population was discovered in 1991 by researchers surveying mollusks in conjunction with the Glen Canyon Environmental Studies program.

Although officially a terrestrial animal, the Kanab ambersnail is really an amphibious creature found in wet or moist environments, such as marshes and seeps located at the bases of sandstone cliffs. Vegetation cover is necessary for this mollusk. The vegetation in the Grand Canyon associated with the Kanab ambersnail is the cardinal monkey flower and water cress. The availability of the cardinal monkey flower and other vegetation near the river in the Grand Canyon, as well as the presence of rock ledges, influence the distribution of the Kanab ambersnail. Since the implementation of the interim flows for the Glen Canyon Dam in 1991, the Kanab ambersnail's habitat has become available at lower elevations, closer to the river.

### Southwestern River Otter

The southwestern river otter is considered an endangered species by the state of Arizona. River otters have always been considered rare in the Grand Canyon; the last sighting was reported in 1983. Unconfirmed reports of their presence continue to be received from several localities, but extensive surveys have not resulted in sightings. The species is generally believed to be extinct.

## Effects of Pre- and Postdam Conditions on Endangered Species

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. The interruption in riverflow and the regulated releases of lake water now support aquatic and terrestrial systems that did not exist before the Glen Canyon Dam. The historic operations of the dam negatively affected some wildlife resources while enhancing others. The impacts of the dam's operations on the various endangered species also vary.

## Issue

As defined in the final EIS, the issue for endangered species is how do dam operations affect the populations of endangered and other special-status species throughout the Glen and the Grand canyons?

## Indicators

Because the seven nonfish endangered species that inhabit the river corridor occupy diverse niches in the Grand Canyon ecosystem, no single resource could be used as an indicator of impacts for endangered species as a whole. Therefore, the EIS team utilized an analytical approach which considered linkages among resources. The team identified the following indicators for individual species:

- for the bald eagle: trout and the aquatic food base;
- for the belted kingfisher: the aquatic food base;
- for the southwestern willow flycatcher: the area of woody plants; and
- for the Kanab ambersnail: maximum river flow.

## Methodology Used to Make Impact Determinations

EIS team members told us that the EIS was developed through a dynamic process involving three main groups—the EIS team, Glen Canyon Environmental Studies officials and researchers, and representatives of the cooperating agencies. The EIS team was responsible for the technical development of alternatives and impact determinations, while the cooperating agency group was a policy-level review body.

The nonfish endangered species impacts and issues were primarily developed by two EIS team members assigned to that task on the basis of their areas of expertise. Unlike the groups formed to address economic issues, no formal endangered species workgroup existed and no formal reports were produced.

These two team members developed their sections of the EIS through an iterative process of drafting, discussions, and formal and informal presentations to, and review by, the EIS team, as well as through input from key researchers and colleagues with whom they shared their work and from whom they solicited feedback. Additionally, the team members presented impact assessments to the cooperating agency group.

Decisions on endangered species issues were handled through voting; the goal was to obtain consensus on the results of the work. The formal minutes of the EIS team meetings were kept as a record of key decisions.

Reclamation received approximately 33,000 public comments on the draft EIS, 1,826 of which related to endangered species. However, only 31 comments specifically focused on nonfish endangered species. On the basis of new scientific information, the public comments, and the comments received from internal reviews, the EIS team as a whole made changes to the endangered species section of the EIS. These changes included the addition of a new indicator for the impact analysis related to the Kanab ambersnail, changes to the text, and modifications to the endangered species impact matrix. Both minor and major changes were made. An example of a minor modification is the change of status in the matrix for the southwestern river otter from presumed "extirpated" to presumed "extinct." A more major addition/modification pertains to the inclusion of updated information on, and an expanded treatment of, the Kanab ambersnail in the final EIS.

According to the principal author of the revised endangered species section, new information received after the release of the draft EIS indicated that the Kanab ambersnail responded to interim flows at the dam by moving into lower elevations than it had inhabited under the dam's historic operations. Kanab ambersnails residing in these locations would be affected by flows higher than 20,000 cubic feet per second (cfs) and the associated habitat maintenance and beach/habitat-building flows.

Because this population survived the 1983-86 floodflows of about 90,000 cfs, the EIS team assumed that infrequent flows of about 45,000 cfs would not jeopardize the continued existence of the population. However, some unavoidable mortality, or "incidental take," would occur. As a result of this information, changes were made to the discussion in the text of the Kanab ambersnail, and the impact determinations in the associated matrix were modified from "no effect" to "some incidental take."

### Data Used for Making Impact Determinations

The research studies used to support the impact determinations on endangered species are listed in the final EIS bibliography. Because of linkages to the fish and vegetation resource areas, the studies done in these fields are pertinent to endangered species. The studies include Glen Canyon Environmental Studies phase I and phase II research, as well as research developed by various state and federal agencies involved in endangered species work. Those studies deemed most useful by a key member of the EIS team who worked on endangered species issues are noted later in this appendix.

## Effects of Flow Alternatives on Endangered Species

Details of the anticipated impacts of the nine flow alternatives on endangered species are found in the final EIS. However, the following general statements can be made about these impacts:

- The Kanab ambersnail is the only species expected to be adversely affected by any of the flow alternatives. Some mortality, or "incidental take," would occur under all alternatives, although the continued existence of the population would not be jeopardized.
- Three species will be unaffected by changes in the dam's operations—the peregrine falcon, the osprey, and the southwestern river otter (which is presumed extinct).
- Habitat conditions for the bald eagle and belted kingfisher would remain stable or potentially improve under all alternatives.
- The southwestern willow flycatcher would experience an "undetermined increase" in habitat under all alternatives except the No-Action and Maximum Powerplant Capacity alternatives.

## U.S. Fish and Wildlife Service's Final Biological Opinion

The U.S. Fish and Wildlife Service's 1994 final biological opinion found that the proposed operation of the Glen Canyon Dam under the preferred alternative is not likely to jeopardize the continued existence of the bald eagle, the peregrine falcon, or the Kanab ambersnail. Few of the researchers and EIS team members we spoke with commented on the biological opinion as it related to nonfish endangered species. When asked about this, two EIS team members said that the "no jeopardy" finding was key to the lack of controversy on endangered species issues in team discussions. Another EIS team member added that the no jeopardy finding probably did allow the team to target their discussions and efforts on those endangered fish which had a jeopardy finding. Still, another team member told us that the team was not surprised by FWS' no jeopardy finding and knew even before the opinion was released that fish would be the primary concern.

## Assessment of Impact Determinations

Nonfish endangered species were not a controversial issue in the preparation of the Glen Canyon Dam's EIS. This is particularly true in comparison to fish, which generated a great deal of controversy and difference of opinion. When asked to comment on "endangered species," most researchers we spoke with talked only about endangered fish.

Several EIS team members pointed to the indirect impacts of the dam's operations on most endangered species as a key reason for this lack of controversy. A few EIS team members noted that nonfish species represent only a small percentage of the endangered species in the canyon and that concern about nonfish species was low compared to fish because of these small populations. One EIS team member used as an example of this the fact that only two nesting pairs of southwestern willow flycatchers are in the affected area. However, another EIS team member disputed the view that the smaller numbers of endangered species made them less controversial. This individual stressed that the smaller numbers actually made it even more crucial that these species be protected and taken very seriously in the EIS process. One researcher noted that there is a long history of fish research in the canyon but that there is no such research history for other species. This individual said that of the nonfish endangered species, most interest focused on the Kanab ambersnail and the southwestern willow flycatcher. Another researcher simply stated that "the fish drive the system" in the canyon and are more politically important than the other species. Furthermore, he said that the connection between fish and the dam's operations can be easily seen, while this connection is harder to see with terrestrial species.

## Reasonableness of the Methodology

Few concerns exist among the experts we interviewed about the process used in making the endangered species impact determinations. Most EIS team members we interviewed were satisfied with the process of analyzing the linkages among resources in determining impacts. However, one EIS team member noted that analyzing linkages was only one way to look at impacts on endangered species. The member noted that while analyzing linkages was an acceptable and reasonable approach, it was not necessarily the best or the worst way to proceed.

EIS team members acknowledged that because some linkages were quite indirect, professional judgment was important in this process. They stressed, however, that professional judgment was supported by the best available data.

One researcher expressed some dissatisfaction with this process. This individual said that, on the basis of his experience in the canyon observing the connections among bird species and other terrestrial resources, the connections are more direct than they were represented in the final EIS. He felt that although the team claimed to have looked at linkages, they did not do as thorough a job as they say and looked more at the impacts that could be directly ascribed.

## Opinions on Data Used for Impact Determinations

Individuals we interviewed had few concerns about the data used in making the impact determinations for nonfish endangered species. One EIS team member told us that with the possible exception of the Kanab ambersnail and the southwestern willow flycatcher, endangered species were not controversial in terms of the data or the process used in making the impact determinations. In fact, one researcher with whom we spoke characterized the terrestrial and bird-related research used as a basis for these determinations as “top notch.” Nevertheless, one EIS team member said that the data used for endangered species were even less solid than they were for fish.

A researcher who was also a member of the EIS team told us that while professional judgment played a role in their decision-making, the team worked hard to collect all of the information available. This person said that when necessary, to fill in data gaps, the team contacted researchers directly and asked them to provide information in the form of written communications that could then be cited as documentation.

Another member of the EIS team told us that, in his opinion, the data on the bald eagle were "adequate," data on the southwestern willow flycatcher were "on the cusp," and much of the new data on the Kanab ambersnail became available only after the EIS process was substantially complete. This individual went on to say, however, that the data available to the team on most species provided adequate information to make informed decisions. He stressed that complete information is never available in the process of scientific decision-making.

### Response to the Issues Raised

The principal author of the endangered species section of the final EIS provided us with detailed comments on and responses to each of the issues noted above. He agreed with some statements or positions and disagreed with others. For example, he disagreed that the data available on which to base impact determinations were less solid than those for fish. He noted that because impacts based on linkages are difficult to quantify, they can give the impression that they are less solid. However, he stressed that linkages are a legitimate and useful scientific approach and that they yield useful information. Moreover, he agreed that the data available on the various species produced reasonable results that were adequate for informed decision-making.

## Scope and Methodology

To determine the data and process used in developing endangered species issues, we identified and reviewed the following documents: the draft EIS and associated appendixes; the preliminary final EIS; the final EIS; public comments on the draft EIS; Reclamation's analysis of and the EIS team's responses to these comments; copies of the minutes of the EIS team meetings; summaries of the meetings of the cooperating agencies; and Reclamation's newsletters on the EIS process. We also obtained and reviewed FWS' draft biological opinion and final biological opinion on the operation of Glen Canyon Dam, Reclamation's comments on the draft biological opinion and official response to the final biological opinion, and FWS' Fish and Wildlife Coordination Act report. (See below for a list of related documents and full citations.)

We obtained a copy of the final EIS bibliography from Reclamation, with titles sorted by each resource area. The endangered species bibliography contains 29 titles; however, most of these titles relate to endangered fish. The wildlife and habitat bibliography also contains 29 titles, several of which specifically relate to nonfish endangered species. We asked the EIS team member recommended to us, as a key initial contact on nonfish endangered species issues, to identify those studies which had been the most useful in developing the impact determinations. This individual was also one of the two individuals primarily responsible for writing the endangered species section of the final EIS.

To assess the procedures followed and obtain views on the quality of the data used in preparing the endangered species impact determinations, we interviewed the EIS team members who had primary responsibility for writing this section of the draft EIS, as well as several other members of the EIS team. We spoke with several scientists identified by team members and others as having done key research used by the team in developing the endangered species section of the EIS. We also interviewed other agency officials with information on the EIS and the Glen Canyon Environmental Studies processes.

Finally, we asked the principal author to review our description of the endangered species impact determination process for factual accuracy. He agreed that our description was generally accurate but made some suggestions for changes. We have incorporated these changes into our description of the process. We also presented him with our preliminary findings on endangered species in order to provide him an opportunity to comment on and respond to the various issues raised through our audit work. He generally agreed with the facts as presented.

## Key Studies Identified

The following are key titles selected from the endangered species bibliography not related to fish.

"Biological Opinion of the Effects of Glen Canyon Dam on the Colorado River as It Affects Endangered Species." Memorandum from Regional Director, U.S. Fish and Wildlife Service, Albuquerque, New Mexico, to Acting Regional Director Harl Noble, Bureau of Reclamation. Salt Lake City, Utah: U.S. Fish and Wildlife Service, 1978.

Clarke, A.H., "Kanab Amber Snail—Oxyloma Haydeni Kanabinsis, Pilsbry, 1948," Status Survey of Selected Land and Freshwater Gastropods in Utah. Denver, Colorado: Prepared by Ecosearch, Inc., Portland, Texas, for the U.S. Fish and Wildlife Service, 1991, pp. 23-36.

Handbook of Federally Endangered, Threatened, and Candidate Plants of Arizona, S. Rutman, compiler. Phoenix, Arizona: U.S. Fish and Wildlife Service, 1990a.

Influences of Glen Canyon Dam Fluctuating Flows on Spawning Rainbow Trout and Wintering Bald Eagles, With Observations on the Effects of Human-Bald Eagle Interactions on the Colorado River in Grand Canyon National Park. Final Report from Northern Arizona University to Grand Canyon National Park, National Park Service, 1992.

Unitt, P. "Empidonax Traillii Extimus: An Endangered Species," Western Birds, Vol. 18, No. 3, pp. 137-162, 1987.

The following titles were selected from the wildlife and habitat bibliography related to nonfish endangered species.

Brown, B.T. Abundance, Distribution, and Ecology of Nesting Peregrine Falcons in Grand Canyon National Park, Arizona. Final report submitted to Grand Canyon National Park, Grand Canyon, Arizona, 1991b.

Brown, B.T. "Monitoring Bird Population Densities Along the Colorado River in Grand Canyon," Glen Canyon Environmental Studies Technical Report. Salt Lake City, Utah: Bureau of Reclamation, 1987.

Brown, B.T. "Status of Nesting Willow Flycatchers Along the Colorado River From Glen Canyon Dam to Cardenas Creek, Arizona," Endangered Species Report No. 20. Phoenix, Arizona: U.S. Fish and Wildlife Service, 1991a.

Brown, B.T., and R.R. Johnson. "The Effects of Fluctuating Flows on Breeding Birds," Glen Canyon Environmental Studies Executive Summaries of Technical Reports. Salt Lake City, Utah: Bureau of Reclamation, 1988.

Brown, B.T., and W.C. Leibfried. "The Effect of Fluctuating Flows from Glen Canyon Dam on Bald Eagles and Rainbow Trout at Nankoweap Creek in Grand Canyon National Park, Arizona," Glen Canyon Environmental Studies Phase II Draft Integrated Research Plan, Vol. 2. Salt Lake City, Utah: Bureau of Reclamation, 1990.

Brown, B.T., R. Mesta, L.E. Stevens, and J. Weisheit. "Changes in Winter Distribution of Bald Eagles Along the Colorado River in Grand Canyon, Arizona," Journal of Raptor Research, Vol. 23, No. 3, pp. 110-113, 1989.

Brown, B.T., G.S. Mills, R.L. Glinski, and S.W. Hoffman. "Density of Nesting Peregrine Falcons in Grand Canyon National Park, Arizona," Southwestern Naturalist, Vol. 37, No. 2, pp. 188-193, 1992.

Brown, B.T., and L.E. Stevens. Written communication, National Park Service, 1991.

Brown, B.T., and M.W. Trosset. "Nesting Habitat Relationships of Riparian Birds Along the Colorado River in Grand Canyon, Arizona," Southwestern Naturalist, Vol. 34, No. 2, pp. 20-270, 1989.

Spamer, E.E., and A.E. Bogan. "Mollusca of the Grand Canyon and Vicinity, Arizona: New and Revised Data on Diversity and Distributions, With Notes on Pleistocene-Holocene Mollusks of the Grand Canyon," Proceedings of the Academy of Natural Sciences in Philadelphia, Vol. 144, pp. 21-68, 1993.

Threatened Native Wildlife in Arizona. Phoenix, Arizona: Arizona Game and Fish Department, 1988.

In addition to the studies identified above from the final EIS bibliography, other documents are relevant to endangered species issues.

Carothers, S.W., and B.T. Brown. The Colorado River Through Grand Canyon: Natural History and Human Change. Tucson, Arizona: University of Arizona Press, 1991. The coauthors of this book were both key researchers identified in our work. Furthermore, Dr. Carothers was a member of the EIS team and the Aquatic Biology Team workgroup. Portions of this book address fish and endangered species issues, drawing from Glen Canyon Environmental Studies research.

Final Biological Opinion: Operation of Glen Canyon Dam as the Modified Low Fluctuating Flow Alternative of the Final Environmental Impact Statement, Operation of Glen Canyon Dam. (2-21-93-F-167) U.S. Fish and Wildlife Service, Dec. 21, 1994. The Final Biological Opinion and its related Reasonable and Prudent Alternative were developed by FWS in response to Reclamation's request for formal consultation under section 7 of the Endangered Species Act. The Final Biological Opinion states that the Modified Low Fluctuating Flow preferred alternative is likely to jeopardize the continued existence of the humpback chub and razorback sucker but is not likely to jeopardize the bald eagle, peregrine falcon, or Kanab ambersnail.

Glen Canyon Dam: Beach/Habitat-Building Test Flow, Final Environmental Assessment and Finding of No Significant Impact, Bureau of Reclamation, Feb. 1996. This report presents the findings of the required environmental assessment prepared prior to implementing the spring 1996 "spike" flow.

Operation of Glen Canyon Dam - Fish and Wildlife Coordination Act Report, U.S. Fish and Wildlife Service, June 28, 1994. In accordance with the Fish and Wildlife Coordination Act, FWS submitted this report to Reclamation with recommendations in connection with the Glen Canyon Dam's operations. The act does not require Reclamation to accept the recommendations; however, reasonable and practicable recommendations will be implemented. The act ensures that fish and wildlife receive equal consideration during the planning and construction of federal water projects.

"Organisms and Biological Processes," River Resource Management in the Grand Canyon, pp. 84-117. National Research Council, Committee to Review the Glen Canyon Environmental Studies, 1996. This is a chapter of a National Research Council committee report on the Glen Canyon Environmental Studies. The purpose of this report and the committee's task was to review research that was done in connection with the Glen Canyon Environmental Studies and to comment on the application of science in the management program of the Colorado River.

"Response to the Final Biological Opinion on the Operations of Glen Canyon Dam," Bureau of Reclamation, Apr. 6, 1995. This is Reclamation's official response to, and addressing of, the issues presented in the Final Biological Opinion. In its response, Reclamation states that it does not agree with all the points made or positions taken by FWS but will take steps to comply with them.

## Officials Interviewed

We interviewed the following individuals about endangered species and other related Glen Canyon Dam EIS issues.

Michael Armbruster, Bureau of Reclamation, principal author of the endangered species section of the EIS
Frank Baucom, U.S. Fish and Wildlife Service
Debra Bills, U.S. Fish and Wildlife Service
Byran Brown, SWCA, Inc.
Christine Karas, Bureau of Reclamation
Dennis Kubly, Arizona Game and Fish Department

William Leibfried, SWCA, Inc./Hualapai Tribe
Gordon Lind, Bureau of Reclamation
Margaret Matter, Western Area Power Administration
Debra McGuinn-Robbins, Arizona Game and Fish Department
Anthony Morton, Western Area Power Administration
Ronald Moulton, Western Area Power Administration
S. Clayton Palmer, Western Area Power Administration
Timothy Randle, Bureau of Reclamation
Lawrence Riley, Arizona Game and Fish Department
David Wegner, Bureau of Reclamation, Glen Canyon Environmental Studies

# Fish

The construction of the Glen Canyon Dam altered the natural dynamics of the Colorado River, including the downstream aquatic system. The predam aquatic system supported an array of native and nonnative fish. The decline of the native fish in the Glen and Grand canyons is attributed to the presence of nonnative competitors and predators and to subsequent postdam river conditions that affected habitat and redefined the relationship between native and nonnative fishes. Scientific opinions differ about the potential impacts on fish resources of the flow alternatives addressed in the Glen Canyon Dam environmental impact statement.

The U.S. Fish and Wildlife Service's (FWS) final biological opinion expressed concern that the Modified Low Fluctuating Flow, the EIS's preferred alternative, would jeopardize the continued existence of two endangered fish species, the humpback chub and the razorback sucker. The biological opinion's reasonable and prudent alternative identified actions that would modify the preferred alternative with seasonally adjusted steady flows about 25 percent of the time. FWS and Reclamation agreed to categorize these flows as experimental, or research, flows so that studies could be conducted to verify an effective dam flow regime and to include those flows with another element of the reasonable and prudent alternative, "adaptive management." Reclamation intends to initiate a process of adaptive management that would provide for long-term monitoring and research to measure the actual effect of the selected dam-operating criteria. The results of this effort would form the basis for possible future modifications of the dam's operations and, with other conservation measures, may lead to the removal of the jeopardy opinion.

EIS team members and resource scientists express a variety of opinions about the process and data used in making the impact determinations for fish. Because of incomplete information, as stated in the final EIS, the impact of steady flows on fish is still uncertain.

## Description of the Resource

Several elements comprise the aquatic ecosystem downstream of the Glen Canyon Dam. These elements include the aquatic food base, native fishes, and nonnative fishes. Nonnative fishes include warmwater, coolwater, and coldwater species. Due to the very limited data collected before the construction of the dam, the predam distribution and relative abundance of native and nonnative fish are largely unknown and subject to speculation.

In general, the ability of fish populations to persist and thrive depends on how well their life requirements are met. Life requirements include food supply, habitat, and the ability to avoid or minimize competition and predation.

Before the dam was closed, the aquatic food base for fish was founded on coarse organic material carried into the river from the drainage basin. Today, this coarse material is trapped above the dam in Lake Powell. Algae in the river (especially the filamentous green alga Cladophora glomerata) has now become an important part of the aquatic food base, along with associated diatoms (microscopic, single-celled, or colonial algae) and invertebrates (especially insects and the amphipod Gammarus lacustris).

The predam aquatic ecosystem contained eight native fish species and several introduced species such as the channel catfish and the carp. The eight native species were the humpback chub, razorback sucker, Colorado squawfish, bonytail chub, roundtail chub, flannelmouth sucker, bluehead sucker, and speckled dace. The Colorado squawfish, the roundtail chub, and the bonytail chub are considered extirpated (i.e., extinct in a given area) from the Grand Canyon, and the razorback sucker is very rare. The population of humpback chub in the Grand Canyon is the largest of five remaining populations and the only population of the species in the Lower Colorado River Basin.

Warmwater nonnative fish species began to be introduced into the river system possibly as early as the late 1800s. About the time that the dam was completed, warmwater nonnative fish found near the dam site included channel catfish, carp, fathead minnow, green sunfish, killifish, largemouth bass, mosquito fish, and red shiner. Coolwater nonnative fishes introduced into the river include striped bass, smallmouth bass, and walleye. In addition to these warmwater and coolwater nonnatives, coldwater nonnative trout species were introduced for sport purposes beginning in the 1920s. Rainbow trout make up the major part of the sport fishery, but brook trout, brown trout, and cutthroat trout also have been stocked in the river.

The variety of native and nonnative fish present in the system leads to the issue of “interactions” among them. Interaction in the form of competition from, and predation by, nonnative fish has been cited along with habitat modification as causes of the decline of native fish in the Colorado River system. Potential competitors for habitat with native fish include carp, fathead minnow, killifish, rainbow trout, and red shiner. Species cited as predators on native fish include striped bass, channel catfish, brown trout, and possibly rainbow trout. Because of limited data, opinions vary about interactions between native and nonnative fish and how operational changes would affect these interactions.

## Effects of Pre- and Postdam Conditions on Fish

The aquatic ecosystem originally developed in a sediment-laden, seasonally fluctuating river environment. The construction of the Glen Canyon Dam altered the natural dynamics of the Colorado River. Today, the ecological resources of the Glen and Grand canyons depend on the water releases from the dam and the sediment that comes from tributaries below the dam. Lake Powell traps water, sediment, and the associated nutrients that previously traveled down the Colorado River.

The interruption of riverflow and regulated release of lake water now support aquatic and terrestrial systems that did not exist before the Glen Canyon Dam. The predam aquatic system supported an array of native and nonnative fish. Native fish evolved in a river that carried large amounts of sediment and was subject to extreme seasonal variability in flow and temperature. The construction of the dam created a relatively clear river with near constant year-round cold temperatures. These water temperatures limit the possibility of successful reproduction by warmwater fish, including the five native fish still present in this portion of the Colorado River system. The decline of the native fish in the Glen and Grand canyons is attributed to the presence of nonnative competitors and predators and to postdam river conditions. The tributaries of the Colorado River in the Grand Canyon are used by native fish species for spawning and rearing young.

## Issue

As defined in the final EIS, the issue of concern for fish resources is how do dam operations affect fish—their food base, life cycles, habitat, and ability to spawn?

## Indicators

The indicators for fish resources listed in the final EIS are the

- abundance of Cladophora and associated diatoms for the aquatic food base;
- reproduction, recruitment(survival to adulthood), and growth of native fish;

- reproduction, recruitment, and growth of nonnative warmwater and coolwater fish; and
- level of interactions between native and nonnative fish.

Both the biological productivity of the aquatic food base and the physical characteristics of the environment (temperature, reliable flow, turbidity, etc.) determine the limits of fish development. Therefore, the EIS team's assessments of impacts on fish included both of these areas. The analysis of impacts on the food base focused on Cladophora production and used changes in the length of wetted perimeter (the productive band of shoreline) to demonstrate the differences between the alternatives.

The analyses of the impacts of the alternatives on native and nonnative fish addressed (1) direct sources of mortality, (2) potential for reproduction and recruitment, and (3) potential for growth. The analysis factors included the temperature of the water in the mainstem and access to tributaries for reproduction, food base and stable nearshore and backwater environments for recruitment and growth, flood frequency reduction measures, and beach/habitat-building flows. The evaluation of native and nonnative interactions was qualitative and focused on the effects of each alternative on nearshore and backwater habitats used by native and nonnative fish.

## Methodology Used to Make Impact Determinations

EIS team members told us that the EIS was developed through a dynamic process involving three main groups—the EIS team, Glen Canyon Environmental Studies officials and researchers, and representatives of the cooperating agencies. Researchers provided data to the EIS team that was responsible for the technical development of alternatives and impact determinations, while the cooperating agency group was a policy-level review body.

The initial impact determinations for fish and endangered fish were primarily developed by two EIS team members assigned to that task on the basis of their areas of expertise. These team members were from the Arizona Game and Fish Department and FWS. No formal fish subgroup or workgroup existed at that time and no formal reports were produced.

These two team members developed their sections of the EIS through an iterative process of drafting, discussions, and formal and informal presentations to, and review by, the whole EIS team, as well as through input from key researchers and colleagues with whom they shared their work and from whom they solicited feedback. Additionally, presentations of the impact assessments were made to the cooperating agency group.

The EIS team's decision-making on fish issues was handled through voting; the goal was a consensus-based product. Formal minutes of the EIS team meetings were kept as a record of key decisions.

After public comments were received on the draft EIS, the Aquatic Biology Team (ABT) workgroup was formed by Reclamation to respond to the comments and to reorganize and rewrite the fish and endangered species sections of the final EIS. This workgroup consisted of the two original individuals and five additional EIS team members representing Reclamation, the Hopi Tribe, the Hualapai Tribe, and the Arizona Game and Fish Department. The workgroup was formed because of the controversy and diametrically opposed positions of many of the comments pertaining to aquatic biology. All members of the workgroup participated in discussions and consensus decision-making on fish issues and revised impact determinations; however, two individuals were principally responsible for the rewrite of the sections under review, with assistance and input from other EIS team and ABT workgroup members. Of the 33,000 comments received on the draft EIS, 291 related to fish and 1,826 related to endangered species. However, the vast majority of endangered species comments focused on endangered fish.

The ABT did its work through an iterative process similar to that used by the EIS team as a whole. Individuals were given assignments, interactive discussions were held, and decisions were made through consensus. According to ABT workgroup members, no official documentation of the discussions and decisions of this group were kept. Rather, information was shared among members through personal communications, working meetings, and other collegial interactions. Some information relevant to fish resources is contained in the official minutes of the EIS team meetings.

On the basis of the comments received on the draft EIS and the internal review, the EIS team/ABT workgroup made several major changes to the fish section of the final EIS. Specifically:

- In order to make the document less confusing and to facilitate better integration of material, the fish section was substantially revised and reorganized to include new information and to integrate the extensive treatment of endangered fish previously covered in the endangered species section of the EIS.

- In response to the comments received and ongoing discussions, Reclamation and FWS jointly agreed to move the endangered fish research flows identified in FWS's reasonable and prudent alternative from the preferred alternative to the Adaptive Management Program. The EIS team implemented this change.
- In response to the comments and concerns about interactions between native and nonnative fish, information on competition and predation and the predam fish population was expanded in the final EIS. Information on nonnative fish and native/nonnative interactions was added to the summary table of impacts.
- In order to more explicitly recognize the uncertainty and disagreement that exist among resource scientists about the responses of fish to steady flow alternatives, the final EIS describes those areas of uncertainty and includes reference to this uncertainty in the matrix of potential impacts.

Because final results were not available to the ABT from many of the phase II fish studies for the Glen Canyon Environmental Studies, professional judgment was an important factor in developing fish impact determinations for the final EIS. However, as one ABT member stressed, these impact determinations were criterion based, using important resource indicators as the basis for judgment. The ABT workgroup and EIS team thus used a combination of available data and professional judgment in developing the impact determinations for fish.

### Data Used for Making Impact Determinations

The research studies used to support the impact determinations on fish resources are listed in the bibliography of the final EIS. These studies include Glen Canyon Environmental Studies research, as well as research developed by various state and federal agencies involved with fish resources. Those studies deemed most useful by several members of the EIS team who worked on fish issues are noted in the Key Studies Identified subsection of this appendix.

## Effects of Flow Alternatives on Fish

Details of the anticipated impacts of the nine flow alternatives on fish resources are found in the final EIS. However, the following general statements can be made about the impacts of restricted fluctuating flows versus steady flows on fish:

- Fluctuating releases may affect fishes' access to tributaries and backwater habitat and destabilize these backwaters by alternately draining and refilling them with cold water from the Colorado River mainstem.

- Daily fluctuations in water level and cold water temperatures would continue to suppress reproduction and recruitment of nonnative warmwater fishes in the mainstem.
- Fluctuations may increase turbidity (cloudiness) of the water, which may provide cover for native fish and a degree of protection from predation. Increased turbidity could also provide foraging opportunities for the adult chub.
- Steady flows would allow for increased warming of backwaters, which would benefit young native fish. However, such improved habitat conditions for native species might also benefit nonnative species that are competitors or predators of these native endangered fish. The potential for increased interaction between native fish and their competitors and predators is greatest under steady flows.
- Steady flows might adversely affect maintenance of backwaters, allowing them to become isolated and filled with sediment.
- Steady flows could reduce the availability of fish forage and slow its transport downstream.

The final EIS points out that any change in the dam's daily operations or other management actions that result in improved habitat conditions for native fish also would improve conditions for nonnative warmwater and coolwater fish. Resource scientists are not in agreement about what improving habitat conditions means in terms of interactions between native and nonnative fish.

## U.S. Fish and Wildlife Service's Final Biological Opinion

The U.S. Fish and Wildlife Service conditioned its support of the preferred alternative in the Glen Canyon Dam's EIS on the basis that Reclamation would agree to additional research on the impact of steady flows on fish as part of the Adaptive Management Program. In December 1994, FWS issued its final biological opinion on the operations of the Glen Canyon Dam, as required by section 7 of the Endangered Species Act. In its final opinion, FWS supports a flow regime that includes steady flows, and especially the Seasonally Adjusted Steady Flow alternative, on the basis of the supposed benefits for native fish. The final biological opinion concludes that the Modified Low Fluctuating Flow preferred alternative is likely to jeopardize the continued existence of the humpback chub and the razorback sucker. Therefore, FWS issued a "jeopardy opinion" concerning the EIS preferred alternative for those fish species.

In support of its 1994 opinion and findings, FWS states that "the preferred alternative (without a selective withdrawal structure) does not remove the issue of coldwater temperatures on reproductive success in the mainstem....” Furthermore, FWS asserts that

> “fluctuating flows limit solar warming of backwaters, flush organisms and nutrients important as food resources, and force earlier life stages of endangered and other native fishes out of quiet protected waters into unfavorable mainstem conditions. These conditions might include increased exposure to predation and debilitating effects of cold water and increased velocities.”

Regulations implementing section 7 of the Endangered Species Act state that a “reasonable and prudent alternative” to the recommended action can be identified during the formal consultation process. For the Glen Canyon Dam’s EIS, FWS’ reasonable and prudent alternative recommends further studies of the effects of steady flows on endangered and native fish, otherwise known as endangered fish research flows. When implemented, these research flows would require as many as 5 low release years (annual water releases at or near 8.23 million acre-feet). Because low water release years are expected to occur only about half the time, it is uncertain how many total years it would take to complete the research program. However, it is likely that research flows could be completed within 10 years.

Endangered fish research flows would likely be between 8,000 cfs and 20,000 cfs with a spring through fall pattern and monthly releases similar to the Seasonally Adjusted Steady Flow alternative. The 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 is to implement, through the Adaptive Management Program, any necessary changes in dam-operating criteria necessary to comply with the Endangered Species Act. Reclamation and FWS are to meet at least annually to coordinate reasonable and prudent alternative activities and ensure that sufficient progress is being made to remove the jeopardy opinion for the endangered species that are affected by the operation of the Glen Canyon Dam. FWS agreed to support the preferred alternative as modified by the reasonable and prudent alternative.

Reclamation does not agree with FWS’ jeopardy opinion on the preferred alternative. In its comments on a draft version of the biological opinion, Reclamation presented its concerns about FWS’ support of steady flows by noting that “scientific experts on native fishes in the Colorado River system who were convened to discuss the merits and detriments of flow alternatives on March 2, 1994, were not totally supportive that the draft biological opinion flow scenario will provide quantifiable benefit to native fish without additional temperature modification." Furthermore, Reclamation was also concerned that

> "the logic for identifying the effects of steady flows as related to the Colorado River system in the Grand Canyon is not well supported. Data coming from the GCES program and in other research programs on Southwestern ecosystems consistently point to the importance of disturbance in maintaining the native species assemblages. The statement that the ecology of the Grand Canyon will be supported by steady flows is not supported in the document or in the literature."

Nevertheless, Reclamation has agreed to implement elements of FWS' reasonable and prudent alternative, including continued study of the effects of steady flows on fish.

## Assessment of Impact Determinations

EIS team and ABT workgroup members told us that they were pleased with the process used in developing the EIS, believed that this process was "reasonable," and were satisfied with their product. Several noted the professional and open-minded approach brought to the work by most of the team members. FWS representatives to the team also said that they were pleased with the process up to the point where the draft EIS and the draft biological opinion were released. However, with the formation of the ABT workgroup, they said, the focus shifted to a concern for supporting the preferred alternative and "discrediting" the Seasonally Adjusted Steady Flow alternative. Other EIS team/ABT workgroup members took exception to this assertion, with one member stating that the preferred alternative was not forced upon FWS. Another team member stated that when it comes to the operations of the Glen Canyon Dam, NEPA (the EIS) and the Endangered Species Act (the reasonable and prudent alternative) did not complement each other very well.

## Reasonableness of the Methodology

We received a variety of comments on the implementation of the fish impact determination methodology. For example, many interviewees expressed regret about the lack of coordinated time frames between the completion of Glen Canyon Environmental Studies research and the EIS development schedule, because the timing problem led to the use of incomplete data for the fish resources.

One of the ABT workgroup's tasks was to explicitly deal with the uncertain impacts of steady flows on fish resources. The leader of the ABT workgroup told us that there were significant disagreements among team members about how to handle this uncertainty, and that the FWS representatives held a different opinion from other members of the ABT. As with other decisions, this disagreement was handled through open discussion with the goal of establishing consensus. Many interviewees expressed the belief that the final EIS' increased, explicit acknowledgement of uncertainty about flow impacts on the fish resources was an important improvement in the document. Some of these individuals told us that this change to the fish resource section accurately reflects the disagreements and uncertainties within the scientific community.

EIS team members told us that an important component of the process of developing the impact determinations was the team's contacts with Glen Canyon Environmental Studies officials for updates on research results and the team's interactive relationship with key researchers. However, while some of the key researchers with whom we talked acknowledged that they had worked with EIS team members in this way, others told us that the EIS team's contact with them had been minimal or even nonexistent.

Some interviewees expressed the belief that private consultants should not have been included on the EIS team because their loyalty may be to present or future clients rather than to objective science. On the other hand, one consultant was also mentioned by several interviewees as one of the most knowledgeable individuals on fish and other resource issues in the canyon. Furthermore, several individuals expressed high regard for the work done by another consultant on some of the key Glen Canyon Environmental Studies research on the humpback chub.

Some EIS team members were also researchers whose work was being reviewed for the EIS. One EIS team member expressed the belief that this dual role was beneficial to the team because of their knowledge about the latest scientific findings as they developed. Two researchers, however, told us that they were troubled by this dual role for EIS team members. One suggested that it constituted a conflict of interest; the other was concerned that having individuals reviewing their own work might have affected the objectivity with which the research was examined.

## Opinions on Data Used for Impact Determinations

Limited data permit opinions to vary among members of the scientific community on a number of issues related to fish. Some of these differences occur because of disagreements over scientific interpretations and viewpoints; others reflect personal, institutional, and academic affiliations and rivalries. Differences of opinion also exist on the issues related to the development of the impact determinations on fish for the final EIS.

A number of the individuals we talked with both inside and outside of the EIS preparation process expressed frustration that the final results from many of the Glen Canyon Environmental Studies phase II fish studies were not available to the EIS team and the ABT workgroup for the development of the impact determinations in the final EIS. According to several interviewees, this lack of final results—or "hard data," as one EIS team member not on the ABT called it—inevitably lead to an increased reliance on professional judgment in developing impact determinations related to fish.

Opinions varied as to whether the lack of final results from some phase II studies constituted a "limitation" on or simply a "hindrance" to the development of the impact determinations. Some interviewees told us that while it was unfortunate that final results from phase II were not in, this was not a limitation on the usefulness of the available data or the conclusions drawn from them. They believed that if the final data had been available, the team's determinations might have been more refined or supported, but their conclusions (and the preferred alternative) would have remained the same. Others believed that the lack of final results represented a significant limitation on the impact determinations. Some of these even suggested that the determinations or decisions might have changed on the basis of these final research results or that if the EIS team had used all the science available to them, "they would have come up with a different alternative."

Despite these differences, most of those who expressed an opinion to us said that the EIS team had used the "best available data" in determining the impacts on fish. One said that the best available data were used, although these data were not complete. Another told us that while the best available data were used, other, better data might have been available had the EIS time frames been changed to accommodate the completion of the Glen Canyon Environmental Studies. This individual further stated that the EIS team had developed "reasonable interpretations from unreasonable data." Even some of those individuals critical of the overall process agreed that the "best available data" had been utilized.

## Peer Review of Studies

Reclamation and Glen Canyon Environmental Studies officials and researchers told us that a three-tiered review process was developed for all Glen Canyon Environmental Studies, regardless of resource area. This process included (1) internal agency/organizational review by the research entity, (2) Glen Canyon Environmental Studies office review, and (3) external peer review under the auspices of the Senior Scientist. However, a number of the researchers that we interviewed were critical of the actual review process. Furthermore, the individual responsible for overseeing this process told us that only about 30 to 35 out of approximately 140 anticipated Glen Canyon Environmental Studies had actually undergone the complete three-step review.

## Results of the Process

As to the results of the process, the views on the preferred alternative varied among interviewees. Several supported the preferred alternative, especially when combined with the beach/habitat-building "spike" flow. Others supported flow regimes that include the Seasonally Adjusted Steady Flow alternative favored by FWS. Some interviewees told us that they were originally inclined to support steady flows but changed their views in favor of fluctuating flows on the basis of the developing data. Two interviewees endorsed a flow regime that closely resembles the "natural hydrograph," including floods and low flows. Some researchers told us that they had not read or reviewed the final EIS and were unfamiliar with the specifics of the flow alternatives.

## ABT Workgroup Leader's Responses to the Issues Raised

The leader of the ABT workgroup provided us with detailed comments on and responses to each of the issues noted above. He agreed with some statements or positions and disagreed with others. For example, he agreed that the lack of final results from the fish research studies was frustrating and that the limited data allow differences of opinion on and scientific interpretation of the impacts on fish resources. However, he disagreed with the statement that had final results been available, the impact determinations might have been different. Rather, he said the final data would have refined the EIS team's understanding of the issues and supported their conclusions but would not have changed the impact determinations or the preferred alternative.

His overall position, taking into consideration the various perspectives and opinions expressed, was that

- the process used in making the impact determinations on fish resources was reasonable,
- the methodologies employed in this process were appropriate,
- the data used were the best available, and
- the results of the impact determinations are reasonable.

## Scope and Methodology

To determine the data and process used in developing the impacts on fish resources, we identified and reviewed the following documents: the draft EIS and associated appendixes; the preliminary final EIS; the final EIS; the public comments on the draft EIS; Reclamation's analysis of and the EIS team's responses to these comments; copies of minutes of the EIS team meetings; summaries of the meetings of the cooperating agencies; and Reclamation's newsletters on the EIS process. We also obtained and reviewed FWS' draft biological opinion and final biological opinion on the operation of the Glen Canyon Dam, Reclamation's comments on the draft biological opinion and official response to the final biological opinion, and FWS' Fish and Wildlife Coordination Act report (see list of related documents below for full citations).

We obtained a copy of the final EIS bibliography from Reclamation, with titles sorted by each resource area. The fish bibliography contained 57 titles, while the endangered species bibliography contained 29 titles. We asked three EIS team members recommended to us as key initial contacts on fish and endangered species issues to review the titles related to these resources and to point out those studies they believed had been most useful in developing the impact determinations.

To assess the procedures followed and obtain views on the quality of data used in preparing fish issues, we interviewed the EIS team members who had primary responsibility for writing the fish and endangered species section of the draft EIS, as well as all other members of the ABT workgroup, which was formed to revise and reorganize these two sections following the receipt of public comments on the draft EIS. Additionally, we met with several other members of the EIS team, including two EIS team members not on the ABT workgroup who requested the opportunity to discuss fish and endangered species issues with us. We spoke with several scientists identified by team members and others as having done key research used by the workgroup and the full EIS team in developing the fish impact determinations. We interviewed other agency officials with information about the EIS and Glen Canyon Environmental Studies processes.

Finally, we asked the leader of the ABT workgroup to review the factual accuracy of our description of the process for developing the impact determinations for fish resources. He agreed that our description was generally accurate but made some suggestions for changes. We have incorporated these changes into our description of the process. We also presented him with our preliminary findings on fish resources in order to provide him with an opportunity to comment on and respond to the various issues raised through our audit work.

## Key Studies Identified

The following are titles from the fish bibliography selected by at least two of the three key initial contacts recommended to us.

Angradi, T.R., R.W. Clarkson, D.A. Kinsolving, D.M. Kubly, and S.A. Morgensen. "Glen Canyon Dam and the Colorado River: Responses of the Aquatic Biota to Dam Operations," Glen Canyon Environmental Studies Technical Report. Phoenix, Arizona: Arizona Game and Fish Department, 1992.

Glen Canyon Environmental Studies Phase II 1992 Annual Report. Prepared for the Bureau of Reclamation, Glen Canyon Environmental Studies. Phoenix, Arizona: Arizona Game and Fish Department, 1993.

Gorman, O.T., S.T. Leon, and O.E. Maughan. "Habitat Use by Humpback Chub, Gila Cypha, in the Little Colorado River and Other Tributaries of the Colorado River in the Grand Canyon," Glen Canyon Environmental Studies Phase II Annual Report. Prepared for the Bureau of Reclamation by the U.S. Fish and Wildlife Service, Pinetop, Arizona, and the Arizona Cooperative Fish and Wildlife Research Unit, Tucson, Arizona, 1993.

Leibfried, W.C. "Utilization of Cladophora Glomerata and Epiphytic Diatoms as a Food Resource by Rainbow Trout in the Colorado River Below Glen Canyon Dam in Arizona," Masters Thesis. Flagstaff, Arizona: Northern Arizona University, 1988.

Leibfried, W.C., and D.W. Blinn. "The Effects of Steady Versus Fluctuating Flows on Aquatic Macroinvertebrates in the Colorado River below Glen Canyon Dam, Arizona," Glen Canyon Environmental Studies Technical Report. Salt Lake City, Utah: Bureau of Reclamation, 1987.

Maddux, H.R., D.M. Kubly, J.C. DeVos, Jr., W.R. Persons, R. Staedicke, and R.L. Wright. "Effects of Varied Flow Regimes on Aquatic Resources of

Glen and Grand Canyons," Glen Canyon Environmental Studies Technical Report. Phoenix, Arizona: Arizona Game and Fish Department, 1987.

McGuinn-Robbins, D.K., Comparison of the Number and Area of Backwaters Associated With the Colorado River in Glen and Grand Canyons, Arizona. Phoenix, Arizona: Arizona Game and Fish Department, 1994.

Suttkus, R.D., G.H. Clemmer, C. Jones, and C.R. Shoop. Survey of Fishes, Mammals and Herpetofauna of the Colorado River in Grand Canyon. National Park Service, Colorado River Research Series Contribution no. 34, 1976.

Usher, H.D., D.W. Blinn, G.C. Hardwick, and W.C. Leibfried. Cladophora Glomerata and Its Diatom Epiphytes in the Colorado River Through Glen and Grand Canyons: Distribution and Desiccation Tolerance. National Technical Information Service No. PB88-183454/AS, 1986.

Weiss, J. "The Relationship Between Flow and Backwater Fish Habitat of the Colorado River in Grand Canyon" (draft report), Glen Canyon Environmental Studies Technical Report. Flagstaff, Arizona: Bureau of Reclamation, 1993.

Weiss, S.J. Spawning, Movement, and Population Structure of Flannelmouth Sucker in the Paria River. Masters Thesis. Tucson, Arizona: University of Arizona, 1993.

Titles related to fish selected from the endangered species bibliography by at least two of these contacts were as follows.

Kubly, D.M., The Endangered Humpback Chub (Gila Cypha) in Arizona: A Review of Past Studies and Suggestions for Future Research (draft report). Salt Lake City, Utah: Prepared by the Arizona Game and Fish Department for the Bureau of Reclamation, 1990.

Tyus, H.M., and C.A. Karp. "Habitat Use and Streamflow Needs of Rare and Endangered Fishes, Yampa River, Colorado," Fish and Wildlife Service Biological Report, vol. 89, no. 14. Vernal, Utah: 1989.

Valdez, R.A. Life History and Ecology of the Humpback Chub in Grand Canyon. Logan, Utah: BIO/WEST, 1994.

Valdez, R.A., and M. Hugentobler (editors). Characterization of the Life History and Ecology of the Humpback Chub (Gila Cypha) in the Grand Canyon. Annual Report 1992 to Bureau of Reclamation. Logan, Utah: BIO/WEST Report No. TR-250-06, 1993.

Valdez, R.A., W.J. Masslich, and W. Leibfried. Characterization of the Life History and Ecology of the Humpback Chub (Gila Cypha) in the Grand Canyon. Annual Report to the Bureau of Reclamation. Logan, Utah: BIO/WEST Report no. TR 250-04, 1992.

Valdez, R.A., A. Wasowicz, and W. Leibfried. Characterization of the Life History and Ecology of the Humpback Chub (Gila Cypha) in the Grand Canyon. Logan, Utah: BIO/WEST Trip Report no. 7-1992, 1992.

In addition to the studies identified above from the final EIS bibliography, other documents are relevant to fish issues. These documents include the following.

Carothers, S.W., and B.T. Brown. The Colorado River Through Grand Canyon: Natural History and Human Change. Tucson, Arizona: University of Arizona Press, 1991. The coauthors of this book were both key researchers identified in our work. Furthermore, Dr. Carothers was a member of the EIS team and the Aquatic Biology Team workgroup. Portions of this book address fish and endangered species issues, drawing from GCES research.

Clarkson, R.W., O.T. Gorman, D.M. Kubly, P.C. Marsh, and R.A. Valdez. “Management of Discharge, Temperature, and Sediment in Grand Canyon for Native Fishes.” Mar. 1994. A “white paper” provided to the EIS team, written by a number of key fish researchers from various agencies/organizations. In it, the researchers present their thoughts on native fish management issues. This document was mentioned by EIS team members as influential in their early discussions on fish issues. However, it does not appear in the final EIS bibliography.

Colorado River Endangered Fishes Critical Habitat Draft Biological Support Document. U.S. Fish and Wildlife Service, Sept. 3, 1993. Critical habitat must be designated for endangered species. This document was mentioned by one researcher with whom we spoke as an example of how agencies should handle scientific data in environmental policy papers.

Draft Recovery Implementation Program for Endangered Fish Species in the Upper Colorado River Basin. U.S. Fish and Wildlife Service, Sept. 3, 1993. This document is not directly related to activities at the Glen Canyon Dam but contains information about the recovery of endangered fish in the Colorado River Basin.

Final Biological Opinion: Operation of Glen Canyon Dam as the Modified Low Fluctuating Flow Alternative of the Final Environmental Impact Statement (2-21-93-F-167). U.S. Fish and Wildlife Service, Dec. 21, 1994. The final biological opinion and its related reasonable and prudent alternative were developed by FWS in response to Reclamation's request for formal consultation under section 7 of the Endangered Species Act. The final biological opinion states that the preferred alternative is likely to jeopardize the continued existence of the humpback chub and razorback sucker and is likely to destroy or adversely modify designated critical habitat. FWS' position is that the Seasonally Adjusted Steady Flow alternative may be more beneficial for these endangered native fish.

Glen Canyon Dam: Beach/Habitat-Building Test Flow, Final Environmental Assessment and Finding of No Significant Impact. Bureau of Reclamation, Feb. 1996. This report presents the findings of the required environmental assessment prepared prior to implementing the spring 1996 "spike" flow.

Glen Canyon Dam Discharge Temperature Control Draft Appraisal Report. Bureau of Reclamation, June 14, 1994. This draft report discusses options for studying and implementing temperature controls at the Glen Canyon Dam, including building a selective withdrawal structure.

Minckley, W.L. "Native Fishes of the Grand Canyon Region: An Obituary?" Colorado River Ecology and Dam Management. Proceedings of a Symposium, May 24-25, 1990, Santa Fe, New Mexico, pp. 124-177. Washington, D.C.: National Academy Press, 1991. This paper is listed in the final EIS bibliography. It is a part of the book developed from a symposium sponsored by the National Research Council's Committee to Review the Glen Canyon Environmental Studies. This paper is an overview of native fish issues by a recognized expert in the field.

Operation of Glen Canyon Dam - Fish and Wildlife Coordination Act Report. U.S. Fish and Wildlife Service, June 28, 1994. In accordance with the Fish and Wildlife Coordination Act, FWS submitted this report to Reclamation with recommendations in connection with the dam's operations. The Fish and Wildlife Coordination Act does not require

Reclamation to accept the recommendations; however, Reclamation has agreed that reasonable and practicable recommendations will be implemented. The Fish and Wildlife Coordination Act ensures that fish and wildlife receive equal consideration during the planning and construction of federal water projects.

"Organisms and Biological Processes," River Resource Management in the Grand Canyon, pp. 84-117. National Research Council Committee to Review the Glen Canyon Environmental Studies, 1996. This is a chapter of a National Research Council Committee report on GCES. The purpose of this report and the committee's task was to review research that was done in connection with the GCES and to comment on the application of science in the management program of the Colorado River.

Response to the Final Biological Opinion on the Operations of Glen Canyon Dam. Bureau of Reclamation, Apr. 6, 1995. This is Reclamation's official response to, and addressing of, the issues presented in the final biological opinion. In it, Reclamation states that it does not agree with all the points made or positions taken by FWS but will take steps to comply with them.

Threatened Native Wildlife in Arizona. Phoenix, Arizona: Arizona Game and Fish Department, 1988. This publication presents information on a variety of species and subspecies including fish, amphibians, reptiles, birds, and mammals.

## Officials Interviewed

We interviewed the following individuals about the fish impact determinations and the related Glen Canyon Dam EIS issues.

Michael Armbruster, Bureau of Reclamation
Frank Baucom, U.S. Fish and Wildlife Service
Debra Bills, U.S. Fish and Wildlife Service
Bryan Brown, SWCA, Inc.
Steven Carothers, SWCA, Inc., Hopi Tribe
Michael Douglas, Arizona State University
Owen Gorman, U.S. Fish and Wildlife Service
David Harpman, Bureau of Reclamation
Christine Karas, Bureau of Reclamation
Dennis Kubly, Arizona Game and Fish Department
William Leibfried, SWCA, Inc., Hualapai Tribe
Gordon Lind, Bureau of Reclamation

Paul Marsh, Arizona State University, Center for Environmental Studies
Margaret Matter, Western Area Power Administration
Debra McGuinn-Robbins, Arizona Game and Fish Department
Wendell Minckley, Arizona State University
Anthony Morton, Western Area Power Administration
Ronald Moulton, Western Area Power Administration
Clayton Palmer, Western Area Power Administration
Timothy Randle, Bureau of Reclamation
Lawrence Riley, Arizona Game and Fish Department
John Thomas, SWCA, Inc., Navajo Nation
Harold Tyus, University of Colorado, Boulder
Richard Valdez, BIO/WEST, Inc.
David Wegner, Bureau of Reclamation, Glen Canyon Environmental Studies
Judy Weiss, Former Glen Canyon Environmental Studies Researcher (currently not active in the research community)

# Hydropower

The purpose of this appendix is to review the methodology and key assumptions that the Bureau of Reclamation used to estimate the economic impact on hydropower of alternative water releases at the Glen Canyon Dam. The Glen Canyon Dam, which began producing power in 1964, is part of the Colorado River Storage Project, a federal project for water development in the Upper Colorado River Basin. Reclamation's purpose in analyzing hydropower issues in the EIS was to determine the impacts on the power system of potential changes in the Glen Canyon power plant operations. We found that Reclamation's methodology for estimating the economic cost of changing the dam's operations is reasonable and that Reclamation used the best available information at the time of the study.

Reclamation has estimated that the annual economic cost of changing the operations at the dam could range from –$1.5 million under the Maximum Powerplant alternative to $123.5 million under the Seasonally Adjusted Steady Flow alternative (in 1991 dollars, relative to the No-Action alternative). We found shortcomings in several of the assumptions Reclamation used in the power analysis, inconsistencies in some results, and two phase III computational errors, which suggest that the estimated economic impacts may be either overstated or understated. Because future events are inherently uncertain and because the actual cost of changing the dam's operations could also depend on factors yet to be determined, such as whether or not an Endangered Fish Research Program is implemented and the pace of deregulation in the electric utility industry, the actual economic impacts on power users may differ from those estimated. However, because the shortcomings we identified generally affect the estimates for all of the alternatives, we do not believe that addressing the shortcomings would alter the relative ranking of the fluctuating and steady flow alternatives. Furthermore, Reclamation and representatives of the power industry believe that the results of the hydropower analysis presented in the final EIS are reasonable and usable. As a result, we believe that Reclamation's estimated economic impacts can be used to compare in a general way the economic trade-offs that are associated with the various flow alternatives.

## Introduction

The Glen Canyon Dam is owned, operated, and maintained by the Bureau of Reclamation. The Western Area Power Administration (WAPA)—a power-marketing administration established in the Department of Energy Organization Act of 1977—markets and transmits the power produced at the dam (that is, power in excess of that used by projects involving irrigation and flood control). WAPA, in compliance with the Colorado River Storage Project (CRSP) Act of 1956, is obligated to provide first priority to the power needs of CRSP Participating Projects (for example, Reclamation's irrigation projects). Power that is surplus to this "project use" requirement is then marketed by WAPA to wholesale firm-power customers entitled to preference allocations (for example, municipal and county utilities, rural electric cooperatives, and other nonprofit organizations financed under the Rural Electrification Act of 1936). WAPA generally enters into long-term contracts with its preference customers to sell firm power (that is, long-term capacity and energy) at a rate that is limited to the recovery of its costs and all costs assigned to power for repayment, including that portion of irrigation costs beyond the ability of the user to repay per the CRSP Act (this rate is referred to as the Salt Lake City Area/Integrated Projects—SLCA/IP—rate). If its customers require additional energy and additional energy is available, WAPA may sell short-term power to them at a price ranging from the SLCA/IP rate to the spot market rate, depending on market conditions. If WAPA's generation exceeds the needs of Reclamation's project use requirements and of the SLCA/IP's firm-power customers, energy may be exchanged with other suppliers or may be sold on the spot market. On the other hand, if WAPA's generation is less than the long-term firm-power commitments, WAPA must purchase replacement power on the spot market, make short-term contractual purchases, or exchange energy from other suppliers to make up the deficit.

Historically, maximum power production at the dam has been limited to 1,300 megawatts, which corresponds to a water release of 31,500 cubic feet per second. Power production (that is, instantaneous output, measured in watts) is a function of reservoir head, flow, and the generating capacity of the dam's turbines. The dam has eight electric generators that were originally installed when the dam was constructed and "uprated" to 1,356 megawatts during the 1980s. Energy production (that is, power produced over time, measured in watt-hours) is a function of capacity over time or the amount of water released over time. During a typical year, water releases average about 10 million acre-feet, corresponding to an average annual energy production of about 5 million kilowatt hours.[1]

Currently, WAPA markets power from the Glen Canyon Dam to approximately 180 preference customers located mainly in Colorado, New

[1]A kilowatt hour is the amount of electrical energy involved in a demand or requirement for 1 kilowatt over a period of 1 hour.

Mexico, Arizona, Utah, Nevada, and Wyoming. These customers sell electricity to about 1.7 million residential, commercial, industrial, and agricultural customers. Since November 1, 1991, the Department of the Interior has operated the dam under an interim flow regime, whereby water releases are generally limited to a maximum of 20,000 cubic feet per second (cfs).

Reclamation's purpose in preparing the Glen Canyon Dam's environmental impact statement was to determine specific options that could be implemented to minimize the adverse impacts on the downstream resources and Native American interests in the Glen and Grand canyons. In connection with hydropower production, the key EIS issue was to determine the impacts on the power system of potential changes in the Glen Canyon power plant's operations. Reclamation was responsible for evaluating the economic, project repayment, and rate impacts of changing the magnitude and timing of water releases from the Glen Canyon Dam. To make its assessment, Reclamation identified power operations flexibility (for example, the ability of WAPA to provide services to its customers) and power-marketing resources (for example, capacity and energy), costs, and rates as EIS indicators. Reclamation examined the effect that nine different alternative flow regimes could have on the EIS indicators. However, only the impact on the power-marketing indicator was quantified; the impact on power operations flexibility was assessed qualitatively.

Under each of the nine alternative flow regimes, the total volume of water released annually would be the same and would depend on a number of factors, including long-range operating criteria, such as an annual minimum flow of 8.23 million acre-feet and balanced storage between Lake Powell and Lake Mead (formed by the Hoover Dam). However, the nine alternatives would differ in terms of their daily, monthly, and seasonal flows.

The nine alternative flow regimes can be grouped into three main categories: (1) unrestricted fluctuating flows, (2) restricted fluctuating flows, and (3) steady flows. The unrestricted fluctuating flow alternatives include the No-Action and Maximum Powerplant regimes. The No-Action alternative, which reflects pre-1991 historic operations, would allow daily fluctuations up to 30,500 cfs, depending on the season. The Maximum Powerplant alternative would allow daily fluctuations up to 32,200 cfs, also depending on the season.

The restricted flow alternatives include the high, moderate, modified low, and interim low fluctuating flow regimes. In general, the restricted fluctuating flow alternatives would restrict ramping (increases or decreases in cfs per hour) and daily fluctuations (cfs per 24 hours) and increase the daily minimum release. In general, maximum releases would be no greater than 31,500 cfs for the high and moderate flow alternatives, 25,000 cfs for the modified low flow alternative, and 20,000 cfs for the interim low flow alternative.

The steady flow alternatives include the existing monthly volume, seasonally adjusted, and year-round steady flow regimes. In general, the steady flow alternatives would restrict daily fluctuations to plus or minus 1,000 cfs, providing steady flows on either a monthly, seasonal, or year-round basis. Under the seasonally adjusted flow alternative, the highest releases (that is, no greater than 18,000 cfs) would occur in May and June, and the lowest releases would occur between August and December.

Under habitat maintenance flows, however, releases could be greater than 31,500 cfs under the Moderate Fluctuating Flow alternative, greater than 25,000 under the Modified Fluctuating Flow alternative, and greater than 18,000 cfs under the Seasonally Adjusted Steady Flow alternative.

One of the key attributes of hydropower is that it can be turned on and off relatively quickly, allowing operators to respond to daily, hourly, or instantaneous fluctuations in the demand for electricity. Demand is typically highest during on-peak periods (for example, Monday through Saturday, 7 a.m. to 11 p.m.) and lowest during off-peak periods. Operationally, hydropower generators can respond to changes in load more easily than most other types of generation, which makes hydropower operationally more valuable any time load following (power generation that instantaneously rises and falls in response to the demand for electricity) is required. As a result of the operating constraints under the restricted and steady flow regimes, the maximum flows would generally be lower during on-peak periods, reducing on-peak energy production. Consequently, in general, the flexibility of power operations would be reduced under the restricted and steady flow alternatives. In addition, capacity (that is, instantaneous output) would be lower, generally speaking, under the restricted and steady flow alternatives, leading utilities to seek alternative and potentially higher-cost sources of peaking capacity. However, the total energy produced at the Glen Canyon Dam would not change—energy production would simply be shifted from the on-peak demand periods when it is most valuable to off-peak periods when it is less valuable. The additional energy produced during the off-peak periods would be available for sale in regional and other electricity markets.

## Reclamation's Power Impacts Methodology Is Generally Reasonable

We found that Reclamation's methodology for estimating the economic impact of alternative water releases at the dam is generally reasonable. For example, a strength of Reclamation's power analysis is that it was conducted by a committee of specialists from the federal government, the utility industry, and the environmental community, and as a result, the analysis reflects a broad range of views. Other key features of the power analysis that we found appropriate include the use of a detailed analysis to determine the impact of alternative flows on hydropower production at the dam, a national perspective to estimate economic impacts, utility-specific data to determine the economic impact to the regional power system, and a sensitivity analysis to test the impact of key assumptions. Finally, Reclamation was responsive to the comments received on the draft EIS and partially revised the power analysis for the final EIS.

### Power Resources Committee Conducted Power Study

To draw on expertise from the federal government, the utility industry, and the environmental community, Reclamation created a Power Resources Committee (the Committee) in 1989 to study the impacts of the various flow alternatives on the power system. Under Reclamation's lead, the Committee's responsibility was to define the scope of analysis, select modeling techniques, make basic assumptions, review preliminary analyses, and report findings. The Committee included representatives from the Colorado River Energy Distributors Association, the Environmental Defense Fund, and WAPA. In addition, Reclamation's primary contractor—HBRS, Inc. (now Hagler Bailly Consulting)—subcontracted with Stone & Webster Management Consultants, Inc., to serve as technical advisor to the Committee, collect data, run simulation models, synthesize findings, and write and prepare the Committee's reports. Another subcontractor, EDS Management Consulting Services, Inc., was involved in later phases of the power analysis. We found that the Committee conducted a comprehensive analysis of the impacts on the power system.

Using federal principles and guidelines for water resource projects and the professional judgments of its members, the Committee conducted an extensive analysis of the potential impacts on the power system from alternative water releases at the dam. For example, the Committee analyzed the impact on the regional power market that receives power from the dam, involving utilities in Arizona, New Mexico, Nevada, Utah, Colorado, and Wyoming. In addition, using historic operations as a base case or "No-Action" alternative, the Committee estimated the economic impacts of several different alternative flow regimes on the dam's power output and the regional power system over a 50-year period beginning in 1991.

## Power Resources Committee Conducted Detailed Analysis of Impacts on Power Production

The Committee conducted a detailed analysis to determine the potential impact of the alternative water releases on the dam's power production. For example, the Committee used future projections of hydrologic conditions at the dam, two different marketing approaches, and standard microeconomic principles to estimate the amount of power that would be available for sale under each alternative flow regime over the 50-year analysis period.

To develop long-term monthly projections of water releases and power and energy production at the dam, the Committee used Reclamation's Colorado River Simulation System. This system projects future water conditions at the dam on the basis of historic water conditions. In addition, the Committee used two marketing approaches to estimate the power and energy that could be marketed over the analysis period. One marketing approach—the Contract Rate of Delivery (CROD)—is based on the current marketing practices used by WAPA to market the dam's power and assumes that a fixed amount of power would be available for marketing. The other approach—the Hydrology approach—assumes that a variable amount of power would be available for marketing, depending on the actual hydrologic conditions at the dam. In general, the Committee found that more capacity is forgone under the CROD approach than under the Hydrology approach in moving from the No-Action alternative to the fluctuating and steady flow alternatives.

Under the CROD approach, the power available under each alternative flow regime would be fixed at an amount that could be expected to be available roughly 9 years out of 10.[2] During periods when less power is available, WAPA is responsible for purchasing the replacement power needed to meet its contract commitments.

[2]The CROD level is based on WAPA's desire to reduce the risk of not being able to provide a reliable level of power and energy.

By contrast, the Hydrology marketing approach assumes that the power and energy available for marketing would depend on the actual hydrologic conditions at the dam, which could vary monthly, daily, or hourly, depending on streamflow and reservoir storage conditions. WAPA's customers would be responsible for purchasing additional power during periods when the dam's production is insufficient to meet their needs.

The Committee used two different methods to estimate the capacity and energy that would be available under the CROD and Hydrology marketing approaches for the fluctuating flow alternatives. The geometric method was used to estimate the power and energy available under the CROD. The peak-shaving algorithm was used to estimate the capacity and energy available under the Hydrology marketing approach. The geometric method uses geometric principles to approximate hourly operational constraints and calculate the amount of capacity and energy available on a daily basis. By contrast, the peak-shaving algorithm uses load projections, which vary hourly, daily, and seasonally, and operational constraints to optimally allocate water releases during periods of peak demand. The resulting estimates of capacity and energy represent the amount that would be available for each marketing arrangement for each of the alternatives.[3]

In general, less capacity is available for the No-Action alternative under the Hydrology approach than under the CROD approach. For example, the Committee found that the marketable capacity during the winter under the CROD would be about 1,058 megawatts compared to an average of 923 megawatts under Hydrology.

## Power Resources Committee Used National Perspective to Estimate Economic Impacts

The Committee followed federal principles and guidelines for water resources planning where applicable in developing the analysis of the impacts to the power system. For example, consistent with the federal principles and guidelines, the Committee used a "federal economic analysis" approach to estimate the economic costs to society from changing water releases at the federally owned Glen Canyon Dam. The Committee also analyzed the financial impacts on individual utilities using a "utility economic analysis" approach, and the impact on the retail rates of selected end-users.

[3]Both the geometric method and the peak-shaving algorithm have limitations. The geometric method assumes load does not vary on a daily basis, and thus may not accurately capture daily changes in load, and the peak-shaving algorithm assumes perfect knowledge of future hourly demand, and thus may overoptimize the hydro dispatch.

Federal principles and guidelines state that the federal objective of water and related land resources planning is to contribute to the national economic development consistent with protecting the environment, pursuant to national environmental statutes, applicable executive orders, and other federal planning requirements.[4] The principles and guidelines further state that contributions to national economic development are increases in the net value of the national output of goods and services, expressed in monetary units. Consistent with this guidance, the Committee included in its economic analysis only those costs associated with constructing and operating new generating resources and operating those existing generating resources that would be needed to replace forgone power at the dam. The Committee excluded other costs—referred to as "transfer payments"—from the economic analysis. Transfer payments, including the fixed capital costs of currently operating powerplants, reflect a redistribution of income from one group in society to another and, as a result, do not reflect a net cost to society. For example, when a utility purchases power from another utility to replace forgone power at the dam, the appropriate measure of costs for the national economic perspective is the marginal cost of production. The fixed capital cost of the existing powerplant is considered a "sunk" cost. Because the decision to build the existing powerplant was made before the decision to change the dam's operations, the fixed costs of the existing plant are not an economic impact of changes in the dam's operations.

Because the regional power system currently has excess generating capacity, the economic impacts of the alternative flow regimes are lower during the early years of the 50-year analysis period. Economic costs rise over time, however, as the region's excess capacity is used up and new resources are constructed to replace forgone capacity at the dam.

In addition to the federal economic analysis, the Committee also measured the financial cost to individual utilities in a utility economic analysis. In estimating the financial impact on utilities, the Committee included transfer payments that incorporate such costs as the fixed costs of existing powerplants. In general, the financial impacts are substantially higher than the economic impacts because they include transfer payments between utilities. The Committee also examined the impact of higher financial costs on the retail rates of some end-use customers.

[4] Economic and Environmental Principles and Guidelines for Water and Related Land Resources Implementation Studies, U.S. Water Resources Council, Mar. 10, 1983.

## Power Resources Committee Conducted Detailed Analysis of Impacts on Large Utilities

The Committee conducted a detailed analysis of the impact of alternative flows on seven utilities from the regional power market.[5] In addition, the Committee used state-of-the-art and industry-standard simulation models to project the power resource additions and the production costs that the large utilities would incur to replace forgone power at the dam. In addition to the large-utility analysis, the Committee also estimated the impact of the alternative flow regimes on about 100 smaller utilities, using a spreadsheet model.

The Committee divided the regional power market into two basic groups: (1) seven large utilities, which own generating resources and sell power to other utilities and which represent about one-half of the regional power market, and (2) about 100 small utilities, which rely primarily on other utilities to generate their power needs.

From the large utilities, the Committee collected detailed data such as load and peak demand forecasts, the capacity and the operating costs and operating life of each generating unit, firm load purchases and sales, and the current and projected demand-side management programs.[6] In addition, the Committee developed assumptions about future prices for natural gas, oil, coal, and nuclear power and the future costs of adding new generating resources.

On the basis of the utility-specific data and using the Electric Generation Expansion Analysis System (EGEAS), the Committee calculated for the base case and each alternative flow regime each large utility's future expansion plan. The expansion plans represent the least-cost combination of new generating resources (or demand-side management programs) and purchased power that each utility would need to meet future demand for electricity.[7] In addition to the EGEAS model, the Committee used the Electric Utility Financial and Production Cost Model (Elfin) to cross-check the production cost estimates. The Committee used a 20-year planning period, beginning in 1991, to develop the expansion plans; a 30-year extension period was added on to complete the 50-year analysis period. Under the extension period, load was held constant but costs were allowed to escalate.

[5]One of the seven large utilities is no longer in existence.

[6]Demand-side management programs are used by utilities to promote more efficient energy use and include, for example, rebating or subsidizing the purchase of more efficient home appliances.

[7]The expansion plans were determined on the basis of the impacts of each alternative for the CROD marketing approach. The Committee used the expansion plans developed for the CROD approach to analyze the impacts of each alternative under the Hydrology marketing approach.

To model the large utilities in an integrated way, the Committee used several interconnected utility systems—consisting of a large utility and other utilities that sell or purchase power from the large utilities—to determine the effect of resource coordination on the selection of future generating resources by the large utilities. The large utilities were modeled to use their own generation resources to meet load demand. However, a utility was allowed to meet deficits or surpluses by purchasing energy from or selling it to its interconnected system.

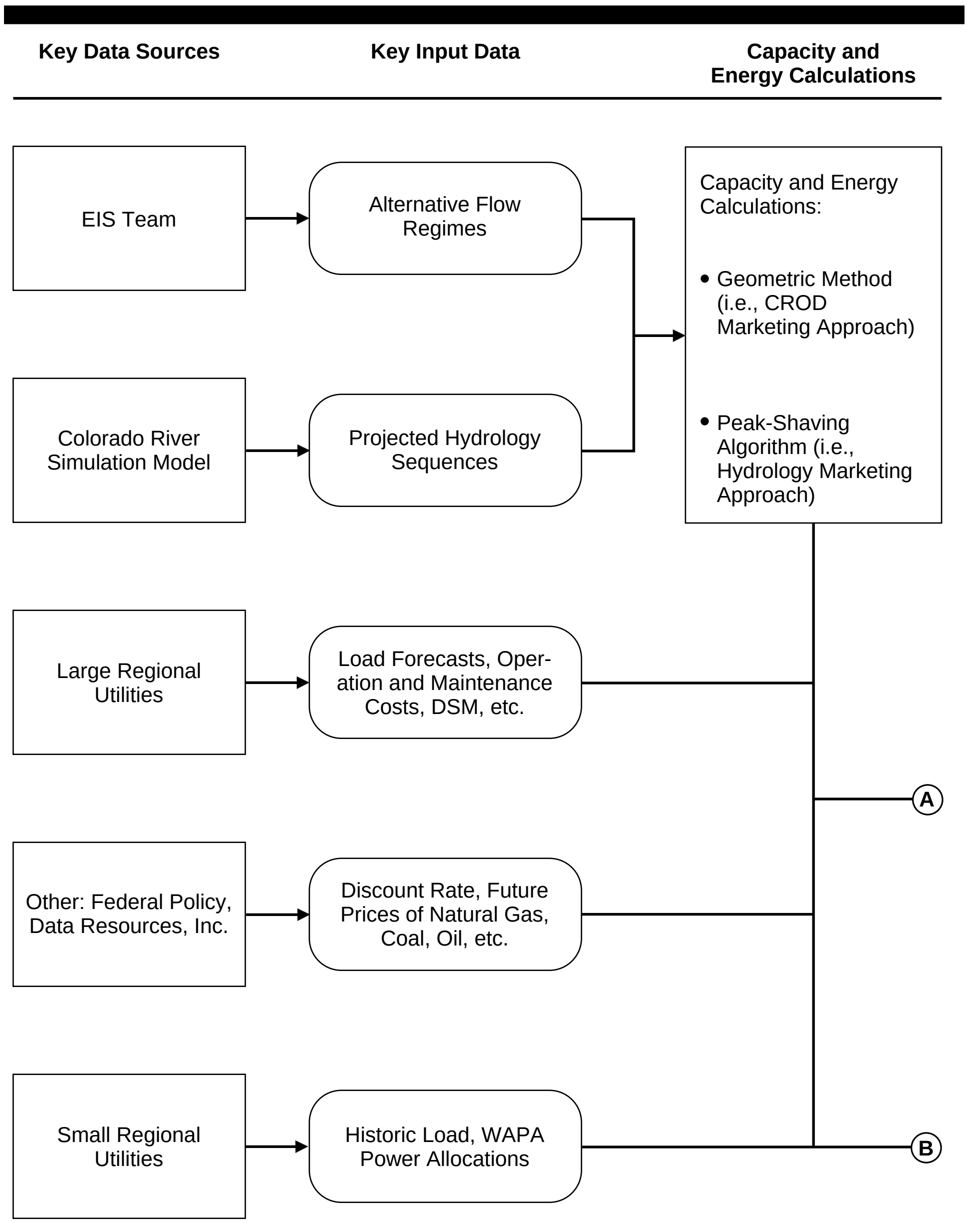
Because most of the modeled small utilities rely on other utilities to generate their power needs, the Committee used historic load data from the small utilities, replacement costs from the large-utility analysis, and a spreadsheet model to estimate the economic impact on small utilities over the analysis period. For example, the cost to a small utility of replacing forgone capacity was calculated as the increase in capacity and/or production costs incurred by the small utility's alternate supplier (that is, large utility). Unlike the large-utility analysis, however, the estimated costs for small utilities may not necessarily reflect the least-cost approach for replacing forgone power. For example, demand-side management programs were not considered as an option that small utilities could use to replace forgone power.

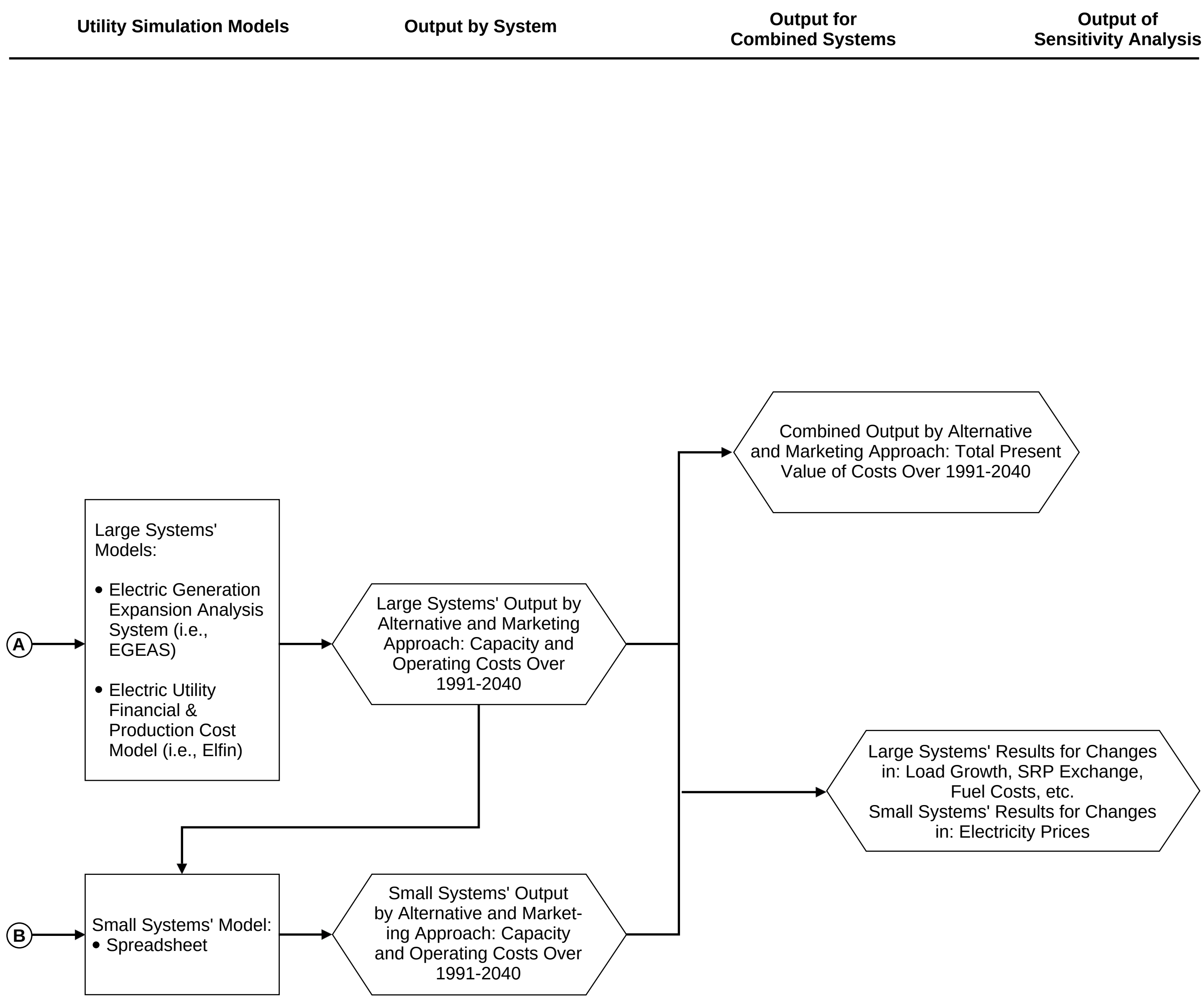
For both large and small utilities, the Committee calculated the economic costs for the base case and each alternative flow regime, under both the CROD and Hydrology marketing approaches. A discount rate of 8.5 percent was used to convert the annual stream of future economic costs to 1991 present valued dollars.[8] The Committee also "levelized" the total present-value cost estimate over the 50-year period to determine the annual levelized costs.

The difference between the base case and each alternative flow regime reflects, essentially, the cost of adding new generating capacity to replace forgone peaking power, and the cost of operating new and existing generating units to replace the energy shifted from on-peak periods to off-peak periods. A simplified representation of the Committee's methodology is shown in figure V.1.

[8]The Committee measured costs in nominal terms (that is, including inflation) partly because the federal discount rate policy for water resources planning requires the use of a nominal discount rate. The Committee also conducted a separate analysis using inflation-adjusted dollars and the nominal rate; however, this analysis is inconsistent because it uses a nominal rate to discount inflation-adjusted dollars.

**Figure V.1: Simplified Representation of the Power Resource Committee's Power Systems Economic Impact Methodology**






GAO presentation of the Bureau of Reclamation's data.

## Power Resources Committee Used Sensitivity Analysis to Test Impact of Key Assumptions

The Committee assessed the impact of changes in several key assumptions on the estimated economic costs. For example, for the large-utility analysis, the Committee assessed the impact of changes in assumptions about load growth, capital costs, fuel costs and escalation rates, environmental costs, hydrologic conditions, demand-side management program costs, and the potential for a curtailment in electricity transmission between WAPA and the Salt River Project (Salt River) in Phoenix, Arizona. WAPA and Salt River currently have an agreement for the exchange of surplus Glen Canyon Dam generation.

In addition to the large-utility analysis, the Committee also assessed the impact on the small systems of changes in the assumptions about escalation rates for electricity prices paid by the small utility to their alternate supplier.[9] The sensitivity analysis for the large utilities indicated that in particular the results for the Hydrology marketing approach are very sensitive to changes in load growth and in the level of curtailment in the WAPA-Salt River exchange agreement.

To conduct the sensitivity analysis, the Committee selected several variables that were the most influential in determining economic impacts. In addition, the Committee evaluated the effect of changes in these variables on the No-Action, Low Fluctuating Flow, and Seasonally Adjusted Steady Flow alternatives. For each variable, the Committee assumed low and high values. For example, zero annual growth was used for the low load-growth scenario, and double the medium load growth (medium annual growth was assumed to average 1.5 percent) was used for the high load-growth scenario.

To examine the effect of alternative curtailment levels on the Salt River exchange agreement with WAPA, the Committee assumed that a curtailment in the transmission of electricity between Salt River and WAPA would occur more or less frequently than the base case, depending on the scenario. Salt River entered into an agreement with the United States in 1962 to exchange surplus Glen Canyon Dam generation. Under the agreement, and when generation at federally owned facilities is sufficient, WAPA exchanges surplus Glen Canyon generation with Salt River for thermal generation at three units in which Salt River owns shares.[10] In addition, under certain

[9]Because the sensitivity analysis was conducted separately for the large and small systems using different sensitivity variables, the analysis does not fully capture the potential impact of changes in the key variables.

[10]Salt River has generation rights at Craig (29 percent of Units 1 and 2) and Hayden (50 percent of Unit 2) in Northern Colorado, and Four Corners (10 percent of Units 4 and 5) in New Mexico.

conditions, WAPA wheels power generated at Salt River's units to its main customer base in Arizona. However, because power generation would be reduced at Glen Canyon Dam under many of the flow alternatives, WAPA may be unable to continue to meet its load commitments and also continue to exchange generation with Salt River. To approximate the potential for a curtailment in the exchange of electricity between WAPA and Salt River, the Committee assumed that Salt River's generation shares in the three generating units would undergo periodic nonscheduled shutdowns. In the sensitivity analysis, the Committee increased the probability of a shutdown for a high forced-outage-rate scenario and decreased the probability of a shutdown for a low forced-outage-rate scenario, relative to the base case.

The sensitivity analyses indicated that alternative assumptions in load growth and in transmission curtailment can have a large impact on the estimated economic impacts, depending on the alternative and the marketing approach. For example, the Committee found that under a high-load growth forecast, on average, the 50-year economic cost of the Low Fluctuating Flow alternative using the Hydrology marketing approach would be higher by about $1.5 billion, compared to the No-Action alternative. Similarly, under a high probability of curtailment in the WAPA-Salt River exchange agreement in the Seasonally Adjusted Steady Flow alternative under the CROD marketing approach, on average, the 50-year economic cost would be higher by about $620 million, relative to the No-Action alternative.[11]

## Power Resources Committee Partially Revised Power Analysis for Final EIS

The Committee's initial analysis of the impacts on the power system, published in October 1993 and referred to as the phase II study, was included in the draft EIS. Reclamation received numerous comments on the draft EIS' power analysis. In addition, the Committee solicited additional review from three external energy experts, and Reclamation partially modified the draft EIS' preferred alternative. As a result, the Committee partially revised the power analysis in a phase III study, which was published in July 1995. For example, the Committee updated the projected costs of building gas-combustion powerplants, conducted additional

[11]The Committee's transmission exchange analysis is based on an assumption that WAPA would continue to market load at 1991 levels even though less Glen Canyon Dam capacity would be available for marketing under most of the alternatives. Because WAPA's load requirements would be lower than assumed, the likelihood and subsequent cost of a curtailment would be less, all else being the same.

sensitivity analyses, and revised the retail rate analysis.[12] However, because of Reclamation-imposed funding constraints, the Committee was able to revise the economic impacts only for the No-Action and the Modified Low Fluctuating Flow (preferred alternative) alternatives.

Furthermore, before the release of the draft EIS, but too late for inclusion in the phase II power analysis, Reclamation modified the characteristics of the Moderate Fluctuating Flow and Seasonally Adjusted Steady Flow alternatives to include beach-building flows and habitat maintenance flows. To include the impact of these modifications in the final EIS, the Committee used phase II cost and capacity data and a regression model to project the annual economic impacts of the two alternatives.

In addition, to develop comparable results between the phase II alternatives and the revised preferred alternative, the Committee also used the regression approach and phase II data to estimate the annual economic impact of implementing the preferred alternative. Before the release of the final EIS, Reclamation modified the preferred alternative to include a higher maximum release, a greater allowable daily increase in releases from the dam, and beach-building and habitat maintenance flows. Because this revised preferred alternative was not analyzed in the phase II study, comparable results with the other phase II alternatives were not available. As a result, the Committee used the regression approach to derive the economic impacts for the preferred alternative.

Consequently, the economic impacts for all nine alternatives shown in table IV-26 in Reclamation's final EIS (see page 300) are based on the phase II analysis and are generally comparable. The revised phase III power analysis for the preferred alternative is discussed separately on page 312 in the EIS under the description of the preferred alternative. Because the phase III results reflect a revised methodology and updated data, they are not comparable with the phase II results.

Although the phase III analysis reflects an improvement in methodology and in some data, it is of limited use in assessing the economic trade-offs between alternatives because only the No-Action and Modified Low Fluctuating Flow alternatives were modeled. Consequently, to show the impacts across alternatives, we display in table V.1 the estimated marketable resource and the comparable phase II economic results (that is, the point estimates) for the No-Action, High Fluctuating Flow, Modified

[12]In the phase III sensitivity analysis, the Committee tested the impact of changing the base year to 1995. The 1995 base year results indicated that the economic impact would be higher than the 1991 base year results, due partly to lower amounts of excess generating capacity.

Low Fluctuating Flow, and Seasonally Adjusted Steady Flow alternatives under the CROD marketing approach.

**Table V.1: Projected Impacts of Operational Changes at Glen Canyon Dam on Hydropower Over the Period 1991-2041**

| Glen Canyon Dam hydropower[a] | No Action | High Fluctuating Flow | Modified Low Fluctuating Flow | Seasonally Adjusted Steady Flow |
|---|---|---|---|---|
| Annual energy (gigawatt-hours) | 6,010 | 6,010 | 6,018 | 6,123 |
| Winter capacity (megawatts) | 1,407 | 1,383 | 965 | 640 |
| Summer capacity (megawatts) | 1,315 | 1,272 | 845 | 498 |
| Change in annual economic costs (1991 nominal $), compared to No-Action alternative | $0 | $2,500,000 | $44,200,000 | $123,500,000 |

Source: Bureau of Reclamation.

[a]Energy and capacity estimates are for WAPA's Salt Lake City Area/Integrated Projects facilities in total, including Glen Canyon Dam, which represents about 72 percent of WAPA's Salt Lake City Area/Integrated Projects generating resources. The change in annual economic costs are only for the operation of the Glen Canyon Dam.

## Estimated Impacts on the Power System Could Be Over- or Understated

We found shortcomings in certain phase II and phase III assumptions, inconsistencies in some phase II results, and computational errors made by Reclamation during the phase III analysis. For example, the Committee did not explicitly consider in either the phase II or phase III analysis the effect that higher electricity prices would have in reducing the demand for electricity and the need to replace forgone power at the dam. In addition, the Committee's escalation rates for future natural gas prices are relatively high, potentially increasing the cost of replacing forgone power. These shortcomings would suggest that the estimated economic impacts may be overstated. However, we also found that in the phase III analysis the Committee did not incorporate the possibility of a curtailment in the Salt River exchange agreement with WAPA. This factor (all else being the same) would tend to understate the estimated economic costs to hydropower because a curtailment in the exchange agreement might require Salt River to purchase additional higher-cost capacity. Because of the time and expense that would be required to recompute the results with revised methodology and data, we did not determine the net effect of these factors on the estimated economic impacts.

## Shortcomings in the Committee's Assumptions

Price elasticity effects were not explicitly incorporated into either the phase II or phase III analysis.[13] The Committee assumed that both load demand and electricity price would continue to rise over the planning period. However, the rise in electricity price would likely induce some electricity consumers (wholesale and end-use) to consume less electricity or switch to cheaper alternative suppliers. Consequently, fewer resources would be needed to replace forgone power at the dam, and the subsequent economic impacts would be lower than estimated (all else being the same). The Committee attempted to approximate the effects of price elasticity by using a low load-growth scenario in the sensitivity analysis. However, the inclusion of price elasticity effects in the base-case assumptions would give a more accurate picture of the potential economic impact of the alternative flow regimes.

Relatedly, demand-side management programs were not included as an option available to small utilities for replacing forgone power. The Committee assumed that the small systems would replace forgone power by purchasing power from their alternative supplier (that is, a large utility). Because this approach limits the choices that small utilities have in replacing forgone power, it may not reflect the least-cost option of replacing forgone power at the dam. Small utilities, for example, could also implement demand-side management programs as a way to mitigate the impact of forgone power, possibly at a lower cost.

We also found that the estimated economic impact of the preferred alternative in the phase III analysis does not incorporate the possibility of a curtailment in the Salt River exchange agreement with WAPA. During the phase III study, the Committee initially assumed that the preferred alternative (that is, the Modified Low Fluctuating Flow) would not affect the transmission exchange agreement between WAPA and Salt River, on the basis of the phase II analysis conducted for the draft EIS. However, some Committee members later revised their original assessment after Reclamation modified the preferred alternative to incorporate an increase in the maximum release and upramp rates and the beach-building and habitat maintenance flows. Implementation of beach-building and habitat maintenance flows could negatively affect the exchange agreement by effectively reducing water releases and subsequent power production during the summer months, when the demand for electricity is fairly high and when Salt River's system is at its peak. As a result, the economic

[13]The price elasticity of demand is a measure of the percentage change in the quantity demanded resulting from a percentage change in price. For example, assuming an estimated price elasticity of demand for electricity of –0.4, if the price of electricity rose by 1 percent, the quantity demanded for electricity would be expected to fall by 0.4 percent.

impact could be greater because a curtailment in the exchange could require Salt River to add additional higher-cost capacity. The key consultant who directed the power analysis told us that if curtailments increase in the summer months the impact on economic costs would be significant. According to some Committee members, a lack of time prevented the contractor from including these potential impacts in the phase III analysis.

In addition, the Committee's escalation rates, used to project future natural gas prices in the phase II and phase III analyses, are relatively high. The Committee used the escalation rates from DRI/McGraw-Hill's fourth-quarter 1991 forecast to project gas prices for the western states over the 50-year analysis period (the same escalation rates were used for the base case and the alternative cases). DRI has since revised downward its price forecast for natural gas. Despite comments from several reviewers that these escalation rates were too high, the Committee did not revise its analysis. For example, using DRI's 1991 forecast for Arizona and New Mexico, the Committee assumed that the average gas price would increase annually by 8 percent from 1991 through 2010. By contrast, DRI's 1994 forecast projected that gas prices would increase by about 6 percent annually from 1991 through 2010. Its 1995 forecast assumes that prices will rise by only 5 percent annually over the forecast period. Similar to hydropower, some gas-powered resources can be ideal as peaking resources because they can be turned on and off relatively quickly to meet fluctuations in demand. The higher escalation rates could affect the power analysis in two ways: (1) gas resources are selected later than they would be if fuel were cheaper and (2) gas resources are more expensive to operate than they would be under a lower gas-price trend. The Committee tested the impact of lower escalation rates in the phase II sensitivity analysis. However, the inclusion of the lower gas-price trend in the base-case assumptions would give a more accurate picture of the potential economic impact of the alternative flow regimes.

Finally, the Committee did not give full credit to the value of off-peak energy in mitigating the on-peak demand and energy costs in the small-utilities analysis in the phase II analysis. In general, the alternatives shift energy production from the on-peak period to the off-peak period. Even though less energy is produced during on-peak periods when it is more valuable, additional energy production during the off-peak period may help offset the cost of the forgone energy during the on-peak period. In the phase II analysis, however, the Committee essentially assigned a value of zero to some of the off-peak energy in the small-utilities analysis.

In a separate exercise, the Committee estimated that the value of the off-peak energy could reduce annual economic costs by as much as $19 million, depending on the alternative and the unit price of the energy.[14]

## Inconsistencies in the Committee's Results

We found two inconsistencies in the Committee's results. First, the economic results for the large utilities and the fluctuating flow alternatives under the Hydrology marketing approach are inconsistent in the phase II analysis. For example, in the phase II analysis the Committee found that on average less capacity is lost under the Hydrology marketing approach than under the CROD approach. However, the economic impacts are higher for the fluctuating flow alternatives under the Hydrology approach than for the fluctuating flow alternatives under the CROD approach. The key consultant who directed the power analysis told us that the inconsistency is due to the Committee's use of the CROD-based utility expansion plans to represent expansion plans in the Hydrology marketing approach. However, even though the expansion plans are least-cost under a CROD marketing approach, they may not reflect least-cost conditions under a Hydrology approach.

In addition, some of the phase II sensitivity analysis results are inconsistent. For example, the Committee found that under a wide range of possible expansion plans, the economic impact of the Low Fluctuating Flow alternative versus the No-Action alternative would be approximately $173,923,000 under the "all medium" scenario (all variables held at expected values) and about $143,170,000 under the "high-load forecast" scenario. This result is inconsistent because we would expect that the impact of the Low Fluctuating Flow alternative versus the No-Action alternative would be greater under a future scenario of high-load growth than a future scenario in which all variables were held at their expected values. The key consultant who directed the power analysis agreed that this result is inconsistent and stated that the most likely explanation is that more inefficient generation is replaced in the high-load forecast scenario.

## Computational Errors in the Committee's Analysis

Computational errors were made by the Reclamation staff during the phase III analysis. The Committee acknowledged these errors in its phase III report and stated that the errors affected the results in opposite ways. For example, in revising the monthly hydrologic release volumes,

[14]Power System Impacts of Potential Changes in Glen Canyon Power Plant Operations, Final Report (phase II) (Oct. 1993), page ES-17.

Reclamation incorrectly assumed that the beach-building flows would occur every year rather than every so many years, as is planned. As a result, more water was projected to flow through the spillways and less capacity and energy would be available for marketing purposes. The Committee stated that this error may have overstated the economic and financial impact of the preferred alternative. In another case, instead of using the average hydrological sequence (that is, the average of dry and wet years) to calculate future hydrological conditions and the impact on power production at the dam, the Committee used a different hydrological sequence. The Committee stated that this error may have understated the economic impact of the preferred alternative under the Hydrology marketing approach. The Committee was unable to correct these errors because of time and resource constraints and, consequently, was unable to determine the effect of the errors on the estimated economic and financial impacts.

## Power Results Can Be Useful Despite Limitations

Because future events are inherently uncertain and the actual cost of changing the dam's operations could also depend on factors yet to be determined, such as whether or not an Endangered Fish Research Program is implemented and the pace of deregulation in the electric utility industry, the actual economic impacts on power users may differ from those estimated. Often a point-estimate forecast is used to represent the most likely or expected outcome. In the case of the Committee's hydropower analysis, however, the limitations we have identified indicate that the point estimates lack precision. As a result, it should not be anticipated that the actual impacts will equal the estimated impacts. However, because the shortcomings we identified generally affect the point estimates for all of the alternatives, we do not believe that addressing the shortcomings would alter the relative ranking of the fluctuating and steady flow alternatives. In addition, we do not believe that addressing the inconsistency in the Hydrology marketing analysis (for example, using Hydrology-based expansion plans in the expansion analysis) would alter the relative ranking of the fluctuating and steady flow alternatives. Moreover, the inconsistency noted in the sensitivity analysis does not affect the phase II point estimates. Because the phase III analysis was limited to an assessment of the impacts of the No-Action and preferred alternative, the computational errors have no impact on the relative ranking of the phase II alternatives. Furthermore, Reclamation and representatives of the power industry believe that the results of the hydropower analysis presented in the final EIS are reasonable and usable. As a result, we believe that the estimated economic impacts can be used to compare in a general way the economic trade-offs that are associated with the various flow alternatives.

Consequently, we believe that Reclamation's estimated economic impacts are useful for comparing the economic trade-offs that may be associated with the fluctuating and steady flow alternatives. The Committee's analysis indicates that the estimated impacts are robust across alternatives; that is, the relative ranking of the fluctuating and steady flow alternatives is consistent even when taking into account changes in key assumptions such as load growth. Thus, in making a determination about the future operational plan for the dam, a decision maker can anticipate that, for example, a Seasonally Adjusted Steady Flow alternative would cost substantially more than a Modified Low Fluctuating Flow alternative. Furthermore, officials from Reclamation and the electric utility industry believe that the results are reasonable and usable. The Reclamation economist who served on the Power Resources Committee stated that he generally agreed with our observations but believed the methodology and the results are reasonable and should be useful in comparing economic trade-offs between alternatives. Similarly, an official from a regional utility who also served on the Committee said that the methodology and results are reasonable. Although the association that represents the affected power utilities maintained throughout the power studies process that the costs to the power system are understated, the association does not believe that Reclamation's cost estimate is understated by a large magnitude. The Salt River Project has also maintained that the estimated costs do not fully account for the higher costs that Salt River could incur as a result of a curtailment in the exchange agreement. However, the Salt River Project did not provide us with documentation supporting its position.

As indicated by the Committee's sensitivity analysis, changes in variables such as load growth can have a substantial impact on the estimated impacts. Economic impacts could also be affected by other factors yet to be determined, including whether or not an Endangered Fish Research Program (fish research) is implemented, and the pace of deregulation in the electric utility industry. For example, fish research could require higher-than-average water releases in the spring and summer months periodically to enable scientists to conduct fish research. As a result, water releases and power production during the other half of the year—between September and February—will be lower than average. Consequently, WAPA and its customers may have to seek alternative power supplies during certain periods, possibly at higher cost. In addition, the impact of fish research on Salt River could be substantial, because the decrease in the capacity available in the summer could limit the Salt River-WAPA electricity exchange agreement when the Salt River system peaks. As indicated by the Committee's sensitivity analysis, the economic costs of changes in the dam's operations increase substantially under assumptions of a greater probability of a curtailment in the Salt River-WAPA exchange agreement. According to the draft EIS, the economic impact of implementing fish research would fall within the range of impacts identified for the Modified Low Fluctuating Flow alternative and the Seasonally Adjusted Steady Flow alternative. The former alternative does not include the potential impact of fish research, and thus it represents the minimum potential impact. On the other hand, the latter alternative would involve flows similar to fish research flows but on a seasonal and annual basis; thus, it represents the maximum potential impact.

Finally, partly as a result of the Energy Policy Act of 1992, more opportunities for producing and delivering low-cost power to customers could emerge in the regional power market, which could help mitigate some of the economic burden that some small utilities in particular may bear as a result of changes in the dam's operations. For example, under the act, electricity generators (utilities, alternative energy producers) can use a competitor's transmission grid to wheel power directly to other utilities. As a result, small utilities may have access to alternative power sources that may be cheaper than their traditional suppliers.

## Scope and Methodology

To gain an understanding of the Bureau of Reclamation's power methodology, key economic assumptions, and results, we reviewed documentation that describes the methodology, economic assumptions, and results, including reports by the Power Resources Committee, entitled Power System Impacts of Potential Changes in Glen Canyon Power Plant Operations, Final Report (phase II) (Oct. 1993), and Power System Impacts of Potential Changes in Glen Canyon Power Plant Operations, Phase III Final Report (July 1995). Also, we interviewed members of the Power Resources Committee, including the Reclamation officials who served as Chairman and economist; representatives from the Western Area Power Administration, the Colorado River Energy Distributors Association, and the Environmental Defense Fund; and representatives from the primary contractor, HBRS, Inc., and subcontractor Stone & Webster Management Consultants, Inc. We also interviewed Ms. Leslie Buttorff who directed the power analysis for Stone and Webster.

To assess the reasonableness of the power methodology, economic assumptions, and results, we reviewed federal guidance on water resource projects entitled Economic and Environmental Principles and Guidelines for Water and Related Land Resources Implementation Studies (U.S. Water Resources Council, Mar. 10, 1983); public comments on the draft and final EIS; and comments by three energy consultants retained by HBRS, Inc., to review the power analysis. Also, we reviewed comments by the National Research Council on the power analyses in the draft and final environmental impact statements. In addition, we interviewed members of the Power Resources Committee, including representatives from Reclamation, the Western Area Power Administration, the Environmental Defense Fund, the Salt River Project, and the Platte River Power Authority, as well as officials from the Colorado River Energy Distributors Association, HBRS, Inc., Stone & Webster Management Consultants, Inc., the National Research Council's EIS review team, and several regional utilities. Finally, we used standard microeconomic principles to assess the reasonableness of the Power Resource Committee's methodology, analytical framework, economic assumptions, and results.

Our assessment of the reasonableness of Reclamation's methodology was limited to a review of the general analytical framework and an assessment of the reasonableness of key assumptions and data. We did not evaluate the Committee's calibration of the EGEAS and Elfin power simulation models or the small systems spreadsheet model, nor did we verify the accuracy of data inputs.

The organizations and individuals we contacted include those in the following list.

Arizona Public Service Company, Phoenix, Arizona
Bureau of Reclamation, Denver, Colorado
Buttorff, Leslie, A.T. Kearney, Inc., Englewood, Colorado
Colorado River Energy Distributors Association, Salt Lake City, Utah
Environmental Defense Fund, Oakland, California
Goodman, Ian, The Goodman Group, Boston, Massachusetts
HBRS, Inc., Madison, Wisconsin
Marcus, David, Berkeley, California
National Research Council, Washington, D.C.
Plains Electric Generation and Transmission Cooperative, Inc., Albuquerque, New Mexico
Platte River Power Authority, Fort Collins, Colorado

Salt River Project, Phoenix, Arizona
Stone & Webster Management Consultants, Inc., Englewood, Colorado
Tucson Electric Power Company, Tucson, Arizona
Western Area Power Administration, Salt Lake City, Utah

# Non-Use Value

The construction and operation of the Glen Canyon Dam changed river flows and the environment along the Colorado River, affecting, among other things, fish populations, beach and wildlife conditions, and sites of archeological significance in and near the Glen and the Grand canyons. The values that people may receive from the knowledge that such things as, for example, rare plants, animals, and unspoiled natural environments exist, even if people do not consume or use these goods directly, have been defined as "non-use values." The non-use value concept, which is generally attributed to economist John Krutilla,[1] can be relevant in natural resource and environmental policy settings that focus on proposals to develop the natural environment or to mitigate prior resource damage. In the context of the Glen Canyon Dam's EIS, individuals suffered losses in non-use values to the extent they valued the natural resources that were affected negatively by the changes in river flows after the construction of the dam. Conversely, the changes in the operation of the Glen Canyon Dam that are currently under consideration could result in environmental improvements in downstream riparian resources and hence gains in non-use values. At the urging of the National Research Council, an entity of the National Academy of Sciences, Reclamation undertook the non-use value study as part of the Glen Canyon Dam's EIS to provide estimates of the non-use values placed on changes in environmental quality that may be expected to result from particular operating changes at the Glen Canyon Dam.

The purpose of this appendix is to review the methodology and economic assumptions that Reclamation used to estimate non-use values and the reasonableness of the results. A key aspect of Reclamation's non-use value study[2] is its use of the "contingent valuation" method (CVM) to estimate economic impacts. While CVM is currently the only known method of estimating non-use values empirically, some prominent economists question the usefulness of the estimates of non-use values produced by contingent valuation studies. We are not taking a position on the appropriateness of contingent valuation generally.

[1]"Conservation Reconsidered," American Economic Review, vol. 57, Sept. 1967, pp. 777-786.

[2]The term non-use value applies to the value an individual places on a resource without directly or indirectly using that resource. The term total value applies to the value an individual places on a resource, including non-use and use components. According to Reclamation's non-use value study, the study actually measures total values. That is, a respondent to the non-use value survey could have been motivated by an experience of direct use (such as rafting or fishing) or indirect use of the natural resources in the study area, and thus the estimates may include values associated with recreation. Reclamation states, however, that the estimated total values are likely to consist primarily of non-use values.

The Glen Canyon Dam's EIS non-use value study was carried out in a manner consistent with contingent valuation and survey research guidance developed to produce high-quality contingent valuation studies. Non-use values were estimated for the level of change associated with each examined alternative compared to the no-action base case. As such, no estimate for the level of non-use values associated with the No-Action Flow alternative is provided. The study produced results that suggest that there are substantial non-use values associated with each of the examined alternatives to current operations at the Glen Canyon Dam. However, the results of the non-use value study were not available at the time the Glen Canyon Dam's final EIS was issued; therefore, the study did not receive public comment. Reclamation noted that although the non-use study did not go through the public comment process, the study team was comprised of interests that will be affected by changes to the Glen Canyon Dam, such as power groups and environmental groups. Furthermore, Reclamation stated that the study team received peer review at various key decision points in the process and that the final results received a positive review by the National Research Council.[3]

## Reclamation Used the Contingent Valuation Method as Basis for Estimating Economic Impacts

While economists have traditionally preferred to rely on information on what people do rather than on what they say they would do, economists and survey researchers working in the natural resource and environmental areas have developed the theory and practice of contingent valuation to estimate non-use values.[4] Non-use values are typically expressed in terms of willingness to pay by individuals or households for a specified environmental improvement. Typically, economists are more accustomed to calculating willingness-to-pay measurements for marketed goods because, in markets, information on how consumers value goods can be determined by their purchases of goods and services. Because by its definition a non-use good is not used, information from market transactions in which consumers reveal information about how much they are willing to pay for the good is not available. Contingent valuation methods currently offer the only known method of estimating non-use values empirically.

[3]River Resource Management in the Grand Canyon, Committee to Review the Glen Canyon Environmental Studies, National Research Council, Washington, D.C.: National Academy Press, 1996, p. 135.

[4]See, for example, Using Surveys to Value Public Goods: The Contingent Valuation Method, by Robert Cameron Mitchell and Richard T. Carson, Resources for the Future, 1989.

Contingent valuation studies rely on surveys to elicit information from consumers to estimate how much they would be willing to pay for a non-use good. In an overview of contingent valuation practice, a leading resource economist described three general features typically contained in contingent valuation studies.[5] First, a contingent valuation study contains descriptions of the policy or program at issue and the likely environmental effects so that respondents can understand the good they are valuing. Second, a contingent valuation study contains a framework or mechanism for eliciting willingness to pay. Several mechanisms have been used in contingent valuation studies, such as open-ended questions (How much would you be willing to pay?) and referendum formats (Would you vote for the described proposal if your taxes increase by $10?). Third, a contingent valuation study gathers information on socioeconomic variables and attitudes about the environment. This information is used in estimating willingness-to-pay functions using econometric techniques.

Some prominent economists have voiced strong criticisms of contingent valuation methods.[6] One of the main concerns about contingent valuation methods is the ability of survey research and statistical techniques to adequately capture true estimates of willingness to pay. Particularly with respect to non-use values, critics argue that it can be very difficult for individuals to comprehend a particular environmental or resource valuation issue, or to distinguish what researchers envision as a well-defined specific issue from a more general "warm glow" effect. Furthermore, some critics argue that the statistical estimation process by which willingness-to-pay estimates are produced from survey responses can be very imprecise.[7] Nonetheless, the contingent valuation method has become a standard tool for analyzing many natural resource issues.

[5]Paul R. Portney, "The Contingent Valuation Debate: Why Economists Should Care," Journal of Economic Perspectives, 8(4), Fall 1994, pp. 3-17.

[6]A collection of studies critical of contingent valuation can be found in Jerry A. Hausman, Contingent Valuation: A Critical Assessment. Amsterdam: North Holland Press, 1993; and also Peter A. Diamond and Jerry A. Hausman, "Contingent Valuation: Is Some Number Better Than No Number?," Journal of Economic Perspectives, 8(4), Fall 1994, pp.45-64.

[7]Daniel McFadden, "Contingent Valuation and Social Choice," American Journal of Agricultural Economics, 76(4), Nov. 1994, pp. 689-708.

## Developing Criteria to Examine Reclamation's Non-Use Value Study

To evaluate Reclamation's Glen Canyon non-use value study, we made use of some general guidelines that focus on the quality of a contingent valuation study and on the underlying survey research. Specifically, we relied on (1) the statement of a panel of prominent researchers convened by the National Oceanic and Atmospheric Administration (NOAA) to develop some general guidelines applicable to conducting contingent valuation studies[8] and (2) the total design method for conducting mail surveys developed by Dillman.[9]

## NOAA Panel Developed General Guidelines

As part of a process by which it developed regulations related to oil spill damages,[10] NOAA convened an advisory panel to address such issues as whether the contingent valuation method was capable of providing reliable estimates of non-use values for use in resource damage assessments.[11] The panel stated that contingent valuation "can produce estimates reliable enough to be the starting point of a judicial process of damage assessment, including lost passive-use (non-use) values," listed some guidelines for producing credible studies, and noted concerns about some past studies.

The panel suggested (1) using probability sampling and appropriate statistical sampling procedures, (2) subjecting the survey instruments to pretesting, and (3) taking steps to reduce nonresponse rates. Additionally, the panel suggested that contingent valuation studies disclose information on the sample selection process and provide information on survey instruments and responses. The panel also suggested that the use of the referendum format, as opposed to open-ended elicitation, was desirable.

The panel suggested that respondents be provided with a reminder that paying for the non-use good at issue would result in a smaller budget to spend on other goods and services and that they be told of any available substitutes. In this way, the decisions made by the respondents may more

[8]The panel's report was published in the Federal Register. See 58 Fed. R. 4601, Jan. 15, 1993.

[9]The most widely accepted written standards for mail questionnaires are presented by Don A. Dillman in Mail and Telephone Surveys, the Total Design Method (1978).

[10]The Oil Pollution Act of 1990, Pub. L. No. 101-380, 104 Stat. 484, required NOAA, within the Department of Commerce, to develop regulations for use by natural resource trustees in assessing damages due to oil spills.

[11]The panel was composed of Kenneth Arrow, Robert Solow (co-chairs), Edward Leamer, Roy Radner, Howard Schuman, and Paul Portney. Schuman is a prominent survey researcher, and the others are economists. Arrow and Solow are Nobel laureates.

closely resemble market transactions in which consumers make choices in the face of budget constraints.

The panel stated a preference for the use of in-person surveys as superior to telephone or mail surveys. The panel's report stated that it is "unlikely that reliable estimates of values could be elicited with mail surveys." This guideline in particular has been criticized by some contingent valuation practitioners, who argue that the use of large-scale, in-person surveys can dramatically increase the cost of conducting contingent valuation studies.

The NOAA panel echoed the concern that estimated willingness-to-pay figures be consistent with common notions of rationality. One aspect of rationality is that, generally speaking, people are willing to pay more for greater amounts of a good. The panel was troubled by evidence presented in one contingent valuation study finding that estimated willingness to pay "for the cleanup of all lakes in Ontario was only slightly more than willingness to pay for cleaning up lakes in just one region" and in another study that "willingness to pay to take measures to prevent 2,000 migratory birds (not endangered species) from dying in oil-filled ponds was as great as that for preventing 20,000 or 200,000 birds from dying." The sensitivity of a study to these so-called scope effects can be important in evaluating its credibility.

## Dillman's Standards Reflect a Total Survey Design Method

While the usefulness of contingent valuation methodology has been debated, survey research, a key component of contingent valuation studies, is itself a mature discipline with an accepted set of standards. For example, Dillman's "total design method" has become an accepted standard in survey research for maximizing the quality and quantity of responses to mail questionnaires.

By maximizing the quality of responses, researchers can have greater confidence in the validity of their work; that is, they can be surer that they are measuring what they intend to measure. By maximizing the quantity of responses they can have greater confidence in the reliability of their work; that is, repeated investigations will come up with similar results. Dillman's method provides a comprehensive approach that spans the design and implementation of mail questionnaires. From the wording of the questions to the pretest regimen to the design of the survey package and, finally, to the timetables for mailing and following up on the mailing, Dillman has a proven set of techniques that have been embraced by the survey research community.

## Reclamation's Non-Use Value Study Finds Substantial Non-Use Values Associated With Changes in Operations at Glen Canyon Dam

Using a contingent valuation study, Reclamation estimated non-use values for the environmental improvements associated with changing the operations at Glen Canyon Dam. These estimates, which ranged from less than $15 per household annually to almost $30 per household annually, depending on, among other things, the specific dam-operating alternative under consideration, indicate the large non-use values associated with environmental improvements and are consistent with the idea that some change in the dam's operations will lead to these improvements. Furthermore, although the EIS included a discussion of non-use values, the results of the non-use value study were not formally included as part of the EIS and thus were not subject to the same set of formal comments from interested parties.

### An Overview of the Glen Canyon Non-Use Value Study

The Glen Canyon non-use value study was one of the economic studies Reclamation carried out as part of the Glen Canyon Environmental Studies.[12] As part of the study process, a non-use value committee, including representatives from the power industry, environmental groups, Native American tribes, and federal agencies, met to consider interim results and to provide input to the research team. Additionally, the study team received peer review at various key decision points.

The researchers addressed some important preliminary issues in a qualitative research phase designed to establish whether a contingent valuation study would be likely to produce meaningful results. First, the researchers determined that representative individuals were able to distinguish the Colorado River environment in the Grand Canyon from the Grand Canyon itself. This was important because changes in the Glen Canyon Dam's operations would not affect the existence of the Grand Canyon itself. Rather, they would change aspects of the riparian environment along the Colorado River in and around the Grand Canyon. Importantly, if people were unable to distinguish changes to aspects of the riparian environment from broad changes to the Grand Canyon itself, then it would be impossible to provide meaningful estimates of non-use values related to operational changes at the Glen Canyon Dam. The researchers were convinced that people were able to make these distinctions and, moreover, were likely to care about, or to place meaningful values on, these resources.

The researchers also determined that people living far away from the Glen Canyon Dam were likely to care about the affected resources. This is

[12]The study was performed by Hagler Bailly Consulting under contract to Reclamation.

important in estimating aggregate non-use value because an average willingness-to-pay estimate is multiplied by the number of individuals or households believed to have non-use values. Because there are close to 100 million households in the United States, an average household's willingness to pay estimated to be $5 per year yields an aggregate non-use value of $500 million annually.

A pilot test phase was initiated in early 1994. A key research objective of this phase was to investigate whether willingness-to-pay estimates were sensitive to the various flow regimes under consideration, that is, whether non-use values were likely to increase in measurable ways related to the different river flows resulting from the different dam-operating alternatives. The pilot test included a series of nine versions of survey questionnaires given to separate samples of 250 respondents. Three of these versions were sent to national samples of households, with each version describing one river flow alternative and its likely effects on the affected resources. The three versions were the moderate fluctuating flow; the low fluctuating flow; and the seasonally adjusted steady flow. In general, the moderate fluctuating flow version describes the smallest improvement in environmental conditions, and the seasonally adjusted steady flow describes the biggest improvement. The surveys also describe adverse impacts on power customers, with more severe effects described in the seasonally adjusted steady flow version. Two versions, one describing the moderate fluctuating flow and one describing the seasonally adjusted steady flow, were sent to marketing area households.[13] The other four survey versions were sent to national samples and were used to address other methodological issues.

The qualitative research and pilot study phases included a thorough development and pretesting strategy, as well as peer and other reviews. During the qualitative research phase, researchers held 15 focus groups in which various methodological issues were investigated. In particular, focus groups were held in New York, Tennessee, and Nebraska to examine the geographic extent to which people living at some distance from the study area were likely to care about these resources.

The final phase of the non-use value study, built upon the knowledge developed during earlier phases, was designed to estimate non-use values. The researchers selected two samples—a national sample and a marketing area sample—and developed seven versions of a mail questionnaire.

[13]The marketing area refers to the geographic area in which individuals are served by utilities receiving power produced at Glen Canyon Dam.

Multiple versions of the instrument permitted the researchers to investigate the differences in non-use values associated with the differences in river flow conditions. While the overall Glen Canyon Environmental Studies examined nine alternatives, three flow alternatives were considered in the non-use study: moderate fluctuating flow; low fluctuating flow; and seasonally adjusted steady flow. According to the non-use study, these alternatives "covered most of the range of alternative dam operations being studied and were considered to include the set of alternatives most likely to contain the eventual preferred alternative."

## Estimates of Willingness to Pay for Environmental Improvements Associated With Changes in the Operation of Glen Canyon Dam

Non-use values were based on estimates of willingness to pay for the described flow alternatives. Respondents were provided with background information on a proposal to change the dam's operations and the likely downstream environmental effects and were asked how they would vote on the proposal if it were to cost them nothing. If they indicated they would vote yes, they were then asked another voting question, but this time the proposal was tied to a specified annual dollar amount and to a specified "payment vehicle." This form of contingent valuation study is known as the referendum format. The payment vehicle for respondents in the national sample was a tax increase, and the payment vehicle for respondents in the marketing area sample was a utility bill increase. Each respondent was assigned one of the following eight dollar amounts: $5, $15, $30, $60, $90, $120, $150, and $200.

Willingness to pay was then estimated using a logistic regression based on the resulting "yes or no" answers to the voting question. A variable, referred to here as BID, is defined as the specific dollar amount associated with the cost of the referendum proposal presented to the respondent. A variety of other explanatory variables were derived from the survey responses. For example, four variables describing the respondent's environmental attitudes were constructed using factor analysis of a variety of environmental attitude questions provided in the questionnaire. Also, a score variable was calculated from a portion of the survey used to test how well the respondent understood the proposal.

The form of the logistic cumulative density function is:

$$\text{probability(yes vote)}=1/(1 + \exp((-\Sigma\, \beta_i{*}X_i\,) - \beta_{BID}{*}BID)), \qquad (1)$$

where the $\beta_i$ are the coefficients for the explanatory variables and $\beta_{BID}$ is the coefficient on the BID variable specifically. An expression for mean willingness to pay (WTP) is derived from the following formula suggested by Hanemann[14]:

$$WTP = \ln ( 1 + \exp \Sigma \beta_i * X_i ) / -\beta_{BID}. \qquad (2)$$

The samples were split to focus on the different operating alternatives under consideration. The national sample was split four ways, examining two versions of the seasonally adjusted steady flow alternative along with the moderate and low fluctuating flow alternatives—and the marketing area sample was split three ways. For analytical purposes, a set of 0-1 dummy variables were included to indicate the different versions.[15]

The non-use questionnaires did not ask a binary “yes or no” vote question but used a scale which included “definitely yes” and “probably yes.” The researchers investigated two definitions of yes votes for use in the logistic regressions: using “definitely yes” as the definition of yes, and alternatively with “definitely/ probably yes” as the definition of yes. “Definitely yes” models generated mean willingness-to-pay values in the $20 to $38 range across all flow alternatives and for both the national and marketing area samples. “Definitely/Probably yes” models generated mean willingness-to-pay values of $100 to about $130. The researchers believe that the “definitely yes” definition provides better estimates than the use of binary “yes or no” definition. They also believe the “definitely yes” definition yielded lower willingness-to-pay estimates.

To generate population willingness to pay, the researchers had to address additional issues. The regression-derived mean willingness-to-pay values apply to those respondents who voted for the specified proposal when it was presented to them with the condition that they would not have to pay for it. However, some people did not respond to the survey, some respondents did not vote on the referendum question, and some respondents did not vote for the proposal at zero cost. In this study, the respondents who did not vote and those who voted no were both assigned a willingness to pay of $0. The researchers gathered information on

[14]W. Michael Hanemann, “Welfare Evaluations in Contingent Valuation Experiments With Discrete Responses,” American Journal of Agricultural Economics, vol. 66, Aug. 1984, pp. 332-341.

[15]In other words, the explanatory variables (the $X_i$) include a set of intercept dummies which permits different willingness-to-pay amounts to be determined for the different dam operation alternatives. $\beta_{BID}$ is estimated for the whole sample, but the $\Sigma \beta_i * X_i$ component in expression (2) above will be different depending on which flow alternative (survey version) is being considered.

nonrespondents using follow-up telephone interviews.[16,17] The assumed or estimated values for each of the groups were averaged together on the basis of their proportion of the sample. Table VI.1 presents the resulting willingness-to-pay values for the “definitely yes” version (dollars per household per year).

**Table VI.1: Population Average Willingness to Pay, Definitely Yes Model With Imputed Values for Nonrespondents (1991 Nominal Dollars per Household per Year)**

| Riverflow | National sample | Marketing area sample |
|---|---|---|
| Moderate fluctuating | $13.65 | $22.06 |
| Low fluctuating | $20.15 | $21.45 |
| Seasonally adjusted steady | $20.55 | $28.87 |
| Seasonally adjusted steady (but describing lower power cost effects) | $23.79 | • |

In general, the results indicate that individuals have a significant willingness to pay for the environmental improvements associated with a change from the no-action alternative to each of the other flow alternatives (i.e., the moderate fluctuating, low fluctuating, and seasonally adjusted steady flow alternatives). In addition, the national sample results indicate that individuals are willing to pay more for the environmental improvements associated with the seasonally adjusted steady flow alternative, compared to the moderate fluctuating flow alternative, and that the difference is statistically significant. The results also indicate that individuals are willing to pay more for the environmental improvements associated with the low fluctuating flow alternative, compared to the moderate flow alternative; however, this difference is not statistically significant. Consequently, we have less confidence in the precision of the estimate for the low fluctuating flow alternative.

Researchers provided ranges around the average willingness-to-pay values to reflect the statistical uncertainty surrounding the estimates. These ranges were calculated using repeated sampling from the estimated distributions of the parameters generated by the logistic regressions. In essence, the researchers calculated 3,000 estimates of mean willingness-to-pay for each alternative, arrayed them from lowest to highest, and reported the values as the lower and upper limits associated with a 95-percent confidence interval. Table VI.2 presents these results for

[16]The follow-up information was used to estimate willingness to pay on the basis of the characteristics derived through this process in conjunction with the results of a model using the mail survey respondents to predict the likelihood of voting for the proposal at zero cost.

[17]Estimates were provided for population average willingness to pay calculated with the assumption that nonrespondents had zero willingness to pay. These estimates were in the range of 15 to 20 percent less than the corresponding estimates with imputed values for nonrespondents.

the national sample and table VI.3 presents these results for the marketing area sample.

**Table VI.2: Population Weighted Average Willingness to Pay, Definitely Yes Model With Imputed Values for Nonrespondents and the Associated 95-Percent Confidence Interval, National Sample (1991 Nominal Dollars per Household per Year)**

| Riverflow | Population weighted average | 95-percent confidence interval: Lower limit | 95-percent confidence interval: Upper limit |
|---|---|---|---|
| Moderate fluctuating | $13.65 | $9.27 | $20.39 |
| Low fluctuating | $20.15 | $14.22 | $29.29 |
| Seasonally adjusted steady | $20.55 | $14.57 | $29.84 |
| Seasonally adjusted steady (but describing lower power cost effects) | $23.79 | $17.17 | $33.39 |

**Table VI.3: Population Weighted Average Willingness to Pay, Definitely Yes Model With Imputed Values for Nonrespondents and the Associated 95-Percent Confidence Interval, Marketing Area Sample (1991 Nominal Dollars per Household per Year)**

| Riverflow | Population weighted average | 95-percent confidence interval: Lower limit | 95-percent confidence interval: Upper limit |
|---|---|---|---|
| Moderate fluctuating | $22.06 | $16.68 | $29.39 |
| Low fluctuating | $21.45 | $15.84 | $29.28 |
| Seasonally adjusted steady | $28.87 | $22.50 | $37.24 |

Researchers calculated aggregate willingness-to-pay values on the basis of the population averages. This involved gathering estimates of the number of households in the United States and in the marketing area as well as population growth rates nationally and for a set of states to approximate future growth in the marketing area.[18] A 50-year period (1991-2040) was used. Levelized annual aggregate willingness-to-pay values were calculated using a discount rate of 8.5 percent. The results are presented in table VI.4.

**Table VI.4: Annual Aggregate Willingness to Pay, Definitely Yes Model With Imputed Values for Nonrespondents (Millions of 1991 Nominal Dollars)**

| Riverflow | National sample | Marketing area sample |
|---|---|---|
| Moderate fluctuating | $2,286.4 | $62.2 |
| Low fluctuating | $3,375.2 | $60.5 |
| Seasonally adjusted steady | $3,442.2 | $81.4 |
| Seasonally adjusted steady (but describing lower power cost effects) | $3,984.8 | • |

A range of annual aggregate values calculated using the lower and upper limits of the 95-percent confidence intervals for the population weighted

[18]These states were Wyoming, Utah, Colorado, New Mexico, Arizona, and Nevada.

averages are provided in table VI.5 for the national sample and in table VI.6 for the marketing area sample.

**Table VI.5: Range of Values for Annual Aggregate Willingness to Pay, Definitely Yes Model With Imputed Values for Nonrespondents, National Sample (Millions of 1991 Nominal Dollars)**

| | Annual aggregate willingness to pay on the basis of | | |
|---|---|---|---|
| Riverflow | Population weighted average | Lower limit | Upper limit |
| Moderate fluctuating | $2,286.4 | $1,552.7 | $3,415.4 |
| Low fluctuating | $3,375.2 | $2,381.9 | $4,906.2 |
| Seasonally adjusted steady | $3,442.2 | $2,750.3 | $4,998.4 |
| Seasonally adjusted steady (but describing lower power cost effects) | $3,984.8 | $2,875.8 | $5,592.7 |

Note: Lower and upper limits refer to the lower and upper limits of the 95-percent confidence interval for the population weighted average.

**Table VI.6: Range of Values for Annual Aggregate Willingness to Pay, Definitely Yes Model With Imputed Values for Nonrespondents, Marketing Area Sample (Millions of 1991 Nominal Dollars)**

| | Annual aggregate willingness to pay on the basis of | | |
|---|---|---|---|
| Riverflow | Population weighted average | Lower limit | Upper limit |
| Moderate fluctuating | $62.2 | $47.0 | $82.9 |
| Low fluctuating | $60.5 | $44.7 | $82.6 |
| Seasonally adjusted steady | $81.4 | $63.4 | $105.0 |

Note: Lower and upper limits refer to the lower and upper limits of the 95-percent confidence interval for the population weighted average.

## Evaluating the Non-Use Value Study Using the NOAA Panel and Dillman's Findings

We evaluated Reclamation's non-use study on the basis of issues considered by the NOAA panel and Dillman's total design methods as described above.[19] Most of the NOAA panel's suggested practices were part of the design and implementation of the Glen Canyon non-use value study, including those related to the sampling, pretesting, and reporting of results. Samples were based on commercially available sampling frames and were augmented with motor vehicle and postal service address update information. The researchers took random samples proportionate to the number of households in each state for the national sample and

[19]The NOAA panel's findings have no bearing on the Glen Canyon non-use study, and indeed were not published until after the Glen Canyon study was well under way. We refer to them because we believe that the NOAA panel's deliberations represent valuable critical and impartial thinking related to contingent valuation.

proportionate to the number of households in zip codes for the marketing area sample.[20] Respondents to the national survey had higher average levels of educational attainment and household income than the underlying population. It is likely that these characteristics are positively associated with willingness to pay for environmental improvements and thus increase non-use values. However, the magnitude of the effect is uncertain. During the qualitative research phase, draft questionnaires were pretested with six focus groups and six in-depth personal interviews. The questionnaires were reproduced in the report, along with responses to the various questions.

The study used the referendum format in preference to open-ended elicitation, and questionnaires emphasized the consumer's budget constraint, consistent with suggestions by the NOAA panel.[21] The study also provided a test on a respondent's level of understanding of the issue at hand.

A notable exception to the NOAA panel's suggested practices is that the Glen Canyon non-use value study used mail surveys. The panel strongly favored the use of in-person surveys. The Glen Canyon researchers maintain that well-designed mail surveys are capable of producing reliable results.

With respect to the design and implementation of the mail survey, we found that, except for one component, the researchers followed the total design method to the letter. Everything from the size and shape of the documents to the timing and amount of follow-up material was as Dillman suggested, and in general, the questionnaires were designed and implemented with extremely high standards. The researchers made a great effort to ensure that the questions both met the needs of the research design and were easily understood by the respondents.

Only the length of the instrument exceeded the maximum suggested by Dillman. The questionnaires were 18 pages, and according to Dillman, 10

[20]The national sample size was 3,400 individuals, and the marketing area sample size was 2,550. Each of the seven survey versions was administered to 850 individuals. In the national sample, two versions pertained to the Seasonally Adjusted Steady Flow alternative and differed not in their descriptions of environmental impacts but in their descriptions of possible electricity price impacts on users of Glen Canyon power.

[21]Respondents in the national sample were asked to answer the following question: "If this proposal passes and you had to pay $xxx every year for the foreseeable future, on what sorts of things would you spend less money in order to pay for the cost of this proposal?" In the marketing area survey, respondents were asked a similar question about monthly increases in utility bills. The next question then provided an opportunity for the respondent to change his or her vote. (Emphasis is contained in the questionnaires.)

to 12 pages is the maximum length for a questionnaire if a researcher does not want reduced response rates. Nonetheless, the average of 74 percent of the usable sample responding to the mail surveys and an average of 83 percent responding to the mail and follow-up telephone surveys is commendable given the nature of general public surveys. Although a shorter instrument may have led to higher response rates, the researchers faced a trade-off between the amount of background information and environmental attitude questions on the one hand and response rates on the other.

## Evaluating Scope Effects in the Glen Canyon Non-Use Value Study

Scope effects were of concern to the NOAA panel. Scope effects, broadly interpreted to mean that changes in estimated willingness to pay vary in ways that seem consistent with the changes in the degree of environmental improvement, are at the center of the Glen Canyon non-use value study because willingness to pay for the environmental effects of different river flows should differ to the extent that the effects differ. The researchers investigated scope effects in their discussion of the "construct validity" of the non-use value study.[22]

Scope tests can be considered a form of theoretical construct validity, in which hypotheses based on economic theory are addressed. For instance, one potentially important construct validity test is whether income is positively related to measured willingness to pay. In their summary of various construct validity issues, the researchers stated that they believed the national sample results provided the highest level of credibility, but that the marketing area sample results were a little less credible.

Scope issues were examined using both the pilot and final versions of the survey. Compared to the pilot version, the final survey's descriptions of the environmental effects differed less sharply across the various flow alternatives because, over time, scientific assessments carried out in the Glen Canyon Environmental Studies did not support such sharp distinctions.[23] Thus, the pilot test language permitted a somewhat cleaner

[22]Drawing on methods developed by psychologists, contingent valuation researchers often examine three issues relevant to a study's reliability. These are content validity, construct validity, and criterion validity.

[23]For instance, the pilot survey proposal describing the Seasonally Adjusted Steady Flow alternative stated that "There would be a major improvement in conditions for native fish. Populations of most native fish, including one of the species in danger of extinction, would increase." The final survey proposal describing this flow alternative stated that "There would be a major improvement in conditions for fish. Native fish, including one of the endangered species, would most likely increase in numbers. However, competition from non-native fish may still limit the growth of native fish populations."

test of the general issue of whether respondents were able to distinguish among the various degrees of environmental improvement associated with the different flow alternatives. Additionally, some versions of the pilot survey used a multiple-bounded rather than a single-bounded referendum format. This permitted greater statistical precision in testing for scope effects.[24]

Some scope tests are provided by the voting behavior of those respondents who voted for the proposal facing them at zero cost. According to the study, "the portion of respondents who would support proposals if the cost to them were zero varied significantly across proposals in ways that were consistent with prior expectations." Generally, respondents appeared willing to pay more for the environmental improvement associated with the Seasonally Adjusted Steady Flow alternative than for that associated with the Moderate Fluctuating Flow alternative.[25]

Direct tests for scope effects are accomplished by examining the dummy variables indicating the various survey versions. In the regressions, each dummy variable can be interpreted as an additional willingness-to-pay contribution for the additional environmental improvement associated with that flow version over the environmental effects associated with the examined reference case, moderate fluctuating flow.[26] One complicating factor, however, is that the different versions can involve trade-offs. Specifically, the seasonally adjusted steady flow version describes a greater environmental improvement but a more serious adverse effect on

[24]Because the multiple-bounded approach was new, the researchers decided to use the more traditional single-bounded form in the final versions. Using an additional bound would allow a finer partition of the willingness-to-pay range. For instance, if a respondent indicates a willingness to pay $10 but an unwillingness to pay $20, the upper bound has been established. The concern with providing the respondent with another dollar amount is that it may provide a valuation cue to the respondent and thereby introduce a response bias.

[25]Additionally, in the national sample pilot test, survey versions were similar except that one mentioned improved conditions for fish while the other did not produce different willingness-to-pay estimates.

[26]In a regression, one of a set of mutually exclusive and exhaustive dummy variables is omitted as an explanatory variable. In this way, the "omitted" category can be thought of as the reference case. In the Glen Canyon study, the moderate fluctuation flow version is the reference case.

power customers.[27] To focus more clearly on willingness to pay for environmental improvement, researchers developed two versions of the seasonally adjusted steady flow survey, which differed only in the description of the adverse effects on power customers.[28] This permits some disentangling of an environmental improvement scope effect from the combined effect of environmental improvement and adverse power impacts.[29]

Because each survey version designated with a dummy variable offers greater environmental improvement compared to the moderate fluctuating flow version, expectations are that the parameter estimates for variables representing alternative flows should be positive. For the preferred "definitely yes" model, four of the five key parameter estimates are of the correct sign. However, only the coefficients for the two seasonally adjusted steady flow alternatives in the national sample are statistically significant (i.e., different from zero, using a one-tailed test at the 90-percent confidence level). The study acknowledges that the results of these scope tests are mixed but suggests that the totality of evidence (including pilot test versions and the "definitely and probably yes" models) are relevant for discussions of scope tests, and much of that evidence is stronger.

[27]In the national sample, the referendum proposal described effects on households and farmers using power generated at Glen Canyon Dam. The fluctuating flow versions contained the following language: "The average electric bill would increase by $3 per month for 1.5 million households receiving power from Glen Canyon Dam. This average reflects a maximum increase of $9 per month for 3,600 households and a minimum of no increase for 800,000 households. On average, farm incomes would not change significantly. However, about 300 farmers in southern Utah would see their incomes drop by 3%." The steady flow version stated: "The average electric bill would increase by $9 per month for 1.5 million households receiving power from Glen Canyon Dam. This average reflects a maximum increase of $21 per month for 3,600 households to a minimum of no increase for 300,000 households. On average, farm incomes would not change significantly. However, about 300 farmers in southern Utah would see their incomes drop by 6%."

[28]Specifically, the second version of the steady flow proposal included descriptions of the adverse effects on power customers and farmers that were identical to those used in the fluctuating flow versions.

[29]The use of two survey versions describing the seasonally adjusted steady flow also permits investigation into whether a description of the power impacts possibly provides a cue to respondents in answering the referendum question. For example, the value of the dummy with the higher power impacts would be greater in magnitude than the dummy with the lower power impacts if respondents interpreted the larger dollar impacts on power users as an indication of the magnitude of the environmental problem. Conversely, if respondents empathized with the plight of power users, the results would be the opposite.

## Results of the Non-Use Value Study Could Be Significant in the Decision-Making Process

Non-use values represent the highest estimated economic impact from changing the Glen Canyon Dam's operations. Non-use values were based on estimates of the public's willingness to pay for downstream environmental improvement that would likely result from changes in the dam's operations. Willingness-to-pay estimates for the national sample ranged from less than $15 per household annually to about $20 per household annually. Because there are close to 100 million households in the United States, an average household's willingness to pay estimated to be $15 per year yields an aggregate non-use value of $1.5 billion annually, which is very large when compared to the estimated annual power costs.

Although the final EIS discusses non-use values and notes that they are positive and significant, the actual quantified results are not included in the final EIS. Reclamation did not include the non-use value study results in the final EIS because they were not available when the final EIS was published. Nonetheless, the non-use value study will be among the materials provided to the Secretary and, as a result, could be used in the final decision-making. In fact, the National Research Council in its 1996 report stated that the non-use value study results "deserve full attention as decisions are made regarding dam operations."[30]

Because the actual quantified results of the non-use value study were not in the draft or final EIS, they were not available to the general public to offer comments similar to other EIS results. While acknowledging the lack of formal public comment, Reclamation officials point out that the non-use value study was subjected to extensive peer review at key decision points in the process and that the final non-use value study received a positive review by the National Research Council. Reclamation also states that interests likely to be affected by the changes in the Glen Canyon Dam, such as power groups or environmental groups, were involved in the non-use value study process.

## Scope and Methodology

To gain an understanding of Reclamation's non-use value study methodology and results, we reviewed the final report GCES Non-Use Value Study, September 8, 1995. We also reviewed the economics literature on non-use values and the contingent valuation method for estimating them. We interviewed the principal author of the report, a Senior Associate at Hagler Bailly Consulting. We examined reports prepared by peer reviewers

[30]River Resource Management in the Grand Canyon, Committee to Review the Glen Canyon Environmental Studies, National Research Council, Washington, D.C. National Academy Press, 1996, p. 135.

and we also discussed the study with some members of the non-use value committee.

The following is a list of individuals we contacted.

David Harpman, Natural Resource Economist, Bureau of Reclamation
Michael P. Welsh, Hagler Bailly Consulting
Bruce Brown, ECOPLAN Consultants

# Recreation

The purpose of this appendix is to review (1) the methodology and key assumptions that the Bureau of Reclamation used to estimate the economic impact on recreation of alternative water releases at Glen Canyon Dam and (2) the reasonableness of the estimated impacts. The section of the Colorado River below the dam is used by a variety of recreationists, including anglers, boaters, day-rafters, campers, and hikers. We found that the methodology that Reclamation used to estimate the economic impact of alternative flows on recreational activities is generally reasonable. For example, recreationists were surveyed to assess the impact of changes in the dam's operations on recreation activities. In addition, modeling was used to estimate the economic benefits accruing to the national economy from recreational activities under the different flow regimes.

Reclamation has estimated that the economic impact on recreational activities of changing the operations at the dam could range from $0 under the Maximum Powerplant Capacity and High Fluctuating Flow alternatives to benefits of $4.8 million under the Seasonally Adjusted Steady Flow alternative (in 1991 nominal dollars, relative to a No-Action alternative). However, we found several limitations in Reclamation's recreation analysis that suggest that the estimated economic benefits could be over- or understated. For example, because the initial recreation study was completed in 1985 and some recreation conditions have changed since then, some of the study's data may not reflect more recent trends in recreational activities below the dam. Also, recreationists were surveyed during an unusually high water year, limiting the ability of the researchers to capture representative recreational experiences, and some of the survey instruments were not adequately pretested to minimize bias and confusion on the part of survey participants. In addition, anglers who fish within the Grand Canyon were not included in the survey. Because of the inherent uncertainty associated with future events, the actual economic impacts on recreation may differ from those estimated. Nonetheless, despite these limitations, we believe that the estimated impacts can be useful for generally assessing the impacts that may be associated with moving from a No-Action alternative to a fluctuating or steady flow alternative. Moreover, Reclamation and National Park Service officials told us that they were generally aware of the limitations in the recreation analysis but believe that revising the study would not change the basic conclusions of the EIS, the preferred alternative, or the ranking of alternatives. Furthermore, a reviewer of the recreation study for the National Research Council told us that the recreation analysis reflected current professional practices and was well done.

## Introduction

Recreation is an important use of the Colorado River below the Glen Canyon Dam. The 15-mile segment of the river below the dam—located within the Glen Canyon National Recreational Area—is the last remaining riverine section of the 189-mile, river-carved channel that once was Glen Canyon. A variety of recreationists use this portion of the river, including anglers, boaters, day-rafters, campers, and hikers. Downstream from Glen Canyon, the Colorado River runs through Marble Canyon and Grand Canyon. This segment of the river is the longest stretch of river (278 miles) for recreational use that is entirely located within a national park. A large number of rapids, as well as the river's isolation within the Grand Canyon, enhance recreational activities along this portion of the river. After passing through the Grand Canyon, the Colorado River is impounded by the Hoover Dam and forms the largest reservoir in the Western United States—Lake Mead. According to Reclamation, about 100,000 boaters annually use this stretch of the Colorado River and Lake Mead for scenic boating, camping, fishing, and water-skiing.

## Effects of Pre- and Postdam Conditions on Recreation

The Glen Canyon trout fishery has flourished since the construction of the dam. Water flows from the dam are colder, carry less silt, and are more stable on an annual basis than before the dam was constructed. According to the Department of the Interior, following the completion of the Glen Canyon Dam, the first 15 miles of flat water between the dam and Lees Ferry, once stocked with trout, became an excellent coldwater fishery. This section of the river is also used for half-day commercial raft trips, which, depending upon the flow level, depart either from a dock near the Glen Canyon Dam and float down to Lees Ferry or from Lees Ferry and motor part way upstream before floating back downstream.[1]

Before the early 1960s, and before the dam was completed, few visitors entered the canyon or ran the river. However, Reclamation's EIS indicates that white-water boating in the Grand Canyon is a major industry today, with 15,000 to 20,000 commercial and private boaters annually, paralleling an increasing trend nationwide in white-water boating. In order to help minimize impacts by recreationists, the National Park Service established a ceiling on the number of user days allowed each year along with stricter river-use regulations. Before the dam, riverflows were highly variable and ranged from low flows (frequently less than 3,000 cubic feet per second) to peak flows (occasionally in excess of 100,000 cfs) in spring and early summer. Now, riverflows are within a much narrower range—generally

[1]High discharges associated with flood flows preclude rafting trips from departing near the dam. The probability that such flows will occur is diminished by several features of the action alternatives described in Reclamation's EIS.

from 3,000 cfs to 31,500 cfs (20,000 cfs under the interim operating criteria)—and show less seasonal variation, reducing the high- and low-water risks associated with recreating on the river.

Before the construction of the Glen Canyon Dam, spring runoff carried sediment down the Colorado River to Lake Mead. After construction of the dam, sediment from side canyons and beaches continued to be transported down the river, but in smaller quantities. Over the years, these sediment deposits have built up to form broad mud flats at the upper end of Lake Mead. When the water level in Lake Mead falls below 1,180 feet, boat navigation is difficult because the river is too shallow at low flows and the channel changes with water fluctuations.

## Issue

The major issue addressed by Reclamation in its EIS analysis of recreation was how do dam operations affect recreation in the study area? Specifically, Reclamation's assessment focused on how changes in the dam's operations would affect angling, day-rafting, and white-water boating along the Colorado River in the Glen and Grand canyons, as well as the recreationists using lakes Powell and Mead.

## Indicators

Reclamation evaluated the impact of alternative flow regimes on a series of indicator activities. The indicators are:

- 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.

## Effects of Flow Alternatives on Recreation

According to Reclamation's EIS, fishing in the Glen Canyon occurs mostly from boats, but some anglers wade in the area around Lees Ferry. The magnitude and rate of change in the river's stage increases the danger for anglers wading in the Glen Canyon reach. Therefore, fishing safety would improve under the Moderate, Modified Low and the Interim Low Fluctuating Flow alternatives, because fluctuations are reduced and the rate at which the river's stage rises is constrained. Upstream fishing access by boat under the Maximum Powerplant Capacity alternative is the same as under the No-Action alternative. Increased minimum flows under the

High Fluctuating Flow alternative would result in a negligible increase in the ease of upstream access by anglers. Because damage to boats and motors is more likely during the low-flow periods that typically occur in the morning before peak power generation occurs, increased minimums and changes in the magnitude of upramp and downramp rates (that is, changes in cfs per hour) would greatly improve upstream access under all other alternatives.

Reclamation's EIS states that the flood control measures included in the restricted fluctuating and steady flow alternatives would reduce the probability of flood events and the corresponding need to launch from Lees Ferry, thus improving the quality of the day-rafting experience in Glen Canyon. In addition, the risk of white-water boating accidents would be highest under the No-Action and Maximum Powerplant Capacity alternatives, slightly lower under the High Fluctuating Flow alternative, and lower under the remaining restricted fluctuating flow alternatives. All steady flow alternatives would decrease the risk of white-water boating accidents over the No-Action alternative.

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

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

Because riverflows and the magnitude and frequency of fluctuations differ under each alternative, the net economic value of recreation would also differ. The majority of recreational benefits are derived from commercial white-water rafting, which in general is positively related to average daily flows and negatively related to fluctuations. Those alternatives that increase average summer flows or eliminate daily fluctuations in excess of 10,000 cfs tend to increase recreational benefits.

## Reclamation's Methodology for Making Impact Assessments

In assessing the effects on recreation of the different operating regimes for the Glen Canyon Dam, the final EIS gives numerical values where possible; otherwise, it gives qualitative assessments that are based on physical, biological, and economic research. There are three distinct and independent components to the recreational material presented in the EIS. The first is a quantitative assessment of the net economic value of river-based recreation associated with the different flow alternatives. The second component is a qualitative assessment performed by resource managers using the results of scientific studies of the impact of flow alternatives on individual resources. The third recreation component involves an analysis of the regional economic impacts of recreation. Regional economic impact refers to expenditures and their importance to the local economy in the study area. The first two components are based on a study of visitors' preferences conducted by Bishop et al (1987). This appendix will address only the specifics of the first component—the economic benefits associated with recreation.

## Reclamation's Recreation Impact Methodology Is Generally Reasonable

We found that the methodology that Reclamation used to estimate the economic impact of alternative flows on recreation activities is generally reasonable. For example, to obtain information from river recreationists, the researchers used a two-stage research design. They conducted two sets of surveys to obtain information from white-water boaters, anglers, and day-rafters. In addition, the researchers analyzed the survey data using a "logit" regression model to determine the amount of money that recreationists would be willing to pay to experience recreational activities under different flow regimes. Also, they used a national economic perspective in the analysis to estimate the recreation benefits accruing to the national economy.

To design and conduct the recreation study, Reclamation contracted with a private consulting firm, HBRS, Inc. (now Hagler Bailly Consulting; hereinafter, the contractor or researchers). The contractor completed an initial study in 1987 and an updated study in 1993.[2] The updated study was used as the basis for the recreation benefits cited in the final EIS.

[2]Glen Canyon Dam Releases and Downstream Recreation: An Analysis of User Preferences and Economic Values, 1987; and Analysis of the Impact of GCDEIS Alternatives on Recreational Benefits Downstream From Glen Canyon, Madison, Wisconsin: HBRS, Inc., 1993.

## A Two-Stage Research Design Was Used to Obtain Survey Data

The contractor used a two-stage research design to determine the potential impact of alternative flows at the Glen Canyon Dam on three groups of recreationists—white-water boaters, day-rafters, and anglers. Because riverflows during the period the research was carried out were predominately high and steady, there was no way to ensure that a representative sample drawn from the three groups would include recreationists who had experienced the full range of flows being evaluated. Therefore, the contractor asked the respondents to evaluate their actual trips as well as written descriptions (scenarios) of recreational experiences under a variety of flow levels that they may not have experienced.

During the first stage, the contractor surveyed each recreational group to identify the important characteristics (or attributes) of the recreational experience on the Colorado River and what effect, if any, riverflows would have on these experiences. The contractor also administered these attribute surveys to commercial white-water boating guides and private trip leaders to get a more informed view of how riverflows affect the experiences of boaters on the river. White-water boating participants in the attribute survey were selected from the National Park Service's records of trip launches for the 1982 and 1984 seasons. For anglers, the contractor attempted to survey anglers at Lees Ferry during selected days in November and December 1984. The researchers chose day-rafters from a concessionaire's list of individuals who took a Glen Canyon raft trip during the months of April through October 1985.

The contractor applied what had been learned from the attribute surveys to the design of the scenarios for the contingent valuation survey.[3] A contingent valuation survey attempts to measure the willingness of a group of people to pay for hypothetical projects or programs. The contractor used questionnaires to ask individuals about their dollar valuation of a series of specific hypothetical changes in Colorado River flows. Because the valuation is contingent on the specific hypothetical change identified, these values are called "contingent values" and the

[3]Another approach for measuring recreation impacts is the travel cost method. This method uses travel and related costs that are incurred during a recreational activity to approximate the market price for a recreation trip.

method of obtaining data is termed the "contingent valuation method," or CVM.[4]

The scenarios described white-water trips and angling trips at various flow levels in terms of identified flow-sensitive attributes.[5] The scenarios also distinguished between constant and fluctuating flows. A fluctuating flow primarily occurs when the dam is being operated for peak power production. Fluctuations in excess of 10,000 cfs within a 24-hour period constituted a fluctuating flow for the recreation study's purposes. The 10,000-cfs threshold was based on the results of the attribute surveys.

In the second stage, the contractor used the scenarios as the basis of the contingent valuation survey. Along with the actual trip experience and its total cost, the contractor used these hypothetical descriptions to quantify the effects of different flow regimes on the recreational experience. Specifically, the contractor described the change in the recreational experience and asked those surveyed whether they would still take such a trip if their expenses were to increase by a certain randomly assigned dollar amount over their trip's actual cost. The respondents were limited to "yes" and "no" answers. The researchers also provided the respondents with riverflow information corresponding to the date of their actual trip in order to gain information about the trip and establish a context for the responses to the scenarios. In addition to this information, the researchers asked the recreationists about the characteristics of their actual trip and reasons for taking the trip. Also included were questions about the respondent's income level and indicators of how well the respondents understood the survey and thought the results would affect the cost of future recreation.

A 1987 review by the National Research Council stated that the use of the contingent valuation technique to address the public's willingness to pay for angling and rafting opportunities through the Grand Canyon was "a bold application of this promising method. The researchers, who are well

[4]In our review of the contingent valuation survey, we relied on Dillman's total design method as well as on economic reasoning in assessing the reasonableness of Reclamation's application of the CVM approach. Dillman's method is an accepted standard in survey research for achieving the maximum quality and quantity of responses to mail questionnaires. By achieving the maximum quality of responses, for example, researchers can have greater confidence in the validity of the work; that is, they can be more sure of measuring what they intend to measure. By achieving the maximum quantity of responses, researchers can have greater confidence in the reliability of their work that repeated investigations will produce similar results. A more detailed discussion of the CVM approach is presented in app. VI of this report; the total design method is described in Dillman, Don A., Mail and Telephone Surveys: The Total Design Method, John Wiley & Sons, New York, 1978.

[5]Because the attribute survey found day-rafters insensitive to flows, no scenarios were presented to this sample group.

known for their development of the technique, have ably and creatively analyzed the satisfaction of recent recreationists."[6]

## Economic Estimates Developed Using Federal Principles and Guidelines

We found that the contractor followed federal principles and guidelines for water resources planning where applicable in developing estimates of the recreation benefits. For example, federal principles and guidelines state that the federal objective of water and related land resources planning is to contribute to national economic development (consistent with protecting the environment).[7] In addition, the guidelines state that the benefits arising from recreational opportunities created by a project are measured in terms of willingness to pay. The contractor defined recreational benefits in terms of consumers' willingness to pay and calculated the net economic benefit, or "surplus value," associated with the recreational experiences under different flow conditions. Surplus value is the value that the recreationists placed on their recreational experience over and above what they actually paid for the recreational experience. Expenditures, such as the price of a Grand Canyon white-water boat trip, were excluded from the net economic benefit calculations because the expenditures represent a transfer payment to the local economy. Transfer payments simply redistribute income from one group in society to another, and therefore they do not reflect an economic benefit to the national economy.

Nonetheless, expenditures are important because they support local businesses and provide employment for local residents. For this reason, recreational expenditures were the focus of a separate analysis of regional economic activity that Reclamation performed.

## Economic Benefits Were Estimated Using Econometric Model

The contractor used a now standard econometric approach to evaluate the contingent valuation response data. For example, surplus values were estimated using a "logit" model, that was based on the "yes" and "no" answers to the survey's valuation question. Using the logit model, the contractor estimated the probability that a respondent would be willing to pay a specific dollar amount (termed "offer amount") above his/her actual trip cost to recreate under the various flow regimes. This probability was assumed to be a function of several independent variables, including the

[6]River and Dam Management: A Review of the Bureau of Reclamation's Glen Canyon Environmental Studies, National Academy Press, Washington D.C., 1987, p. 63.

[7]Economic and Environmental Principles and Guidelines for Water and Related Land Resources Implementation Studies, U.S. Water Resources Council, Mar. 10, 1983.

offer amount, the amount the recreationist spent to take an actual trip, and the number of days spent on the river.

To update the estimated values obtained during the 1985 survey, the contractor used the 1985 model with the hydrologic conditions for 1991 to generate surplus values for various alternatives by month and by recreational activity. The contractor then multiplied the surplus values by the observed 1991 monthly participation rates for each activity. The resulting estimates were then inflated to 1991 dollars. In addition, because the initial recreation study was completed before Reclamation developed the alternative flow regimes in the EIS, the contractor extrapolated from the flow regimes used in the contingent valuation survey to the EIS flow regimes using a combination of historical data on the dam's operations and projections of future hydrologic conditions over a 20-year planning period. The 20th year was repeated for 30 years to complete the 50-year analysis period. The Colorado River Simulation System model was used to develop the future hydrologic projections, which were identical to those used in the power analysis.

To determine the present value of future recreation benefits over the 50-year analysis period, the contractor discounted future annual benefits using the federal discount rate of 8.5 percent.[8] The present value was "levelized" over the 50-year analysis period to determine equivalent annual benefits. Table VII.1 shows the estimated net economic benefits for recreation associated with the nine alternatives discussed in the final EIS. The table reflects the net benefits associated with white-water boating and angling activities. The number of white-water boating and angler trips were held constant at 1991 levels over the 50-year analysis period. The researchers found that day-rafters are not sensitive to river stage and fluctuations; thus, the economic impact of changes in the dam's operations on day-rafters was estimated to be zero.

[8]The net recreation benefits in each year in the analysis period were inflated by the projected gross national product price deflator for that year. The same deflator and discount rate were also used in the hydropower analysis.

**Table VII.1: Economic Benefits Associated With Recreation Activities, Relative to the No-Action Alternative (1991 Nominal Dollars in Millions)**

| EIS alternatives | Present value of net benefits over 50-year analysis period | Equivalent annual net benefits |
|---|---|---|
| No Action | $0 | $0 |
| Maximum Powerplant Capacity | $0 | $0 |
| High Fluctuating Flow | $0 | $0 |
| Moderate Fluctuating Flow | $4.6 | $0.4 |
| Modified Low Fluctuating Flow | $43.3 | $3.7 |
| Interim Low Fluctuating Flow | $45.6 | $3.9 |
| Existing Monthly Volume Steady Flow | $45.6 | $3.9 |
| Seasonally Adjusted Steady Flow | $55.0 | $4.8 |
| Year-Round Steady Flow | $23.5 | $2.9 |

Source: Bureau of Reclamation.

## Shortcomings in Recreation Analysis Suggest Economic Impacts Could Be Over- or Understated

Although the recreation methodology is generally reasonable, we found limitations in the analysis. For example, because the initial recreation study was completed in 1985 and some recreational conditions have changed since then, some of the study's data may not reflect more recent trends in the recreational activities below the dam. Also, the researchers gathered the survey data during an unusually high-water year, limiting the ability to capture representative recreational experiences, and they did not adequately pretest some of the survey instruments to minimize bias and confusion on the part of the participants. In addition, the contractor did not include Grand Canyon anglers in the survey. Finally, some of the econometric results are inconsistent with expectations based on conventional economic reasoning. These limitations indicate that the estimated recreation benefits could be over- or understated. Because of the time and expense that would be required to recompute the results with revised methodology and data, we did not determine the net effect of the limitations on the estimated economic impacts.

### Recreation Conditions May Have Changed Since the Survey

We found that some of the data used to develop the economic benefits may be dated because of changes in the recreation environment since recreationists were surveyed in 1985. The contractor used 1985 surplus values and number of trips taken in 1991 to derive recreation benefits for alternative flows. However, because the estimated benefits were derived using 1985 surplus values, they may not account for more recent changes in recreational activities that could affect value.[9]

The years 1985 and 1991 combined for use in the model were different in terms of the number of recreational trips taken, especially for anglers. For example, according to study statistics, the actual number of fishing trips at Lees Ferry more than doubled between 1985 and 1991, from 6,064 to 12,902. In addition, the fishing regulations changed during this period, strictly limiting anglers to artificial lures and imposing new restrictions on the size and number of fish caught. Because of the substantial change in the number of fishing trips taken and a change in fishing regulations, it may not be reasonable to assume that the value per fishing trip, relative to other goods and services, would have remained unchanged between 1985 and 1991.

## Survey Data Based on a Year With Unusually High Water

The researchers were not able to capture representative recreational experiences because of the river conditions present during the recreation study. The sample year—1985—used to develop the statistical relationship between flow rates and surplus values was an atypical year for the Colorado River, characterized by relatively high, constant flows and poor fishing. To address this data issue, the contractor used hypothetical scenarios (developed using the attribute survey information) to determine the effect of different flow regimes on recreational experiences. However, two potential problems with the use of the high-water year and scenario data are (1) the estimated surplus values depend heavily on the ability of the respondents to meaningfully interpret the scenarios using their high-water experience and (2) the surplus values generated from scenario data may differ from those based on actual experiences.

Ideally, the respondents should be asked about their willingness to pay for alternative flow regimes that they have actually experienced. At the time of the recreation survey in 1985, however, there had been already 2 consecutive years of high-water flows. In addition, according to Reclamation, it was not feasible to adjust the Glen Canyon Dam's operations to create alternative flow conditions for the recreation study. Therefore, the contractor constructed hypothetical scenarios to simulate recreational experiences under different flow conditions. The contractor then asked the recreationists to compare their actual trip experiences with the hypothetical trip experiences.

[9]Surplus values were adjusted for inflation between 1985 and 1991.

However, because 1985 and the preceding years were unusually high-water years characterized by constant flows, some recreationists may not have experienced a variety of flow conditions. For example, the researchers could not make inferences about the influence of fluctuating flows on white-water boaters using information from actual trips because only 12 percent of the respondents experienced these fluctuations. Similarly, because there was little variation in the actual trip experiences for anglers, the researchers were unable to make a direct link between the actual trip's surplus value and the flow levels experienced by the respondent. This condition is attributable to all anglers having experienced such small variation in flow conditions that substantially all of the respondents compared the scenarios with essentially the same limited actual flow experiences. Consequently, there was no way to determine whether recreationists who experienced other types of flows would have valued the scenarios differently. For example, a recreationist who had experienced low, fluctuating flows might value a medium flow more than a recreationist who experienced only a high constant flow.

## Some Questionnaires Were Not Adequately Pretested

Although the researchers used Dillman's total design method for the implementation of the surveys and tested proposed questions to determine which wording options offered the highest response rates, they did not adequately pretest some survey instruments to detect defects in wording, construction, presentation, or other inadequacies. As a result, we cannot be completely confident that the surveys actually measured what they were intending to measure.

Reclamation's contractor used mail questionnaires to gather data on recreational attributes and contingent values. We found that the contractor generally followed Dillman's total design method in the design and implementation of these questionnaires. For example, the contractor met Dillman's standards for questionnaire design and mailing procedures, which helped to obtain response rates between 70 and 93 percent. These response rates allow the researchers to have greater confidence that they do not have a biased picture of the sample caused by differences between the respondents and nonrespondents.

However, we also found that the contractor did not follow Dillman's pretesting standards. For example, the attribute survey for anglers and the questionnaire used for white-water guides were pretested in person, while other questionnaires were pretested through the mail. According to Dillman, mail pretesting is "destined to be of very limited value." Only by having respondents fill out the draft in the presence of the researchers can they discover such information as: Is each question measuring what it is intended to measure? Are all the words understood? Are the questions interpreted similarly by all respondents? Is any part of the questionnaire biased? Because such pretesting was not done, neither we nor the contractor can be confident about the validity of the questions or the instruments as a whole.

An example of problems that may have resulted from inadequate pretesting can be seen in the interpretation of the water levels experienced by anglers. In the in-person interviews performed for the angler attribute questionnaire, the researchers found problems with the responses to questions that dealt with water levels experienced by the anglers. The authors of the recreation study noted that for the 2 years before the attribute survey, steady high water was the rule. However, some respondents who had fished at Lees Ferry only during 1984 and 1985 answered that they had experienced low, medium, or fluctuating flows. The authors conclude that some anglers may have answered the water-level experience question incorrectly. These responses are evidence of possible problems in the validity of the measures used. We do not know the extent of misunderstanding between the respondents and the contractor, but this example suggests that there was some. Adequate pretesting may have detected and corrected this misunderstanding.

## Grand Canyon Anglers Were Excluded From Survey

The contractor assumed that fishing in locations other than Lees Ferry was an incidental activity and therefore did not include these anglers in the survey. As a result, the data for anglers are based solely on the recreational experiences of anglers at Lees Ferry. To the extent that other anglers who fish downstream in the Colorado River or its tributaries have surplus values that are different from the Lees Ferry anglers (but also positive), the estimated benefits may understate the total benefits to anglers resulting from alternative flow regimes.

The researchers defined the angling population to include those who access the river from Lees Ferry in Glen Canyon, which had the effect of excluding anglers in the Grand Canyon. According to the researchers and recreation subteam members, the Grand Canyon anglers were not included in the study for a variety of reasons. For example, they were thought to represent only a small percentage of fishing activity; they might be difficult to sample; and fishing itself was not considered to be the focus of a Grand Canyon recreational experience. Although little information exists on the extent of angling in the Grand Canyon or the characteristics of these anglers, the EIS makes reference to 15 sites in the Grand Canyon that are managed for anglers who want to catch "fish that are naturally reproduced in the wild." In addition, the National Park Service and Arizona Game and Fish Department officials we contacted indicated that some anglers fish in the vicinity of Marble Canyon to avoid the restrictions on natural bait enforced at Lees Ferry, and other anglers hike down into Phantom Ranch to fish in Bright Angel Creek. The difficulty or expense of reaching or staying at a location other than Lees Ferry, a preference for "wild" rather than hatchery fish, and reasons for going to the river other than fishing could mean that these groups of anglers have different opinions of the values of flows than those who were sampled.

## Survey Data Do Not Precisely Correspond to EIS Flow Alternatives

Because the researchers designed and conducted the recreation contingent valuation survey well before the EIS operating regimes were proposed for the Glen Canyon Dam, the flow regimes used in the survey scenarios do not precisely correspond to the flow alternatives identified in the final EIS. As a result, there is some uncertainty as to whether the survey data reflect the same environmental changes proposed in the EIS alternatives.

An unusual aspect of the recreational modeling effort is that it is composed of two separate segments of work, several years apart, occurring within the framework of the Glen Canyon Environmental Studies. Reclamation's contractor began the initial study of recreational values in 1984, and the results were published in 1987. The 1987 study, however, predated the development of the preferred alternative.

In order to allocate the estimated recreation benefits to the alternative flow regimes in the EIS, the contractor converted the EIS alternatives into the same terms as those used in the original survey. This was done by translating the EIS alternatives into average flow terms and identifying fluctuations in flow using a mixture of theoretical data and data from the dam's actual operations. However, the recreation survey was based on broad groupings of flows, while the EIS flow alternatives are much more detailed in their characteristics. As a result of this sequencing, it is not clear that the aggregate recreational values captured in the 1987 study reflect the same environmental changes proposed in the EIS alternatives. The recreation analysis may not have captured the nuances that distinguish the individual EIS flow alternatives. For example, the scenarios used in the 1987 study used average flow figures (such as 13,000 cfs) to ask individuals about their dollar valuation of a hypothetical change in riverflows, while the EIS describes complex alternatives stated both in terms of minimum and maximum flows (for example, 1,000 cfs to 31,500 cfs) as well as the rate of change in flows per hour (that is, ramping up or down). Although ramping can affect the recreational experience, by using these averages, the recreation analysis was not able to assess the impact of ramping on recreational activities. For example, rapid changes in the upramp rate of the dam's operations can put wading anglers at risk of inundation, as well as affect the "naturalness" of a wilderness boating experience. Similarly, rapid changes in the downramp rate of the dam's operations can strand anglers in boats, as well as fish in backwaters.

A Reclamation official and the contract researchers acknowledge that there is no systematic linkage between the scenarios used in the contingent valuation surveys and the flow regimes in the final EIS. A Reclamation official told us that translating the EIS alternatives into the same terms used in the 1985 scenarios involved a great simplification. For example, the scenarios were based on a dichotomous approach: a single mean monthly flow rate and the presence or absence of fluctuations. If the flow levels varied by more than 10,000 cfs, they were considered fluctuating. If the flow levels varied by less than or were equal to 10,000 cfs, they were considered steady. By contrast, the EIS alternatives involve complex variables, including flow ranges and rates that change hourly. As a result of this simplification, the recreation model cannot distinguish between several alternatives. That is, the model predicted the same economic benefits for the No-Action, Maximum Powerplant Capacity, and High Fluctuating Flows, as well as for the Interim Low Fluctuating Flow and the Existing Monthly Volume Steady Flow.

## Some Econometric Results Are Inconsistent With Conventional Economic Reasoning

Some of the econometric results indicate a positive and significant relationship between surplus value and the expenditure variable, which is inconsistent with conventional economic reasoning. For example, in the analysis of white-water boaters' and anglers' responses, the contractor found that the respondents' surplus values increased with the amounts they spent to take their actual trips. This result is inconsistent with conventional economic reasoning because we would expect that the more an individual spends on a trip, the lower would be his or her surplus value, all else being the same. Because this result may be symptomatic of a technical problem, such as a misspecification of the model, a measurement error, or an insufficient sample size, it suggests that the results lack precision.[10]

Some members of the contract research team acknowledged this inconsistency between the results of the model and conventional economic reasoning. One of the contractor's researchers told us that the positive relationship between surplus value and expenditure may be attributable to an omitted price variable. In his opinion, however, this omission does not affect the validity of the results incorporated into the EIS.

## The EIS Team Used Estimated Recreation Benefits Only to Aid Decision-Making

Reclamation and National Park Service officials involved in the EIS process told us they were generally aware of the limitations of the recreation analysis but believe that addressing the limitations would not change the basic conclusions of the EIS, the choice of the preferred alternative, or the ranking of alternatives. No such changes would occur because the study results were used more as an adjunct in developing a preferred alternative, rather than a focal point.

A Reclamation official involved in the selection of the preferred alternative told us that the first criterion applied to the nine proposed alternatives was how the sediment balance in the canyon would be affected. Alternatives that negatively affected the amount and location of sediment were eliminated, leaving only three alternatives, none of which posed a safety threat to recreationists except at very low flows. Since two of the three remaining alternatives were identical except for a habitat maintenance flow, the EIS team had to choose between only two alternatives. In choosing between these two alternatives, the EIS team weighed the power costs associated with each, the recreational benefits, and unquantified ecological concerns, such as benefits to the aquatic food base. According to this official, the EIS team selected the Modified Low Fluctuating Flow as the preferred alternative because the loss of power revenues was roughly offset by the gains to the other resources.

National Park Service and Reclamation officials told us that Reclamation considered revising the recreation economic study after the EIS alternatives were developed to get better data on how respondents valued a wide variety of actual flow conditions and on anglers' participation in the Lees Ferry fishery. In particular, a researcher raised the prospect of

[10]Researchers were unable to calculate a standard error because the appropriate statistical techniques were not available at the time of the study. However, a Reclamation official told us that the estimates are subject to an error of about plus or minus 20 percent.

further investigating anglers' values to overcome the limitations of the original study. However, Reclamation decided not to spend additional resources on revising the recreational analysis in order to further study areas that were deemed more critical. A National Park Service representative told us that because most of the unanswered questions were in the areas of sediment, vegetation, and endangered fish, funds were directed to these "higher-priority data gaps."

## Recreation Results Can Be Useful Despite Limitations

Because there is inherent uncertainty associated with projecting future impacts, the actual economic impacts on recreation may differ from those estimated. The limitations we have identified suggest that the estimated impacts could be over- or understated. Nonetheless, despite these limitations, we believe that the estimated impacts can be useful for generally assessing the impacts that may be associated with moving from a No-Action alternative to a restricted fluctuating or steady flow alternative. Moreover, a reviewer of the recreation study for the National Research Council indicated to us that the recreation modeling was conducted using current professional practices and was a state-of-the-art effort given the budget and time constraints. In addition, this reviewer indicated that the work on the economics of recreational use was well done and a good use of taxpayer money given the many other demands on the Glen Canyon Environmental Studies budget.

## Reclamation's and the National Park Service's Response to the Recreation Issues Raised

We discussed our findings with a National Park Service and a Reclamation official who, as EIS team members, were responsible for incorporating recreation and the economics of recreational use into the EIS. These officials, a resource management specialist with the National Park Service and an economist with the Bureau of Reclamation, generally agreed with our statements concerning the strengths and weaknesses of the recreation analysis. Reclamation's economist acknowledged that recreational conditions may have changed since the study's survey was implemented in 1985. Both officials said that the methodology was reasonable and appropriate and the data were the best available at the time of the study. For these reasons, they told us that neither the ranking of alternatives nor the choice of a preferred alternative would change, even if the issues we identified as shortcomings were resolved.

## Scope and Methodology

To gain an understanding of general recreational issues we reviewed studies on recreation use in the Glen and Grand canyons. To assess the reasonableness of the recreation methodology, assumptions, and results, we reviewed the documents that describe Reclamation's methodology, assumptions and data, and literature on the contingent valuation method, and we used standard economic principles. Our assessment was limited to a review of the general analytical framework and an assessment of the reasonableness of key assumptions and data. We did not validate data inputs.

The documents we reviewed include the following:

Analysis of the Impact of GCDEIS Alternatives on Recreational Benefits Downstream From Glen Canyon (draft report). Madison, Wisconsin: HBRS, Inc., 1993.

Bishop, R., C. Brown, M. Welsh, and K.J. Boyle. "Grand Canyon Recreation and Glen Canyon Dam Operations: An Economic Evaluation, W-133," Benefits and Costs in Natural Resource Planning: Interim Report 2. Edited by Kevin J. Boyle and Trish Heekin. Orono, Maine: Department of Agricultural and Resource Economics, University of Maine, 1989.

Bishop, R., K. Boyle, M. Welsh, R. Baumgartner, and P. Rathbun. Glen Canyon Dam Releases and Downstream Recreation. Glen Canyon Environmental Studies Technical Report. Salt Lake City, Utah: Bureau of Reclamation, 1987.

Boyle, K., M. Welsh, and R. Bishop. "The Role of Question Order and Respondent Experience in Contingent-Valuation Studies," Journal of Environmental Economics and Management, pp. 80-99, 1993.

Boyle, K., M. Welsh, R. Bishop, and R. Baumgartner. "Analyzing the Effects of Glen Canyon Dam Releases on Colorado River Recreation Using Scenarios of Unexperienced Flow Conditions, W-133," Benefits and Costs in Natural Resource Planning: Interim Report. Compiled by John B. Loomis. Davis, California: Department of Agricultural and Resource Economics, University of California, 1988.

Chestnut, L., R. Raucher, and R. Rowe. A Review of the Economic Studies Conducted in Phase I of the Glen Canyon Environmental Studies. Report to Mr. Dave Wegner, Bureau of Reclamation - Upper Colorado Region, Flagstaff, Arizona. Economic Studies for the Glen Canyon Environmental Studies, Phase II. RCG/Hagler, Bailly, Inc., 1991.

Cummings, R.G., D.S. Brookshire, and W.D. Schulze. Valuing Environmental Goods: An Assessment of the Contingent Valuation Method. Rowman & Littlefield Publishers, 1986.

Diamond, P.A., J. Hausman. "Contingent Valuation: Is Some Number Better than No Number?" Journal of Economic Perspectives, Vol. 8, No. 4, pp. 45-64, 1994.

Economic and Environmental Principles and Guidelines for Water and Related Land Resources Implementation Studies, U.S. Water Resources Council, Mar. 10, 1983.

Final Report: Hualapai Recreation Studies. SWCA, Inc. Environmental Consultants. Feb. 1995.

Final 1993 Annual Report: Hualapai Recreation Studies. SWCA, Inc., Jan. 1994.

Glen Canyon Environmental Studies Final Report. Salt Lake City, Utah: Bureau of Reclamation, U.S. Department of the Interior, 1988.

Hanemann, W. M. "Valuing the Environment Through Contingent Valuation," Journal of Economic Perspectives, Vol. 8, No. 4, pp. 19-43, 1994.

HBRS, Inc. Glen Canyon Dam Releases and Downstream Recreation: An Analysis of User Preferences and Economic Values, 1987.

Jalbert, L. The Influence of Discharge on Recreational Values Including Crowding and Congestion and Safety in Grand Canyon National Park. Grand Canyon National Park Division of Resources Management, 1992.

Jalbert, L. Monitoring Visitor Distribution and Use Patterns Along the Colorado River Corridor: River Contact Survey and Attraction Site Monitoring (status report). Grand Canyon National Park Division of Resources Management and Planning, 1991.

Kearsley, L. Monitoring the Effects of Glen Canyon Dam Interim Flows on Campsite Size Along the Colorado River in Grand Canyon National Park (final report). Grand Canyon National Park Division of Resources Management, National Park Service, 1995.

Kearsley, L., J. Schmidt, and K. Warren. "Effects of Glen Canyon Dam on Colorado River Sand Deposits Used as Campsites in Grand Canyon National Park, USA," Regulated Rivers: Research and Management, Vol. 9, pp. 137-149, 1994.

Kearsley, L., and K. Warren. River Campsites in Grand Canyon National Park: Inventory and Effects of Discharge on Campsite Size and Availability (final report). Grand Canyon National Park Division of Resource Management, National Park Service, 1993.

Operation of Glen Canyon Dam Final Environmental Impact Statement. Bureau of Reclamation, U.S. Department of the Interior, 1995.

Operation of Glen Canyon Dam Draft Environmental Impact Statement: Public Comments Analysis Report. Prepared by the Bear West Consulting Team for the Bureau of Reclamation, 1994.

Portney, P.R. "The Contingent Valuation Debate: Why Economists Should Care," Journal of Economic Perspectives, Vol. 8, No. 4, pp. 3-17, 1994.

Reger, S., K. Tinning, and L. Piest. Colorado River Lee's Ferry Fish Management Report, 1985-1988. Phoenix, Arizona: Arizona Game and Fish Department, 1989.

Richards, M., and D.B. Wood. "The Economic Value of Sportfishing at Lees Ferry, Arizona," Riparian Ecosystems and Their Management: Reconciling Conflicting Uses. Proceedings of the First North American Riparian Conference. Apr. 16-18, 1985. Tucson, Arizona. U.S.D.A. Forest Service General Technical Report RM 120. Ft. Collins, Colorado: Rocky Mountain Forest and Range Experiment Station.

River Resource Management in the Grand Canyon, Committee to Review the Glen Canyon Environmental Studies, National Research Council, Washington, D.C.: National Academy Press, 1996.

River and Dam Management: A Review of the Bureau of Reclamation's Glen Canyon Environmental Studies, Committee to Review the Glen Canyon Environmental Studies, National Research Council. Washington, D.C.: National Academy Press, 1987.

Schulze, W., R. d'Arge, and D. Brookshire. "Valuing Environmental Commodities: Some Recent Experiments," Land Economics, Vol. 57, No. 2, pp. 151-172, 1981.

Shelby, B., T.C. Brown, and R. Baumgartner. "Effects of Streamflows on River Trips on the Colorado River in Grand Canyon, Arizona," Rivers, Vol. 3, No. 3, pp. 191-201, 1992.

Stevens, L., K. Buck, B. Brown, and N. Kline. Dam and Geomorphic Influences on Colorado River Waterbird Distribution, Grand Canyon, Arizona, USA, 1995 (unpublished original research).

We also interviewed researchers, members of the EIS and recreation teams, including Reclamation officials and their contractors, as well as representatives from the National Park Service and the Arizona Game and Fish Department. In addition, we spoke to academic experts in economics and members of the National Academy of Sciences Glen Canyon Dam EIS review team. A list of the researchers, officials, and experts follows.

Richard Bishop, Professor, University of Wisconsin
Kevin Boyle, Associate Professor, University of Maine
Curtis Brown, Social Psychologist, Bureau of Reclamation
Bonnie Colby, Associate Professor of Agricultural and Resource Economics, University of Arizona, Tucson
Galen Collins, Assistant Dean of Hotel and Restaurant Management, Northern Arizona University
Diane Dupont, Associate Professor of Economics, Brock University - Ontario, Canada
Marshall Flug, Water Resources Engineer and Research Hydrologist, National Biological Service and Colorado State University
Rusty Gattis, Acting Superintendent, Glen Canyon Dam, Bureau of Reclamation
Terry Gunn, Owner, Lees Ferry Angler's Guides and Fly Shop
W. Michael Hanemann, Professor of Agricultural and Resource Economics, University of California, Berkeley
Martha Hahn, Idaho State Director, Bureau of Land Management
David Harpman, Natural Resource Economist, Bureau of Reclamation
Amis Holm, Environmental Planner III, SWCA, Inc. Environmental Consultants
Brice Hoskins, Project Manager, SWCA, Inc. Environmental Consultants
Charles Howe, Professor of Economics, University of Colorado

Linda Jalbert, Biological Technician, National Park Service
Lisa Kearsley, former National Park Service employee and researcher
Mark Law, Colorado River Subdistrict Ranger, National Park Service
Jerry Mitchell, Chief, Cultural Resource Management, National Park Service
Mike O'Donnell, Supervisory Natural Resource Specialist, Bureau of Land Management
Timothy Randle, Hydraulic Engineer, Bureau of Reclamation
Larry Riley, Supervisor, Arizona Game and Fish Department
Michael Welsh, Senior Associate, Hagler Bailly Consulting

# Sediment

Sediment is unconsolidated material that comes from the weathering of rock and is transported and deposited by water or wind. It is seen as a key indicator resource for the Grand Canyon ecosystem because nearly all of the canyon's resources are strongly linked to sediment. For example, sediment is critical for stabilizing archeological sites and camping beaches, for developing and maintaining backwater fish habitats, for transporting nutrients, and for supporting the vegetation that provides wildlife habitat. The amount of sediment transported through the Glen and the Grand canyons depends to a large degree on the volume of water released by the Glen Canyon Dam.

According to the EIS team members and sediment researchers that we interviewed, the data used in the preparation of the sediment section of the Glen Canyon Dam's EIS were the latest and best scientific information available at the time. Furthermore, they told us that the EIS is as good a document as can be done for reviewing and transferring technical information for use in public policy decision-making. While some sediment study results were based on data that were preliminary, draft, and/or unpublished at the time of the draft and final EIS, the researchers told us that no new or additional information has subsequently been obtained that would alter the information or conclusions presented in the final EIS. Also, for the most part, these researchers agree that the modeling tools used in the sediment impact determinations, while fairly crude in some respects, were the best available at the time and that their use resulted in appropriate conclusions.

## Description of the Resource

Sediment currently entering the Colorado River comes from tributaries downstream from the Glen Canyon Dam, primarily the Little Colorado and Paria rivers. Through several complex processes, the sediment in the river is transported, deposited, and then eroded for further transport. The quantity of the sediment in motion at a given time and its location depend on the amount and particle size of the sediment available, the dimensions and slope of the channel, and the magnitude of the water's flow. Four general classes of sediment, by size, are found in the Glen and Grand canyons:

- silts and clays (finer than 0.062 millimeter),
- sand (0.062 to 2 millimeters),
- gravels and cobbles (2 to 256 millimeters), and
- boulders (greater than 256 millimeters).

The transport and deposition of sediment vary with the size of the particles. Silts and clays are easily transported and generally pass through the system in a relatively short time, although some may be deposited in the low-water-velocity areas on sandbars and in backwaters. Silt and clay-sized particles provide important nutrients for vegetation, and clay also provides cohesion. The most abundant class of sediment found along the river is sand. Many sandbars, frequently called “beaches,” are used as campsites by boaters and rafters and are also important sites for riparian vegetation and wildlife habitats. Some sandbars also contain important cultural resource sites for Native American tribes. Gravel and cobblestones cover the bottom of some streambeds. Some fish species use shallow gravel beds for spawning. The larger boulders fall from the canyon walls or reach the river during flash floods in steep tributary canyons. Boulders create and modify most of the major river rapids and are an important factor in the creation of sandbars.

The river’s capacity to transport sediment increases exponentially with the amount of water flowing in the river. The greater the river’s flow, the greater the velocity and the greater the turbulence. The turbulence of flowing water is the uplifting force that causes sediment particles to be carried in suspension or roll along the streambed. Because sediment particles weigh more than water, they tend to settle to the bottom of the river channel. Small clay and silt particles can be carried in suspension by nearly all dam releases. Riverflows often are large enough to carry sand grains in suspension. The grains may be temporarily deposited in areas where the velocity of the water is insufficient to move them. Larger flows and velocities are needed to move gravel and cobbles, whereas the largest boulders may remain in place in the river channel for decades.

## Effects of Pre- and Postdam Conditions on Sediment

The Colorado River historically carried large quantities of sediment from the states in the Upper Colorado River Basin. The Glen Canyon Dam has caused three major changes to the sediment resources in the canyon. First, the supply of sediment has been reduced. The construction of the Glen Canyon Dam caused virtually all of the high concentration of sediment from the upper basin to be trapped by the dam and deposited in Lake Powell. Second, by controlling the annual historical peak flows that had a tremendous capacity to transport sediment, the dam has reduced the capacity of the river to transport sand and other sediment. Third, the height of the annual deposition of sediment, which is responsible for the size of sandbars, has been reduced because the dam now controls flood flows.

## Issue

As defined in the final EIS, the issue of concern for sediment resources is how the dam's operations affect sediment throughout the Glen and the Grand canyons.

## Indicators

The indicators for the sediment resource listed in the final EIS are

- the probability of net gain in riverbed sand;
- the active width and height of sandbars;
- the erosion of high terraces (high sediment deposits having a relatively flat surface and steep slope facing the river);
- the constriction of debris fans (sloping masses of boulders, cobbles, gravel, sand, silt, and clay formed by debris flows at the mouth of a tributary) and rapids; and
- the elevation of lake deltas (sediment deposits formed where the Colorado River and other streams enter Lake Powell or Lake Mead).

## Methodology Used to Make Impact Determinations

The EIS sediment team used a combination of historical riverflow and sediment discharge data, established computer modeling techniques, preliminary research results, and professional judgment to determine the potential impacts of the nine flow alternatives on the various types of sediment (especially riverbed sand). The long-term impacts on riverbed sand were estimated using empirical data and computer modeling, while the potential impacts on sandbars, high terraces, debris fans, and lake deltas were developed using preliminary research results, modeling, and professional judgment.

The sediment team was comprised of two individuals, a civil engineer with Reclamation and a hydrologist with the U.S. Geological Survey. In order to obtain the most recent scientific information, they obtained the preliminary results of the Glen Canyon Environmental Studies phase II research and attended the meetings of the phase II sediment researchers. The sediment team also attended a special session at an American Geophysical Union symposium to discuss the latest research on backwaters and also participated in several raft trips down the canyon with researchers in order to personally observe the sedimentation processes.

Other researchers involved in the sediment impact determinations included U.S. Geological Survey and National Park Service officials experienced in the sediment resource area. In addition, researchers from Utah State University, the University of Tucson, and the University of Northern Arizona were also active in various projects. All of the researchers were experienced in sedimentation data collection and analysis.

The data used in drafting the sediment section of the EIS were obtained from measurements and observations at selected canyon sites under various conditions, including during floods, historic powerplant operations and operations under the interim operating criteria, and also under specially designed research flows. The data collected underwent several different reviews.

The data obtained by the U.S. Geological Survey and used in the final EIS received additional reviews. Within the Geological Survey, each report was reviewed by at least two other researchers, plus an additional review at the regional level. External review was provided by the editors of outside publications or other professionals when the work was published in a U.S. Geological Survey professional paper.

In addition, the National Academy of Sciences, through its National Research Council, reviewed the preliminary draft EIS and provided official comments. The draft EIS was also made available for public review and comment. Over 470 public comments were received that related to sediment. The public comments reflected many differing and even contradictory views and opinions. For example, some commentors suggested that the dam's historical operations have damaged the beaches and increased erosion. Other commentors said that without the dam, there would be fewer beaches or that the increases in erosion are overstated. The effect of steady flows versus fluctuating flows on beach erosion was also argued on both sides. Some believed that steady flows would preserve beaches, while others said that they would destroy beaches. Other commentors expressed the belief that controlling fluctuation within certain parameters can control erosion, while others said that as long as there is a flow of any kind, erosion will occur.

The EIS team needed detailed analyses of the projected flow patterns for the various alternatives to evaluate different impacts. To develop these technical analyses, the EIS team used the Colorado River Simulation System (CRSS), a package of computer programs and databases designed to assist water resource managers in long-range planning and operations studies. The development of CRSS took place over a 10-year period and stemmed from the need for a comprehensive model of the Colorado River Basin that would incorporate all areas of interest, including legislative requirements. According to Reclamation and other experts, today, CRSS is the most comprehensive and detailed simulation of the Colorado River system that exists.

The CRSS database contains reconstructed natural flow data for the Colorado River between 1906 and 1990. The CRSS model can simulate the Colorado River's operations and the effects of changes to the Glen Canyon Dam's operations for the entire river basin. The modeling process begins with the assumption that previous natural flows in the river are indicative of future activity. Thus, the model uses the historical data to project future water availability. The CRSS can address many of the "what if" questions stemming from proposed changes in the Colorado River's operations, from proposed Colorado River basin development or from changes to present water use throughout the basin. The model's long-term estimates are widely accepted by water resource managers. The short-term estimates, between 5 and 10 years, are considered to be somewhat less precise.

The model produces data on a monthly basis, whereas the EIS team needed hourly projections in order to make their analyses for the fluctuating flow alternatives. The steady flow alternatives did not require this analysis because they provide for essentially steady monthly flows. To make the necessary adjustments for analyzing the fluctuating flows, a peak-shaving model was used to calculate the hourly distributions from the CRSS-projected monthly release volumes. (Peak shaving is the concept whereby hydroelectric powerplants are used to serve (shave) the highest electric load (peak) during a 24-hour period.) These hourly distributions were produced for the No-Action and Maximum Powerplant Capacity alternatives and for each of the restricted fluctuating flow alternatives.

The combined outputs of the CRSS model and the peak-shaving model were then used in the development of a sand-mass balance model. This model used 85 different hydrological scenarios (for 50 years each) to estimate the changes in riverbed sand due to differing flow alternatives from the Glen Canyon Dam. Using regression analysis, the sediment team calculated a sand-load discharge rating curve using the water flow rate as the independent variable and total sand load as the dependent variable. This curve shows the amount of sediment transported for any given discharge rate. The sand-load discharge rating curves were used as input into the 85 water release scenarios to determine the probability that a given flow alternative would result in higher amounts of sand in the riverbed over 20- and 50-year periods. EIS team members stated that the resulting numbers were reasonably accurate indicators of the relative differences between the nine flow alternatives considered in the EIS.

## Effects of Flow Alternatives on Sediment

According to the final EIS, the type of water release pattern selected for the dam's operations will greatly affect sediment. The analysis of the impacts on sediment was limited to the Colorado River corridor from Glen Canyon Dam to Lake Mead and the deltas in Lake Powell and Lake Mead. The direct impacts on sediment will vary with the level and pattern of riverflow. The direct impacts include changes in riverbed sand storage, aggradation (the process of filling and raising the level of a streambed, flood plain, or sandbar by the deposition of sediment) and degradation (the process wherein the elevation of streambeds, flood plains, and sandbars is lowered by erosion) of sandbars, and changes in the capacity to move large boulders from rapids. Future levels of riverbed sand will vary depending on the amount of riverbed sand available and the water volume and release patterns of the alternative implemented.

On the basis of the results of computer models and the most recent scientific research, the EIS sediment team determined what the potential impacts of the various alternatives would be:

- The No-Action, Maximum Powerplant Capacity, and High Fluctuating Flow alternatives all had excessive sand transport capacity, which jeopardized the long-term storage of sediment.
- The Interim Low Fluctuating Flow, Existing Monthly Volume, and Year-Round Steady Flow alternatives all maximized long-term sand storage but provide limited ability to build sandbars. These alternatives would result in vegetation encroachment on sandbars and net erosion of sandbars above the normal river stage.
- The Seasonally Adjusted Steady Flow, the Moderate Fluctuating Flow, and the Modified Low Fluctuating Flow alternatives all provided long-term sand storage and system dynamics.

On the basis of this analysis, the sediment team focused on the Seasonally Adjusted Steady Flow, the Moderate Fluctuating Flow, and the Modified Low Fluctuating Flow alternatives as the ones that would provide preferable potential impacts on sediment.

## Assessment of Impact Determinations

The EIS team members and sediment researchers whom we contacted provided us with comments on a variety of subjects, including the sand-mass balance model, the quality of the data used, the accuracy of the EIS in reflecting the research data, and whether other evidence existed that would change the impact determinations in the EIS. Generally, they agreed that the sand-mass balance model was the best modeling tool available at the time, although two researchers told us that more refined models are currently being developed by U.S. Geological Survey researchers. However, according to two Geological Survey researchers, none of the preliminary results from these newer models contradict the conclusions reached from the sand-mass balance model.

The researchers we spoke to generally complimented the way Reclamation interpreted and used their work in the impact determination process and said that the quality of the data used was the best available at the time. A limitation on the use of the more recent research results was that the data were preliminary (in draft form or unpublished) and the newer models were too complex to simulate multiple years of dam operations. In some cases, definitive information on the impacts of a specific flow alternative was not available. Therefore, the team had to extrapolate from the existing data using their professional judgment to estimate the potential impact of the alternative. However, they always verified the reasonableness of their conclusions and extrapolations with the researchers involved.

The officials we contacted also agreed with Reclamation's selection of a preferred alternative and could find no evidence to change the outcomes of the impact determinations for the sediment resource.

Specific comments made by some of those with whom we spoke included the following:

- Some commentors described the sand-mass balance model as simplistic or fairly crude. However, they agreed that it was the best and only tool available at the time. Also, they agreed that the impact determinations reached as a result of the model were correct. The leader of the sediment team agreed that the sand-mass balance model is simplistic, but he believed it produced reliable results for general, long-term information needs. He did not think that any other model now available would have been better. In fact, he stressed that the models available today cannot handle the amount and types of data that were required for the EIS process.

- Some commentors believed that the sediment information in the EIS was somewhat out of date in that it reflected the scientific data of 1992-93. However, there was a general belief that the EIS team did an excellent job of using the latest sediment research. While more is known about the sedimentation processes in the canyon today than was known when the EIS was written, the EIS does contain the best information available at the time. Also, they told us that even if the newer data had been available, the same decisions would have been reached. The discontinuity between the research and the administrative time frames was a limitation on the EIS process, but they said that the only impact would have been changes in some of the statements made in the EIS. For example, they said that the reasons for the selection of the preferred alternative would have been more clearly supported.
- Most of the researchers we contacted believed that their work was properly used and interpreted in the EIS. With only a few exceptions, discussions and communication between the EIS team and the researchers were frequent and thorough enough to ensure that the work was properly integrated into the EIS. Consequently, the researchers believe that the sediment team came up with the right conclusions. We found no examples that would contradict or change the impact determinations in the EIS or the selection of a preferred alternative. According to one researcher, the sediment team examined all of the existing professional papers and "followed up every lead, public or private, for additional work."

The sediment team leader's overall position, taking into consideration the various perspectives and opinions expressed, was that

- the process used in making the impact determinations for sediment was reasonable,
- the methodologies employed in this process were appropriate, and
- the data used were the best available.

## Scope and Methodology

To determine the process used in developing the impacts on the sediment resource, we identified and reviewed the following documents: the draft and final Glen Canyon Dam environmental impact statements and associated appendixes, the public comments on the draft and final environmental impact statements, and Reclamation's responses to the comments on the draft. We obtained and reviewed copies of the minutes from the EIS team meetings and summaries of the cooperating agencies' meetings. We also reviewed the Colorado River Simulation System Overview, the Final Analysis Report on Scoping Comments, the Glen

Canyon Dam EIS Preliminary Alternatives Report, and the newsletters issued by the Colorado River Studies Office from June 1990 to February 1995. We also obtained and studied the Glen Canyon Dam: Beach/Habitat-Building Test Flow, Final Environmental Assessment and Finding of No Significant Impact, issued in February 1996.

In addition, we reviewed the paper entitled "Sediment Transport in the Colorado River Basin" by Edmund D. Andrews. This paper was published in Colorado River Ecology and Dam Management by the National Academy of Sciences. This book contains various papers presented in a 1990 symposium on the Grand Canyon.

We also reviewed Reclamation's paper entitled "Assessment of Changes to the Glen Canyon Dam Environmental Impact Statement Preferred Alternative From Draft to Final EIS." This paper explained the background and scientific basis for the changes to the preferred alternative between the draft and the final EIS.

To assess the procedures followed and obtain views on the quality of data used in developing the impact determinations, we interviewed the members of the sediment resource team and reviewers of the sediment section of the draft EIS. We also identified and interviewed several key Glen Canyon Environmental Studies principal investigators on sediment issues.

Finally, we asked a member of the sediment team to review our description of the impact determination process for factual accuracy. He agreed that our description was generally accurate but made some suggestions for changes. We have incorporated these changes into our description of the process. We also presented him with our summary of the resource process in order to provide him with an opportunity to comment on and respond to the various issues raised through our audit work.

## Key Studies Identified

Beaus, S.S., and C.C. Avery (editors). The Influence of Variable Discharge Regimes on Colorado River Sand Bars Below Glen Canyon Dam. Flagstaff, Arizona: Northern Arizona University, 1992.

Budhu, M. "Mechanisms of Erosion and a Model to Predict Seepage-Driven Erosion due to Transient Flow," in The Influence of Variable Discharge Regimes on Colorado River Sand Bars Below Glen Canyon Dam, S.S.

Beaus and C.C. Avery, editors. Flagstaff, Arizona: Northern Arizona University, 1992.

Ferrari, R.L. 1986 Lake Powell Survey. Bureau of Reclamation, Report no. REC-ERC-88-6, 1988.

Hereford, R., H.C. Fairley, K.S. Thompson, and J.R. Balsom. Surficial Geology, Geomorphology, and Erosion of Archeological Sites Along the Colorado River, Eastern Grand Canyon, Grand Canyon National Park, Arizona. U.S. Geological Survey Open-File Report 93-517, 1993.

Leopold, L.B. “The Rapids and the Pools—Grand Canyon.” U.S. Geological Survey Professional Paper 669-D, 1969.

Pemberton, E.L. “Sediment Data Collection and Analysis for Five Stations on the Colorado River from Lees Ferry to Diamond Creek,” Glen Canyon Environmental Studies Technical Report. Salt Lake City, Utah: Bureau of Reclamation, 1987.

Randle, T.J., and E.L. Pemberton. “Results and Analysis of STARS Modeling Efforts of the Colorado River in Grand Canyon,” Glen Canyon Environmental Studies Technical Report. Salt Lake City, Utah: Bureau of Reclamation, 1987.

Randle, T.J., R.I. Strand, and A. Streifel. “Engineering and Environmental Considerations of Grand Canyon Sediment Management,” Engineering Solutions to Environmental Challenges: Thirteenth Annual USCOLD Lecture, Chattanooga, Tennessee. Denver, Colorado: U.S. Committee on Large Dams, 1993.

Schmidt, J.C. “Temporal and Spatial Changes in Sediment Storage in Grand Canyon,” The Influence of Variable Discharge Regimes on Colorado River Sand Bars Below Glen Canyon Dam, S.S. Beaus and C.C. Avery, editors. Flagstaff, Arizona: Northern Arizona University, 1992.

Schmidt, J.C., and J.B. Graf. “Aggradation and Degradation of Alluvial Sand Deposits, 1965 to 1986, Colorado River, Grand Canyon National Park, Arizona.” U.S. Geological Survey Professional Paper 1493, 1990.

Smillie, G.M., W.L. Jackson, and D. Tucker. “Colorado River Sand Budget: Lees Ferry to Little Colorado River.” National Park Service Technical

Report NPS/NRWRD/NRTR-92/12. Fort Collins, Colorado: National Park Service, 1993.

Webb, R.H., P.T. Pringle, and G.R. Rink. “Debris Flows From Tributaries of the Colorado River, Grand Canyon National Park, Arizona.” U.S. Geological Survey Professional Paper 1492, 1989.

## Officials Interviewed

We interviewed the following individuals about the sediment impact determination.

Edmund (Ned) Andrews, U.S. Geological Survey, Boulder, Colorado
Julia Graf, U.S. Geological Survey, Tucson, Arizona
Bill Jackson, National Park Service, Ft. Collins, Colorado
Dick Marzolf, U.S. Geological Survey, Boulder, Colorado
Margaret Matter, Western Area Power Administration, Denver, Colorado
Timothy Randle, Bureau of Reclamation, Denver, Colorado
Spreck Rosekrans, Environmental Defense Fund
Jack Schmidt, Utah State University
James Smith, U.S. Geological Survey, Boulder, Colorado
Robert Webb, U.S. Geological Survey, Tucson, Arizona
James Wilson, U.S. Geological Survey, Cheyenne, Wyoming

# Vegetation and Wildlife/Habitat

The resources downstream from Glen Canyon Dam through the Grand Canyon are interrelated, or linked, since virtually all of them are associated with or are dependent on water and sediment. This link is true for vegetation and wildlife and their habitat. The complex Grand Canyon ecosystem contains a variety of native and nonnative plants and animal communities that began developing before the construction of the dam. However, since the dam was completed, the ecosystem immediately surrounding the Colorado River has been significantly influenced by the operations of the dam.

We have combined our analysis of the vegetation and the wildlife/habitat impact determinations in this appendix because (1) with the exception of the abundance of aquatic food base for wintering waterfowl, similar indicators were studied in making the impact determinations for these resources; (2) the riparian vegetation that developed along the Colorado River corridor plays an important role as habitat to support the diversity of wildlife within the Glen and the Grand canyons; and (3) the same EIS team member was responsible for the impact determinations for both resources.

There has been little controversy surrounding the results of the impact determinations as presented in the final EIS for the vegetation and wildlife/habitat resources. Generally, the team leader and other experts we interviewed believed that the processes used in making the impact determinations were reasonable, the methodologies employed in these processes were appropriate, and the data used were the best available.

## Description of the Resource

The plant communities surrounding the Grand Canyon reflect the influences of desert conditions. These plants include barrel cactus, brittle bush, creosote bush, ocotilla, and cholla cactus. The Colorado River and the operations of the Glen Canyon Dam have little effect on these plants. However, the dam's operations, which modified the natural hydrology within the Colorado River corridor, do affect a narrow band of vegetation known as the riparian (near water) zone. The availability of water in the riparian zone supports plants that could not otherwise survive in a desert climate, and the types and abundance of vegetation that exists reflect the water regime that supports it. Among the plants found in areas of the riparian zone are netleaf hackberry, honey mesquite, catclaw acacia, seep-willow, arrowweed, desert broom, coyote willow, and tamarisk.

The riparian zone is the focus of both the vegetation and the wildlife/habitat studies for the EIS. The thick growth and variety of plant species as well as the several thousand species of invertebrates found there make the riparian zone some of the most important wildlife habitat in the Grand Canyon region. For example, riparian plants provide cover and food for 26 species of mammals. Also, of the 303 species of birds that have been documented in the Grand Canyon region, 250 species use the riparian zone within the Colorado River corridor. Over half of the bird species nesting along the river corridor nest in riparian vegetation. Furthermore, 27 species of reptiles and amphibians are supported by the resources found in the riparian zone. In some Colorado River corridor locations, lizard population densities are higher than anywhere else in the Southwest.

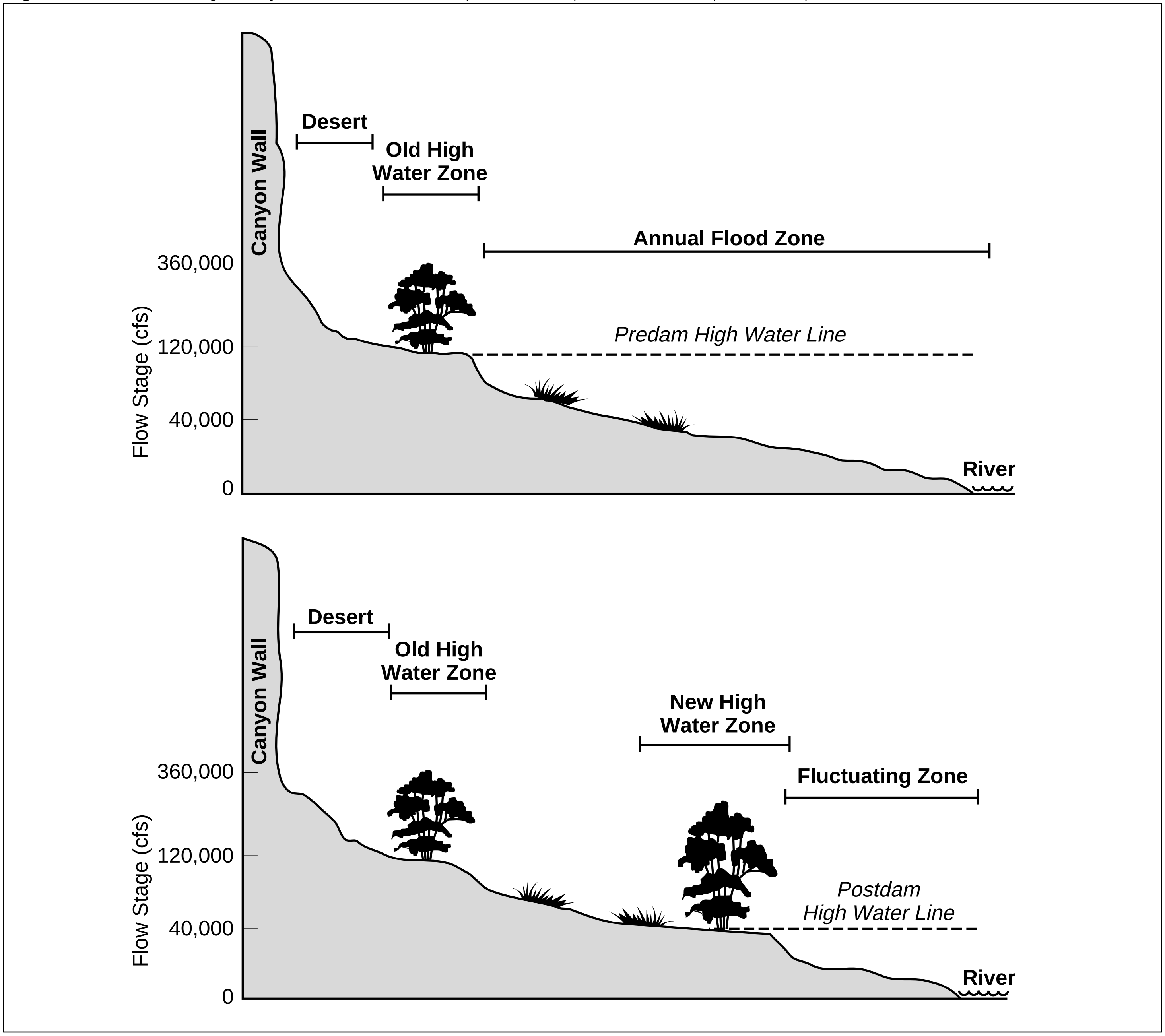
Also, during peak winter months, 19 species of wintering waterfowl have been found along the river corridor between Lees Ferry and Soap Creek. These waterfowl cannot be directly linked to riparian vegetation, but they are attracted to and use the clear, open, cold water of the Colorado River that resulted after the dam was constructed and that supports the abundant algae that are important to the aquatic food chain. Although survey data are not available, the EIS states that before the construction of the dam, the turbid river water was probably not very attractive to wintering waterfowl.

## Effects of Pre- and Postdam Conditions on Vegetation and Wildlife/Habitat

Because of the dynamic interaction between riparian vegetation and water availability, the construction of the dam and any changes in its operations that change specific water release patterns would be expected to affect the abundance and distribution of plants. Before the Glen Canyon Dam was constructed, seasonally high riverflows carried large sediment deposits through the Glen and the Grand canyons and scoured away or buried most vegetation from the river corridor below the 100,000 to 125,000 cubic feet per second river stage elevation. Annual floodflows prevented the establishment of marsh plants (cattails and similar aquatic plants) along the river corridor. Before the dam, the only riparian vegetation present along the river was woody plants (trees and shrubs) that developed in what became known as the old high-water zone. Plants that can withstand the conditions created by periodic flooding characterize the old high-water zone—netleaf hackberry, honey mesquite, and catclaw acacia.

After the dam began operations and controlled annual spring flooding, additional vegetation began to develop near the river below the old high-water zone. This vegetation developed rapidly in what has become known as the new high-water zone. Within this new high-water zone are found both woody plants and emergent marsh plants (cattails and similar aquatic plants). Common woody plants found in the new high-water zone include both native and nonnative species such as the seep-willow, arrowweed, desert broom, coyote willow, and tamarisk. Tamarisk is a nonnative tree that has become the dominant woody plant in the new high-water zone. Besides cattails, emergent marsh plants found in the new high-water zone include bulrushes and giant reed. This new high-water zone provides over 1,000 acres of additional habitat for wildlife. Figure IX.1 illustrates the relative positions of the predam and postdam riparian zones in the Grand Canyon.

**Figure IX.1: Grand Canyon Riparian Zone, Predam** (Before 1963) **and Postdam** (After 1963)




Source: Bureau of Reclamation.

## Issue

As developed in the final EIS, the issue of concern is how the dam's operations affect vegetation and wildlife and their habitat throughout the Glen and the Grand canyons.

## Indicators

Two plant groups found in the Colorado River corridor—woody plants and emergent marsh plants—were selected by the EIS team for detailed evaluation and to serve as indicators of riparian vegetation. The impact determination for vegetation was generally limited to the Colorado River corridor that extends between the Glen Canyon Dam and Separation Canyon. Because of the variety of plants growing in the riparian zone and their differing water requirements, EIS team members concluded that a comprehensive evaluation of the effects of all of the dam's operating alternatives on all plants was beyond the scope of the EIS.

Although very little information on wildlife population exists for either the predam or postdam habitats found along the river corridor, it was assumed that almost all wildlife concerns could be addressed by considering the effects of the operating alternatives on riparian vegetation because it serves as habitat for many wildlife species that inhabit the river corridor. Thus, rather than make specific analyses of impacts on individual wildlife species, the EIS team assumed that almost all wildlife concerns could be addressed by considering the effects of each of the dam's alternative operating procedures on riparian vegetation. However, wintering waterfowl do not depend on riparian vegetation within the Colorado River corridor below the Glen Canyon Dam. Therefore, the EIS team used the abundance of the aquatic food base, mainly Cladophora, as an indicator for wintering waterfowl.

## Methodology Used to Make Impact Determination

Reclamation designated a lead position for each resource and assigned that person the overall responsibility for developing the general impact determinations. For example, a riparian specialist was assigned for both the vegetation and wildlife/habitat resources. The riparian specialist developed his sections of the EIS through an iterative process of report drafting, formal and informal presentations to and review by the entire EIS team, and discussions with and input from key researchers and colleagues. In this process, it was important that the work of resource specialists responsible for other resource impact determinations be considered in the vegetation and wildlife/habitat analyses. For example, sediment is critical for supporting the riparian vegetation that provides wildlife habitat. Therefore, the impact determinations for the sediment resource are directly linked to the vegetation and wildlife and habitat resources and were used in the vegetation analyses. (See app. VIII for a discussion of the impact determinations for sediment.)

The riparian specialist prepared the vegetation and wildlife/habitat sections of the draft EIS and was responsible for any revisions to the EIS that were based on the 170 public comments received on these sections of the draft EIS (123 on vegetation and 47 on wildlife and habitat). In the preparation of material for the EIS impact determinations, he relied extensively on the research work of other scientists that was specific to the canyon's resources. For example, an ecologist, who is considered a leading authority on vegetation in the Grand Canyon region, was a major contributor of science-based information on the vegetation and wildlife and habitat resources of the canyon area. Key documented research considered by the riparian specialist in his analyses of impacts on vegetation and wildlife/habitat can be found in the scope and methodology section of this appendix.

The ecologist was also one of the peer reviewers of the impact determinations prepared by the riparian specialist. Others who reviewed the riparian specialist's work were a zoologist, who has done extensive fieldwork in the Glen Canyon, and a senior Glen Canyon Environmental Studies scientist affiliated with Arizona State University.

# Effects of Flow Alternatives on the Resources

## Summary of Impacts on Vegetation

According to the final EIS, in the short-term period of analysis, which was considered in the EIS to be between 5 and 20 years, the alternative operations of the Glen Canyon Dam would affect riparian vegetation within the river corridor in several different ways. While some plants do well in drier conditions, others require wetter conditions to survive. Some plants would likely decline as others adjusted to new water regimes. The reduced frequency of major, uncontrolled flood releases would result in an unknown, but assumed equal, decline in the area of coverage of riparian vegetation in the old high-water zone under all alternatives. Some plant species found in the old high-water zone would expand into the new high-water zone.

The Maximum Powerplant Capacity alternative would result in reduced areas of riparian vegetation in the new high-water zone because of the higher maximum flows permitted under this alternative. Under the No-Action alternative, woody plants within the new high-water zone would be maintained within stage boundaries equivalent to flows between about 22,000 cfs and 40,500 cfs. Periodic flooding that is similar to existing conditions would maintain emergent marsh vegetation at sites that are currently occupied at elevations between flows ranging from 10,000 cfs to 20,000 cfs.

Under alternatives with lower maximum flows—the restricted fluctuating and steady flow alternatives—new areas of sediment would be exposed, and these areas would be available for plant growth. These flow alternatives would all permit riparian vegetation to expand into sites created by the reduced maximum flows. Woody plants, such as coyote willow and arrowweed, found in the new high-water zone would continue to increase. Some new establishment of emergent marsh plants would occur at suitable sites; however, existing areas of emergent marsh plants that lose their water supply would become dominated by woody plants and eventually disappear.

The habitat maintenance flows included under the Moderate and Modified Low Fluctuating Flow alternatives and the Seasonally Adjusted Steady Flow alternative are assumed to affect the area available for vegetation, but the magnitude of the effect is unknown. Beach/habitat-building flows that restructure sediment deposits would disturb plants and interrupt succession in the riparian community. As a result of these flows, some woody vegetation would be buried and lost as sand is deposited on higher elevations, and patches of emergent marsh plants would be lost through scouring or burial. Both woody plants and emergent marsh vegetation would develop in the years following beach/habitat-building flows that would induce periodic changes in the combination of vegetation and open, bare areas.

In the long-term period of analyses (20 to 50 years), the differences among the alternatives would continue to develop. Because at least one major flood event is assumed to occur in the long term under the No-Action and Maximum Powerplant Capacity alternatives, riparian vegetation would decrease. However, woody and emergent marsh plants would recover after the flooding to a level comparable to baseline or no-action conditions. Also in the long term, riparian vegetation that is supported by

Lake Mead would increase by an unknown but assumed equal amount under all alternatives.

The restricted fluctuating and steady flow alternatives include measures to reduce the frequency of floods that would support increases in the coverage of woody plants at the end of the long-term period of analysis. Over the long term, habitat maintenance and beach/habitat-building flows would maintain woody and emergent marsh plants that developed during the short term. The dryer conditions created in the upper elevations of the new high-water zone would shift species composition from tamarisk and willow to mesquite and other plants. Tamarisk, willow, and other plants would favor the wetter sites at lower elevations.

## Summary of Impacts on Wildlife/Habitat

According to the final EIS, wildlife and habitat would be affected in ways similar to riparian vegetation under the operating alternatives, i.e., those dam-operating alternatives that tend to increase riparian vegetation would result in increased wildlife habitat. In the short term, woody plant coverage, and therefore riparian habitat, would increase under most alternatives. Emergent marsh plants would either remain similar in coverage to the no-action condition or decrease.

The No-Action alternative would maintain the existing riparian vegetation area, while the Maximum Powerplant Capacity alternative would create conditions leading to a decline in habitat area. The remaining alternatives would permit woody riparian vegetation to expand. It is assumed that as the area of woody riparian vegetation increases, so too will the size of the area of wildlife habitat that would provide valuable food resources and shelter. Habitat maintenance and beach/habitat-building flows would move and deposit sediment that would bury some vegetation, thus temporarily reducing its value as habitat. Vegetation that is not buried or that grows up through new sediment deposits would be unusable to area wildlife during the period of inundation.

Generally, individual animals would not be directly affected by the daily operations of the Glen Canyon Dam because animals are mobile and would move as required by the daily fluctuations in water releases. Birds using the riparian zone as a travel lane through the Grand Canyon would not be directly affected by any of the alternatives. However, species that nest in riparian vegetation would be indirectly affected by changes in area coverage of plants.

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 cfs 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.

## Assessment of Impact Determinations

EIS team members and researchers we contacted were generally complimentary of the process used in making the impact determinations of the dam's various operating procedures on the vegetation and the wildlife/habitat resources. Also, scientists we interviewed believed that the data used in the analyses were the best and most current available at the time and that the research used in the analyses was properly interpreted. While some scientists believe that some data may have been incomplete at the time the EIS segments were prepared, subsequent research only served to confirm and refine the analyses presented in the final EIS. Therefore, according to one official, there was little controversy associated with these resources and the presentation of impact determinations in the EIS. This opinion seems to be supported by the relatively low number of comments received on the draft EIS in connection with these resources.

Also, many people we talked to were supportive of the preferred alternative selected by Reclamation. There were, however, some concerns expressed. For example, one researcher believed that to further improve the aquatic food base, the Seasonally Adjusted Steady Flow may be a more advantageous operating regime. However, the riparian specialist disagreed with the researchers who favored the Seasonally Adjusted Steady Flow because he believes that the preferred alternative provides for higher water levels during the summer months, which would be more beneficial to plants that are important as an aquatic food base. Overall, he believes that the preferred alternative was the proper choice and that it would create conditions that permit the recovery of downstream resources to acceptable management levels while maintaining some hydropower capability. Overall, the riparian specialist believed that the results of the impact determinations for the vegetation and wildlife/habitat resources were reasonable. The riparian specialist thought that the methodology used in making the impact determinations was appropriate and properly implemented and the data used were the best available.

## Scope and Methodology

Our analyses of the impact determinations on the vegetation and wildlife/habitat resources were based on an evaluation of scientific studies used by the riparian specialist in his assessments, the study review process used, the impact determinations themselves, and extensive interviews with officials involved in the process. In addition, we provided the riparian specialist with our description of the processes followed in making the impact determinations for his review and comment. He agreed that our description accurately presented the facts.

## Key Studies Identified

We reviewed the following studies and research materials that Reclamation officials said were instrumental in making EIS decisions:

- Anderson, L.S., and G.A. Ruffner. "Effects of Post-Glen Canyon Flow Regime on the Old High Water Line Plant Community Along the Colorado River in Grand Canyon," Glen Canyon Environmental Studies Technical Report. Salt Lake City, Utah: Bureau of Reclamation, 1987.
- Carothers, S.W., and B.T. Brown. "The Colorado River Through Grand Canyon: Natural History and Human Change." Tucson, Arizona: University of Arizona Press, 1991.
- Pucherelli, M.J. "Evaluation of Riparian Vegetation Trends in the Grand Canyon Using Multitemporal Remote Sensing Techniques," pp. 172-181. Anchorage, Alaska: American Society of Photogrammetry and Remote Sensing Technical Papers, 1986.
- Stevens, L.E., and T. J. Ayers. "The Impacts of Glen Canyon Dam on Riparian Vegetation and Soil Stability in the Colorado River Corridor, Grand Canyon, Arizona," Draft Annual Report. National Park Service Cooperative Studies Unit. Northern Arizona University, Flagstaff, Arizona. 1991.
- Stevens, L.E., J.C. Schmidt, and B.T. Brown. "Geomorphic Control of Vegetation Establishment and Marsh Development Along the Colorado River in Grand Canyon, Arizona," in AGU 1991 Fall Meeting Program and Abstracts. American Geophysical Union EOS Transactions, supp. to vol. 72, No. 44, p. 223, 1991.
- Stevens, L.E., and G.L. Waring. "Effects of Post-Dam Flooding on Riparian Substrates, Vegetation, and Invertebrate Populations in the Colorado River Corridor in Grand Canyon, Arizona," Glen Canyon Environmental Studies Technical Report. Salt Lake City, Utah: Bureau of Reclamation, 1986.

In addition to the above studies, which directly addressed vegetation resources, we examined the following other relevant documents in the wildlife and habitat resource area:

- Threatened Native Wildlife in Arizona. Phoenix, Arizona: Arizona Game and Fish Department, 1988.
- Brown, B.T. "Monitoring Bird Population Densities Along the Colorado River in Grand Canyon," Glen Canyon Environmental Studies Technical Report. Salt Lake City, Utah: Bureau of Reclamation, 1987.
- _____. Abundance, Distribution, and Ecology of Nesting Peregrine Falcons in Grand Canyon National Park, Arizona. Final report submitted to Grand Canyon National Park, Grand Canyon, Arizona, 1991b.
- _____. Nesting Chronology, Density, and Habitat Use of Black-Chinned Hummingbirds Along the Colorado River, Arizona, 1991c.
- Brown, B.T., R. Mesta, L.E. Stevens, and J. Weisheit. "Changes in Winter Distribution of Bald Eagles Along the Colorado River in Grand Canyon, Arizona," Journal of Raptor Research, vol. 23, No. 3, pp. 110-113, 1989.
- Brown, B.T., G.S. Mills, R.L. Glinski, and S.W. Hoffman. "Density of Nesting Peregrine Falcons in Grand Canyon National Park, Arizona," Southwestern Naturalist, Vol. 37, No. 2, pp. 188-193, 1992.
- Jakle, M.D., and T.A. Gatz. "Herpetofaunal Use of Four Habitats of the Middle Gila River Drainage, Arizona," Riparian Ecosystems and Their Management: Reconciling Conflicting Uses, R.R. Johnson et al. (technical coordinators). Forest Service General Technical Report RM-120, pp. 355-358, 1985.
- Jones, K.B., and P.C. Glinski. "Microhabits of Lizards in a Southwestern Riparian Community," Riparian Ecosystems and Their Management: Reconciling Conflicting Uses, R.R. Johnson et al. (technical coordinators). Forest Service General Technical Report RM-120, pp. 342-346, 1985.
- Warren, P.L., and C.R. Schwalbe. "Lizards Along the Colorado River in Grand Canyon National Park: Possible Effects of Fluctuating River Flows," Glen Canyon Environmental Studies Technical Report. Salt Lake City, Utah: Bureau of Reclamation, 1988.
- Wilson, M.F., and S.W. Carothers. "Avifauna of Habitat Islands in the Grand Canyon," Southwestern Naturalist, Vol. 24, No. 4, pp. 563-576, 1979.


## Officials Interviewed

In addition to the riparian specialist, we interviewed 11 other EIS team members and researchers from the government, private, and academic sectors. A listing of the officials we contacted and the organizations they represent follows.

Michael Armbruster, Bureau of Reclamation, Denver, Colorado
Steven W. Carothers, SWCA Inc., Flagstaff, Arizona
Byran Brown, SWCA Inc., Salt Lake City, Utah
Duncan Patten, Arizona State University (Retired), Tempe, Arizona

Larry Stevens, Glen Canyon Environmental Studies, Flagstaff, Arizona
Dean W. Blinn, Northern Arizona University, Flagstaff, Arizona
Tina Ayers, Northern Arizona University, Flagstaff, Arizona
Michael Pucherelli, Bureau of Reclamation, Denver, Colorado
Susan Anderson, The Nature Conservancy, Tucson, Arizona
William Leibfried, SWCA Inc., Flagstaff, Arizona
David Wegner, Glen Canyon Environmental Studies, Flagstaff, Arizona
Mark Sogge, National Biological Service, Flagstaff, Arizona

# Water

The construction of the Glen Canyon Dam altered the historical flow pattern of the Colorado River and the characteristics of the water being discharged downstream. While different water flow alternatives would alter the pattern of water that is released from the dam, existing statutes, compacts, a treaty, and operating criteria guide the allocation of water to the seven basin states.[1] Currently, these laws, known collectively as the "Law of the River," establish minimum annual releases of water from the Glen Canyon Dam.

The area of potential impact for the resource water includes the Colorado River downstream from the Glen Canyon Dam, Lakes Powell and Mead, and the upper and lower basin states. These impacts include annual streamflows, reservoir storage, water allocation deliveries, upper basin state yield determinations, and water quality. The EIS team used computer modeling studies to project the dam's operations for 50 years to estimate the long-term impacts and for 20 years to estimate the short-term impacts.

The EIS team found that the impacts on water issues of the dam's various flow alternatives are essentially the same as under the No-Action alternative, except for the volume of monthly water releases and floodflow frequency. The annual streamflows, reservoir storage, water allocation deliveries, upper basin yield determinations, and water quality are only slightly affected by the alternatives.

The EIS team members and researchers we spoke with were confident that the computer modeling tools and the data used in the analyses were the best available at the time. Also, while some researchers believed that the maximum flow parameters under the preferred alternative should be increased, there was general acceptance of the selection of the Modified Low Fluctuating Flow as the preferred alternative.

## Description of the Resource

Most of the Colorado River water flowing into Lake Powell and ultimately released into the Glen and the Grand canyons originates in the Rocky Mountains. Runoff from spring snowmelt in the Rockies is high during April through July, when the flow in the Colorado River above Lake Powell reaches its annual maximum, then recedes for the remainder of the year. During the summer and fall, thunderstorms cause flooding in the tributaries originating on the Colorado Plateau, producing additional peaks in the river, but they are usually smaller than the snowmelt peaks

[1]The basin states consist of the upper basin—which covers parts of Arizona, Colorado, New Mexico, Utah, and Wyoming; and the lower basin—which covers parts of Arizona, California, Nevada, New Mexico, and Utah.

and of much shorter duration. Since the Glen Canyon Dam was completed in 1963, flows immediately below the dam have consisted almost entirely of water released from Lake Powell.

For purposes of the resources addressed in the EIS, water was described in terms of streamflows, floodflows, reservoir storage, annual water allocation deliveries, upper basin state yield determinations, and water quality:

- The annual streamflows are determined by the Law of the River, which currently requires a minimum annual release of 8.23 million acre-feet of water from the Glen Canyon Dam.
- Floodflows are defined as releases in excess of the powerplant capacity of 33,200 cubic feet per second (cfs).
- The reservoir storage in Lakes Powell and Mead depends on annual and monthly reservoir inflow and release volumes. Storage levels affect shore line resources and recreation on the lake. Furthermore, the upper basin states use storage in Lake Powell to meet their water delivery requirements to the lower basin states.
- The water allocation deliveries are the deliveries of Colorado River water to entities in the seven basin states and Mexico in accordance with the Law of the River. In recent years, the demand for water by the lower basin states has approached their entitlement of 7.5 million acre-feet.
- The upper basin state yield determination is the legal maximum volume of water available for annual use by the upper basin states.
- The Glen Canyon Dam altered downstream water quality by changing the water's temperature and clarity.

## Effects of Pre- and Postdam Conditions on Water

Before construction of the Glen Canyon Dam, the Colorado River was sediment-laden, and its flows fluctuated dramatically during different seasons of the year. Flows of greater than 80,000 cfs were common during the spring. In contrast, flows of less than 3,000 cfs were typical throughout the late summer, fall, and winter. The water temperatures ranged from near freezing in the winter to more than 80 degrees Fahrenheit in the summer.

The construction of the Glen Canyon Dam altered the natural dynamics of the Colorado River. The dam replaced seasonal flow variations with daily fluctuations and greatly reduced the amount of sediment in the river. Lake Powell now accumulates the sediment that would have traveled the Colorado River before the dam's construction. In addition, the water released from the dam to produce hydropower is withdrawn from the cold depths of Lake Powell, 230 feet below the surface when the reservoir is full. As a result of this water withdrawal process, the water temperature downstream of the dam is nearly a constant, year-round 46 degrees Fahrenheit.

The quality of the water has also been affected. Most of the nutrients carried by the river are associated with or attached to sediments, and sediments are now trapped by the dam. Variations in the levels of salinity in the water have also been reduced.

## Issue

As defined in the final EIS, the issue of concern for water resources is how the dam's operations affect the amount and quality of water available from Lake Powell at specific times.

## Indicators

The indicators for water resources listed in the final EIS are the

- acre-feet of streamflows,
- frequency and volume of floodflows,
- reservoir storage in Lakes Powell and Mead,
- acre-feet of annual water allocation deliveries (deliveries of Colorado River water to entities in the seven basin states and Mexico),
- acre-feet of upper basin state yield determination (hydrologic assessment of the total water depletion that can ultimately be allowed in the upper basin), and
- chemical, physical, and biological characteristics of water quality.

## Methodology Used to Make Impact Determinations

Reclamation established a water resource team to make the impact determinations for the EIS. The team consisted of two hydraulic engineers from Reclamation; one was a water resource and an environmental specialist, and the other was a water quality specialist.

The water resource specialist was assigned the responsibility for the hydrology impact assessment and provided information on the Colorado River's operations. He wrote the background sections for the water resource area and helped write the technical descriptions of the various alternatives presented in the EIS. The water quality specialist was responsible for water quality issues in the EIS.

The team used the Colorado River Simulation System (CRSS) to analyze the impacts of the nine flow alternatives on the annual and monthly streamflows, floodflows and other spills, water storage, water allocation deliveries, and upper basin yield determinations for the EIS. CRSS, a package of computer programs and databases, is widely regarded as the most comprehensive and detailed simulation system of the Colorado River. CRSS is designed to assist water resource managers in performing long-range planning and operation studies.

The CRSS database contains reconstructed natural flow data from the U.S. Geological Survey for the Colorado River during 1906 through 1990. The CRSS model can simulate the operations of the Colorado River, including the effects of changes to the operation of the Glen Canyon Dam. The modeling process begins with the assumption that the previous natural flows in the river are indicative of future activity. Thus, the model uses historical data to project water availability in the future. The CRSS can address many of the "what if" questions stemming from proposed changes in the Colorado River's operations, from proposed development in the Colorado River Basin, or from changes to present water use throughout the basin. The model's estimates are widely accepted by water resource managers.

CRSS produces data on a monthly basis; therefore, a peak-shaving model was used to predict hourly distribution from the CRSS-projected monthly release volumes. (Peak shaving is the concept whereby hydroelectric powerplants are used to serve (shave) the highest electric load (peak) during a 24-hour period.) These hourly distributions were produced for the No-Action and the Maximum Powerplant Capacity Flow alternatives and for each of the restricted fluctuating flow alternatives. The hourly projections were needed to develop and analyze the effects of fluctuating flows on sediment and other resources. The steady flow alternatives did not require this analysis because flows from hour to hour would be essentially steady.

The water resource specialist developed the technical analyses of the alternatives using the CRSS model. The technical development of the alternatives was an iterative process, whereby the team presented the results of the modeling program at the EIS team meetings; the EIS team would then analyze and discuss the information to determine what additional adjustments to the alternatives were needed. Using the CRSS program, the water resource specialist calculated various parameters for each alternative, including annual releases, monthly releases, reservoir storage, water allocation yield, and floodflows. The EIS team members then prepared impact analyses of each alternative for the various resource areas. Their analyses were based on the CRSS results, preliminary data from various research projects, and their professional judgment. The results of the impact analyses were presented and discussed at the EIS team meetings.

## Effects of the Flow Alternatives on Water

According to the final EIS, the annual streamflows would differ only slightly from the No-Action alternative under all alternatives and are therefore not expected to affect the distribution of water among the basin states. Under the restricted fluctuating and steady flow alternatives, the measures included for reducing the frequency of floods would reduce the frequency of unscheduled floodflows that are greater than 45,000 cfs from an average of once in 40 years to once in 100 years. Other spills would differ only slightly from the No-Action alternative under all other alternatives.

Reservoir storage under all fluctuating flow alternatives would be essentially the same as under the No-Action alternative. Water allocation deliveries would be affected slightly under all alternatives. However, if reserving more space in the reservoir is used to reduce flood frequency, the amount of water available for use by the upper basin states would be reduced. None of the alternatives affect water quality under normal reservoir levels, which occur 95 percent of the time.

## Assessment of Impact Determinations

The CRSS model is widely accepted as the best method available for analyzing the effects of changes to the operations of the Glen Canyon Dam. The officials and researchers we interviewed generally stated that the CRSS model was the best method available at the time for analyzing and describing the various alternatives. Some alternative modeling programs did exist; however, EIS team members told us they would not have produced significantly different results.

The EIS team members and researchers we spoke with generally support the preferred alternative. Two reasons cited were that the alternative (1) strikes a balance for the resources at Glen Canyon Dam and (2) represents a reasonable compromise among the various interest groups. However, two researchers believe that the preferred alternative's operating parameters are still too conservative, even after they were increased following public comment on the draft EIS. They told us that higher maximum releases and higher fluctuating flows are needed and that adaptive management will show that the higher flows are acceptable. They stated that compromises made for the benefit of environmental issues may have gone too far because one-third of the hydropower capacity of the dam was lost.

In addition, none of the EIS team members or researchers we interviewed provided any data or research that would change the conclusions reached by the EIS team.

The team's water resource specialist provided us with his responses to the issues and comments noted above. He agreed with the comments, especially noting that the preferred alternative was a reasonable compromise and that adaptive management may lead to less restrictive flows. He stated that

- the process used in making the impact determinations for the water resource was reasonable,
- the methodologies employed in this process were appropriate, and
- the data used were the best available.

## Scope and Methodology

To determine the process used to develop the flow alternatives, we identified and reviewed the following documents.

### Key Studies Identified

Key documents we reviewed were the draft EIS and final EIS and associated appendixes, the public comments on the draft EIS and final EIS, and Reclamation's responses to the comments on the draft EIS. We also obtained and reviewed copies of the minutes of the EIS team meetings and summaries of the cooperating agencies' meetings. We studied the Colorado River Simulation System Overview prepared by Reclamation and the Glen Canyon Environmental Studies chapter prepared by the Power Resources Committee. We also reviewed the Final Analysis Report on Scoping Comments, the Glen Canyon Dam EIS Preliminary Alternatives Report, and the newsletters issued by the Colorado River Studies Office from June 1990 to February 1995. We also obtained and studied the Glen Canyon Dam: Beach/Habitat-Building Test Flow, Final Environmental Assessment and Finding of No Significant Impact, issued in February 1996.

We also reviewed three papers presented at a 1990 symposium on the Grand Canyon (published in Colorado River Ecology and Dam

Management by the National Academy of Sciences in 1991). These papers were "Sediment Transport in the Colorado River Basin" by Edmund D. Andrews, "Hydrology of Glen Canyon and the Grand Canyon" by David R. Dawdy, and "Reservoir Operations" by Trevor C. Hughes.

Furthermore, we reviewed "Assessment of Changes to the Glen Canyon Dam Environmental Impact Statement Preferred Alternative from Draft to Final EIS," issued by Reclamation in October 1995. This paper explained the background and scientific basis for the changes to the preferred alternative between the draft and final EIS.

EIS team members stated that the documents generated using the CRSS model were key to the development of the water resource area. Appendix VIII of this report contains a list of those documents. Another document that was identified as important to the process was Hydrologic Determination 1988: Water Availability From Navajo Reservoir and the Upper Colorado River Basin for Use in New Mexico. Salt Lake City, Utah: Bureau of Reclamation, 1989.

## Officials Interviewed

To assess the procedures followed and obtain views on the quality of the data used in developing the flow alternatives, we interviewed the water resource team and the internal and external reviewers of the work. Finally, we asked the EIS team's water resource specialist to review our description of the impact determination process for factual accuracy. He agreed that our description was generally accurate but made some suggestions for changes. We have incorporated these changes into our process description. A list of the officials we interviewed follows.

Trevor Hughes, Utah State University/National Research Council
William Lewis Jr., University of Colorado-Boulder/National Research Council
Margaret Matter, Western Area Power Administration, Denver, Colorado
Randy Peterson, Bureau of Reclamation, Salt Lake City, Utah
Craig Phillips, Bureau of Reclamation, Denver, Colorado
Tim Randle, Bureau of Reclamation, Denver, Colorado
Spreck Rosekrans, Environmental Defense Fund
Thomas Slater, Bureau of Land Management, Salt Lake City, Utah
Leslie Stillwater, Bureau of Reclamation, Denver, Colorado

# Summary Comparison of the Alternatives and Impacts as Presented in the Glen Canyon Dam's Final Environmental Impact Statement

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

| 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 | | | 8 to 13 | |
| Potential major increase | Potential major increase | Major increase | Major increase | Major increase |
| Potential minor increase | Potential minor increase | Uncertain potential minor increase | Uncertain potential major increase | Uncertain potential minor increase |
| Potential minor increase | Potential minor increase | Potential minor increase | Potential minor increase | Potential minor increase |
| Potential minor increase in warm, stable microhabitats | Potential minor increase in warm, stable microhabitats | Potential minor increase in warm, stable microhabitats | Potential minor increase in warm, stable microhabitats | Potential minor increase in warm, stable microhabitats |
| Increased growth potential; stocking-dependent | Increased growth potential, stocking-dependent | Increased growth potential, possibly self-sustaining | Increased growth potential, possibly self-sustaining | Increased growth potential, possibly self-sustaining |

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

| Modified Low Fluctuating Flow | Interim Low Fluctuating Flow | Existing Monthly Volume Steady Flow | Seasonally Adjusted Steady Flow | Year-Round Steady Flow |
|---|---|---|---|---|
| 30 to 47% increase | 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 |
| Same as or less than no action | Same as or less than no action | Less than no action | Less than no action | Less than no action |
| Potential increase | Potential increase | Potential increase | Potential increase | Potential increase |
| Potential minor increase | Potential minor increase | Uncertain potential minor increase | Uncertain potential major increase | Uncertain potential minor increase |
| Potential minor increase | Potential minor increase | Uncertain potential minor increase | Uncertain potential minor increase | Uncertain potential minor increase |
| Potential minor increase | Potential minor increase | Uncertain potential minor increase | Uncertain potential major increase | Uncertain potential minor increase |
| Potential increase | Potential increase | Potential increase | Potential increase | Potential increase |
| No effect | No effect | No effect | No effect | No effect |
| Some incidental take | Some incidental take | Some incidental take | Some incidental take | Some incidental take |
| Same as no action | Same as no action | Same as no action | Same as no action | Same as no action |

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

Source: Bureau of Reclamation.

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

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

Note: Reclamation's estimates for the non-use values are presented in table VI .4 in appendix VI.

Source: Bureau of Reclamation.

Source: Bureau of Reclamation.

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

# Comments From the Department of the Interior

Note: GAO comments supplementing those in the report text appear at the end of this appendix.

United States Department of the Interior

OFFICE OF THE SECRETARY
Washington, D.C. 20240

SEP 13 1996

Mr. Victor S. Rezendes
Director, Energy, Resources,
and Science Issues
General Accounting Office
441 G Street, N.W.
Washington, D.C. 20548

Dear Mr. Rezendes:

Enclosed are comments on the draft General Accounting Office report entitled "An Assessment of the Glen Canyon Dam's Environmental Impact Statement" (GAO/RCED-96-221). We appreciate the opportunity to review this draft report and comment on the subject matter. We are impressed with the quality of the product developed by the audit team. In a relatively short time, they have grasped a multitude of technical issues and have produced credible review documents. The comments are intended to clarify and improve the factual basis of the descriptions in the report.

Now GAO/RCED-97-12.

Sincerely,

Patricia J. Beneke
Assistant Secretary
for Water and Science

Enclosure

Bureau of Reclamation Comments

"An Assessment of the
Glen Canyon Dam's
Environmental Impact Statement"
GAO/RCED 96-221

Now GAO/RCED-97-12.

See comment 1.

Suggest the title of the report be changed to "An Assessment of the Environmental Impact Statement on the Operation of Glen Canyon Dam". The focus of the EIS was the operation of the dam, not the dam itself.

See comment 2.
Now on p. 4.

Page 5, 3rd paragraph. Consider describing the high steady releases "periodic" .

Now on p. 6.
See comment 3.

Page 7, 2nd paragraph. The two computational errors referred to here were made only in the Phase III analysis. One might accidentally infer from the sentence here that this occurred in the Phase II analysis. This is correctly described in the power economics appendix.

Now on p. 16, paragraph 1.
See comment 4.

Page 17, 2nd paragraph. Change "1966" to "1968". Releases from the dam were less than 8.23 maf prior to 1968.

See comment 5.

Page 51, 1st paragraph. One problem with paraphrasing is that sometimes the meaning of the original statement is obscured. The NOAA blue ribbon report actually states that, "The Panel concludes that CV studies can produce estimates reliable enough to be the starting point of a judicial process of damage assessment, including lost passive-use values" (page 4610, col 3, par 3).

Now on p. 108.
See comment 6.

Page 143, 2nd paragraph. The computational errors referred to here were made only in the Phase III analysis. Although more specifics are provided later, one might accidentally infer from the sentence here that this occurred in the Phase II analysis.

Now on p. 114.
See comment 7.

Page 152, footnote. Both the words "load" and "demand" appear adjacent to each other in the footnote. As these words are often used synonymously, we suggest deleting one or the other.

Now on p. 123.
See comment 8.

Page 163, table. The heading over the left most column heading indicates that these values are for Glen Canyon. The note correctly indicates that these values are for the SLCA/IP system in total.

## GAO's Comments

The following are GAO's comments on the Department of the Interior's comments enclosed in a letter dated September 13, 1996.

1. We have revised the title of the report as suggested.

2. We have added the term "periodic" to our description of the Modified Low Fluctuating Flow alternative.

3. We revised the text to clarify that the computational errors were made during the third phase of the power analysis.

4. The year was changed to 1968.

5. We have deleted the sentence from the report.

6. See comment 3 above.

7. We deleted the word "load" from the report.

8. We revised the footnote to clarify that the energy and capacity values referred to in the table are attributable to the Salt Lake City Area/Integrated Projects in total, but the change in annual economic costs are attributable solely to the Glen Canyon Dam's operations.

# Major Contributors to This Report

## Resources, Community, and Economic Development Division, Washington, D.C.

Jonathan Bachman
Steve Brown
Jay R. Cherlow
Timothy J. Guinane
Barry T. Hill
Edward A. Niemi
Jim Yeager

## Denver, Colorado

Sandra P. Davis
W. Stephen Lowrey
Craig D. Richards
William J. Temmler
Frank B. Waterous
Alan J. Wernz

## Office of the General Counsel

Martin J. Fitzgerald
Alan R. Kasdan

## Ordering Information

The first copy of each GAO report and testimony is free. Additional copies are $2 each. Orders should be sent to the following address, accompanied by a check or money order made out to the Superintendent of Documents, when necessary. VISA and MasterCard credit cards are accepted, also. Orders for 100 or more copies to be mailed to a single address are discounted 25 percent.

Orders by mail:

U.S. General Accounting Office
P.O. Box 6015
Gaithersburg, MD 20884-6015

or visit:

Room 1100
700 4th St. NW (corner of 4th and G Sts. NW)
U.S. General Accounting Office
Washington, DC

Orders may also be placed by calling (202) 512-6000
or by using fax number (301) 258-4066, or TDD (301) 413-0006.

Each day, GAO issues a list of newly available reports and testimony. To receive facsimile copies of the daily list or any list from the past 30 days, please call (202) 512-6000 using a touchtone phone. A recorded menu will provide information on how to obtain these lists.

For information on how to access GAO reports on the INTERNET, send an e-mail message with "info" in the body to:

info@www.gao.gov

or visit GAO's World Wide Web Home Page at:

http://www.gao.gov