River and Dam Management

A Review of the Bureau of Reclamation's Glen Canyon Environmental Studies

River and Dam Management

A Review of the Bureau of Reclamation's Glen Canyon Environmental Studies

Committee to Review the Glen Canyon
Environmental Studies

Water Science and Technology Board

Commission on Physical Sciences,
Mathematics, and Resources

National Research Council

NATIONAL ACADEMY PRESS
Washington, D.C. 1987

NOTICE: The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the committee responsible for the report were chosen for their special competences and with regard for appropriate balance.

This report has been reviewed by a group other than the authors, according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

Support for the project was provided by the United States Department of the Interior, Bureau of Reclamation under Cooperative Agreement Number 6-FC-40-04240.

Available from

Water Science and Technology Board
National Research Council
2101 Constitution Avenue, N.W.
Washington, D.C. 20418

Printed in the United States of America

COMMITTEE TO REVIEW THE GLEN CANYON ENVIRONMENTAL STUDIES

G. RICHARD MARZOLF, Kansas State University-Manhattan, Chairman

VICTOR R. BAKER, University of Arizona-Tucson

DAVID DAWDY, Consultant, San Francisco, California

CHARLES R. GOLDMAN, University of California-Davis

WILLIAM L. GRAF, Arizona State University-Tempe

EVE C. GRUNTFEST, University of Colorado-Colorado Springs

W. MICHAEL HANEMANN, University of California-Berkeley

DONALD R. F. HARLEMAN, Laboratory for Water Resources and Hydrodynamics, Cambridge, Massachusetts

EVELYN A. HOWELL, University of Wisconsin-Madison

TREVOR C. HUGHES, Utah State University-Logan

JOHN V. KRUTILLA, Resources for the Future, Washington, D.C.

WILLIAM M. LEWIS, JR., University of Colorado-Boulder

NANCY Y. MOORE, The Rand Corporation, Santa Monica, California

DUNCAN T. PATTEN, Arizona State University-Tempe

HEINZ G. STEFAN, University of Minnesota-Minneapolis

A. DAN TARLOCK, Illinois Institute of Technology, Chicago-Kent College of Law

<u>NRC Program Officer</u>

SHEILA D. DAVID, Water Science and Technology Board

<u>NRC Senior Project Secretary</u>

RENEE A. HAWKINS, Water Science and Technology Board

<u>Bureau of Reclamation Project Officer</u>

DAVID WEGNER, Grand Canyon Environmental Studies Manager, U.S. Bureau of Reclamation, Salt Lake City, Utah

<u>Liaison Representatives</u>

EDMUND ANDREWS, U.S. Geological Survey, Lakewood, Colorado

DENNY FENN, U.S. National Park Service, College Station, Texas

WARREN JAMISON, Western Area Power Administration, Golden, Colorado

DICK MORGAN, U.S. Fish and Wildlife Service, Albuquerque, New Mexico

PATRICIA PORT, U.S. Department of the Interior, San Francisco, California

HAROLD SERSLAND, U.S. Bureau of Reclamation, Salt Lake City, Utah

JAMES W. MERCER, GeoTrans, Herndon, Virginia

DAVID W. MILLER, Geraghty & Miller, Inc., Syosset, New York (through 6/30/87)

GORDON ROBECK, Laguna Hills, California (retired)

PATRICIA ROSENFIELD, The Carnegie Corporation of New York

EDITH BROWN WEISS, Georgetown University Law Center

Staff

STEPHEN D. PARKER, Director

SHEILA D. DAVID, Staff Officer

WENDY L. MELGIN, Staff Officer

CAROLE B. CARSTATER, Staff Assistant

JEANNE AQUILINO, Administrative Assistant

RENEE A. HAWKINS, Senior Secretary

ANITA A. HALL, Senior Secretary

COMMISSION ON PHYSICAL SCIENCES, MATHEMATICS, AND RESOURCES

PREFACE

In response to a 1986 request from the Department of the Interior, the Water Science and Technology Board (WSTB) of the National Research Council (NRC) agreed to conduct a review of the Glen Canyon Environmental Studies (GCES) of the lower Colorado River for the Bureau of Reclamation and to provide advice on alternative operation schemes for the Glen Canyon Dam.

The WSTB was eager to conduct this review, in part because it recognized that the Colorado River is one of the most valuable water resources in the United States. Without the development of this water resource, the Colorado River basin and its environs, which cover the southwestern eighth of the United States, would be able to support only a fraction of its present population.

John Wesley Powell recognized in his 1878 Lands of the Arid Region of the United States report that the river would be the sine qua non of agriculture in the region. Now we realize that the river's energy generates electrical power, its water drives political, economic, and legal philosophies, and its flow and its work as a geomorphic agent provide recreation and tourism in the Southwest. The Colorado River epitomizes a regional water resource.

Nearly all of the allocation for the lower basin (that area comprising the state of Arizona, parts of Nevada, and California) has been set aside for specific uses. As demand increases, the quality of the water and the processes that control it will become increasingly dominant issues. Science and technology were required to develop the resource for human use, and so, perhaps science ought to be applied to make assessments and predictions of the long-term results of the development.

The scientific examination of any aspect of any large river would have appealed to the WSTB. The Colorado presented an especially exciting opportunity to examine a set of investigations--the GCES--designed to evaluate the effects of storage and power dam operation on basic earth science phenomena in the context of its extraordinary resource value. Furthermore, the board saw the opportunity to examine the integration of science and technology with economic, political, and legal institutions, and to bring thinking from diverse disciplines to bear on procedures used to investigate large rivers. The committee's membership reflects that intent. The committee members and others who participated in the committee meetings represented a broad range of expertise, including aquatic and terrestrial ecology, limnology and water quality modeling, sediment transport, hydrology/hydraulics, recreation and land use, economics, operations of large dams, and water and environmental law.

As the Glen Canyon Environmental Studies began, the Bureau of Reclamation was being pressed on environmental issues from several quarters. In 1978, the U.S. Fish and Wildlife Service had filed a jeopardy opinion on the effects of Glen Canyon Dam on endangered fishes. Environmentalists were threatening suit to block the bureau's planned increase in generating capacity of the dam. Recreational users (anglers and rafters) in lower

Glen Canyon and in Grand Canyon represented an increasingly vocal and significant economic force. These river users heightened the National Park Service's concerns about their missions in the face of increasing use of the river. These issues were creating a situation that could not be overlooked.

The board was interested in helping and appointed a capable committee that eagerly undertook the task. The members of the Committee to Review the Glen Canyon Environmental Studies achieved solid rapport with the GCES investigators and interaction quickly became productive. The review presented in this report was conducted with candor and received in good spirit.

The committee was directed to (1) review and advise on the Glen Canyon Environmental Studies in progress, and give a general assessment of how well these activities were achieving their intended goals; (2) advise on interpretation of information for impact analysis from the technical data developed; (3) provide advice on the process of identifying the environmental elements for ranking operational alternatives for Glen Canyon Dam; and (4) extrapolate from this case study recommendations to others who may pursue similar environmental studies at other sites in the future.

To fulfill its assigned tasks, the committee provided general advice to the GCES research team at three committee meetings, and the GCES project manager was advised of the committee's progress through quarterly summary reports. The assessment of how well the GCES were achieving their intended goals is given in detail in Chapter 4 of this report. The assessment was difficult because the GCES objectives were not clearly articulated at the beginning, scientific objectives were confused with management/policy objectives, and objectives changed during the course of the study.

Members of the committee agree that changes in the operation of Glen Canyon Dam were reflected in measurable changes in the natural resources in the riparian corridor downstream through the Grand Canyon. Some changes are documented directly. Others are predictions of effects based on the committee's understanding of system function for which data are unavailable. The latter remain as untested hypotheses that could be pursued as part of an impact analysis.

The committee's advice on the process for ranking operational alternatives includes criticism of the GCES studies and advice for future study of this and other rivers. The committee's recommendations call for planning and execution of future studies to test predicted outcomes of releases by management. Details of the testing can vary for different elements of the ecosystem as they are judged to be of greater or lesser value to the users of the Colorado River.

The committee's study included a review of the performance and results of approximately 30 studies conducted by GCES investigators from the Bureau of Reclamation, National Park Service, Fish and Wildlife Service, Arizona Game and Fish Department, U.S. Geological Survey, and other private contractors over the study period (see Appendix C); a review of the Bureau of Reclamation's planning and management of this project; the integration of the GCES into a decision-making report to the Bureau of Reclamation; and, the utility of the GCES results for management of the Colorado River, the Grand Canyon, and the operation of Glen Canyon Dam.

The committee received most of the draft research reports between November 1986 and February 1987. The final document reviewed by the committee was the July 1987 draft of the GCES integrated report. All reports reviewed by the committee were drafts in progress.

Three meetings were arranged over the 18-month study period for the committee to meet with all GCES research investigators, liaison representatives, and personnel from the Bureau of Reclamation, National Park Service, Fish and

Wildlife Service, Arizona Game and Fish Department, and Western Area Power Administration, among others. At these first three meetings the committee concentrated on helping the GCES researchers improve their individual research reports and the final integrated report.

The first meeting in September 1986 was held to define the nature of the problem, the scientific and policy issues involved and to develop the process by which the committee's review would be conducted. The second meeting, in November 1986, provided an opportunity for the committee to discuss research issues with the GCES investigators. Field research was essentially finished by the committee's second meeting. Therefore recommendations on what research should have been conducted and how it should have been organized could not be used, but the committee did assist in analysis and interpretation of data in hand.

At its third meeting (March 1987), the committee met with the team of GCES writers/investigators designated to integrate the separate studies into a synthesis of information about environmental effects. Thus the third meeting was dedicated to advising this team about report integration and to outlining this report and to assigning writing tasks.

The committee scheduled its fourth meeting (July 1987) as a writing workshop. Approximately three weeks before this session, the GCES team completed their integrated report, which included four subteam reports as appendices, and sent it to the committee for review. The committee drafted conclusions and recommendations at this meeting. In September 1987, an executive group appointed by the committee chairman met in Washington, D.C., to further organize and edit this report to the Bureau of Reclamation.

The committee was aware that it was reviewing investigations in progress, i.e., while the interpretations were being drawn and reports were being written and synthesized into recommendations. The timing of the review, the shifting deadlines, and the consequent frustration were, for the most part, borne patiently. The bureau's extension of the deadline for the GCES integration report and of the committee's review schedule was appreciated.

One of the results of these events is that the final report of the GCES team already contains some of the benefit of the committee's scrutiny. This was an exceptional benefit of the cooperative interaction that the committee and the GCES team achieved. The committee consciously has tried to remain objective about the task, and has written what it hopes to be a useful critique for the Bureau of Reclamation and for the citizens of the Southwest.

I am pleased to have worked with both these groups.

G. Richard Marzolf, Chairman
Committee to Review the Glen
Canyon Environmental Studies

CONTENTS

FIGURES

EXECUTIVE SUMMARY

REVIEW OF THE GLEN CANYON ENVIRONMENTAL STUDIES

Since the turn of the century, water issues in the Southwest have centered on the use of irrigation to reclaim land for agriculture and, more recently, the generation of hydroelectric power. The Bureau of Reclamation has a major responsibility for federal government involvement in water resource development and, by most measures of progress, their activities have been successful.

In recent years, however, water quality issues have assumed greater attention. As the limits of the quantity of water are reached and as the population of the Southwest grows and changes, water users other than agriculture and power generation (e.g., recreation and urban water supply) have gained more legal and political standing. As a result, the laws are changing and the Bureau of Reclamation is adjusting to major changes in responsibility, i.e., from irrigation development and power generation to operations planning and environmental management.

The Bureau of Reclamation's performance of the Glen Canyon Environmental Studies (GCES), in the period from 1982 to 1987, is one manifestation of the change. The GCES were initiated in 1982 as a response to some of these new pressures, but now

(1987) the Department of Interior would like to use the GCES results to help make decisions about (1) long-term operational criteria for the dam, (2) opportunities for managing the Colorado River, and, finally, (3) legal requirements for environmental protection.

In 1986, the Department of Interior requested the Water Science and Technology Board (WSTB) of the National Research Council to review the Glen Canyon Environmental Studies (GCES) for the Bureau of Reclamation. The WSTB agreed to provide advice to the bureau as it sought to evaluate the effects of the operation of Glen Canyon Dam on downstream resources.

This review of the GCES is focused on the July 1987 Glen Canyon Environmental Studies Draft Report prepared by Bureau of Reclamation scientists and the planning and work leading to it. The NRC's committee was involved with the GCES scientists throughout the period when the July GCES Draft Report was being prepared. The committee had the opportunity to discuss various issues with them and to review the individual research reports that underpin their integrated draft (see Appendix D). Although the committee does not believe that the Bureau of Reclamation can make long-term decisions concerning the management of Glen Canyon Dam based on the GCES, the studies have yielded some excellent information in the areas of geomorphology, aquatic and terrestrial biology, and recreation.

Many of the individual studies in the GCES resulted in publishable scientific products useful to the bureau. The shortfalls of the GCES program can be placed in four general categories:

- Insufficient attention to early planning and careful articulation of objectives. This lack of planning has led to an appearance that the bureau is not fully open to changes that might be suggested as a result of the research done by the

GCES investigations, or, that by limiting the scope, unwanted options would not be examined.

- **Inadequate consideration of management options. For example, questions to consider include what are the costs of operational changes in terms of lost power revenues and what are the gains from meeting management goals in regard to downstream resources?**
- **Uncertain conversion of the research results into management options.**
- **Failure to identify the rationale for assigning values to downstream resources so management goals could be set. Thus, the GCES researchers have not reached (could not reach) firm conclusions about the operation of the dam.**

Although the final draft GCES report recommends several options, this committee believes that, only those calling for additional work are justified. Therefore, the GCES effort was a mix of success and failure. The committee believes that, despite the obvious inadequacies of the GCES, useful new knowledge has been gained which can serve as the basis for future work by the Department of the Interior. The committee believes that management of resources is feasible but it demands ecological understanding. Such understanding in this case will require sustained research because (1) management of the Colorado River will make use of the control afforded by the dam, (2) the river ecosystem is in disequilibrium because of the dam construction itself, and thus (3) operational decisions will require continuous checking to confirm that the desired effects are being achieved.

To achieve this level of understanding, managers must make new commitments to involve scientists in the development of management strategies. Scientists have been willing to be involved, but unfortunately are often seen by managers as "gadflies." The margin for error is shrinking as management goals become more complex and the effects of mistakes extend further and last longer. Management, approached as if the plans were merely reform actions to solve specific problems, with no subsequent interest in whether management goals were achieved, is unacceptable. Careful planning that incorporates ecosystem principles accompanied by follow up monitoring effort is essential.

If the Bureau of Reclamation seeks to alter its mission from development to resource management, a major revision in perspective and skill will be required. A possible approach might include establishing, among Department of Interior agencies and leading scientists, an oversight group with the necessary breadth of perspective to meld science with natural resource management.

FINDINGS AND RECOMMENDATIONS

The committee's findings and recommendations provide advice to the Department of the Interior not only on the specific components of the GCES but also for the design and conduct of future environmental studies of a similar nature. These brief abstracts of the major findings are followed by recommendations in bold print.

Valuable New Information

The results of the GCES represent a substantial increase in knowledge of the Colorado River ecosystem as it exists in the Glen Canyon and the Grand Canyon. Unfortunately, few data were available to describe the character of the river system prior to the closure of Glen Canyon Dam. This will remain a major impediment to our full understanding of the changes that have occurred as a result of the construction of the dam, although studying reaches of the Colorado not affected by impoundment may give important clues. Thus, the uncertainty about how the river continues to change and how it might be managed will be higher than if pre-dam information had been available. Nevertheless, the GCES provides the beginning of useful documentation at a time when the Bureau of Reclamation is considering improved management of the Colorado River as part of its responsibility.

Although the committee does not believe that the Bureau of Reclamation can make any long-term decisions concerning the management of Glen Canyon Dam based on the GCES, the studies have yielded some excellent information. GCES scientists should be encouraged to submit their work for publication. Clearly, not all reports will yield publishable manuscripts. In some cases the production of unpublishable results is testimony to the inadequacy of the work and of the planning that led to it. Many results, however, represent new knowledge and will contribute to the information base about the Colorado River.

Future work by the Department of the Interior should seek to

- **encourage publication of study results to gain credibility in the scientific community and to assure accessibility of information**
- **establish a data management, storage, and retrieval system to provide easy access and quality assurance**
- **consider investigations of southwestern rivers in other places where impoundment has not altered system interaction**

Aquatic Resources

The studies of aquatic resources have good breadth and touch on most of the subjects that could have been considered of potential significance when the studies began. Program components that were particularly outstanding include extensive documentation of the abundance and distribution of fishes, documentation of physical habitat characteristics, growth and condition factors in fishes, and determination of fish feeding habits. The interpretation of these data provides numerous useful insights concerning the mechanisms that regulate the fish resources of the Colorado River.

The new information improves our understanding of the physical limitations on individual fish species in the Colorado River. However, the data base and data analysis need to be expanded to support predictive modeling of critical habitat space for fish species in both adult and larval stages. This requires integration of research efforts with studies focused on sediment deposition, particle size distribution, and invertebrate and algal productivity in the river downstream from Glen Canyon.

The Department of the Interior should

- **support a monitoring program to evaluate future operations in the context of a Colorado River ecosystem model with priority on sediments and aquatic biota components**
- **evaluate the quality of the water that is released or could be released at different levels from Lake Powell, e.g., temperature, nutrients, particulate organic materials, and zooplankton**
- **include algal and invertebrate productivity in future aquatic study**
- **perform focused studies on sediment movement and deposition in reaches between the dam and Lake Mead**
- **develop predictive, process-oriented models to understand sediments, water temperature, nutrient concentrations, and economics of power production**

Terrestrial Biology

The terrestrial researchers were faced with the difficult task of collecting enough data in a short period of time, and under conditions for which they had not planned, to be able to offer suggestions for river management. This component of the GCES report suffers from a failure to link riverine phenomena (e.g., sediment erosion and deposition) to terrestrial phenomena (e.g., food of terrestrial vertebrates from the river) and from a confusing mixture of science and value judgment. Although it is often useful to remove references and lengthy explanations from the body of the report, in this instance the text became more confusing because assumptions, values, and facts were not documented, differentiated, and/or explained. Even so, the recommendation made by the researchers to continue the monitoring is significant. Willingness to adjust the flow pattern in response to resource changes is the key to managing the system.

The majority of the individual GCES terrestrial biology research projects were carefully executed. The results contribute valuable information. Analysis, however, was limited because some data were missing, numbers were few, and replication was minimal. Many of these problems resulted from unexpected flood conditions during the study period.

Future work by the Department of the Interior should seek to

- **establish links to river productivity in future terrestrial studies**
- **plan for heterogeneity and match methods to the temporal and spatial scales of the phenomena**
- **prepare for the unexpected in schedule and budget preparation; think probabilistically**
- **document the process by which resource values are judged**

Sediments and Hydrology

The sediment and hydrology research effort has produced some excellent new understanding of certain critical components of the complex system of water and sediment movement through the Grand Canyon. The information about mechanisms of sand erosion and deposition in recirculation zones, observations of changes in sediment storage in the river channel, observation of the deposition resulting from debris flows, and the physical analysis of flow dynamics in rapids are examples of this good work. Integrating these elements into a fuller understanding of sedimentary phenomena was hindered, however, because the modeling study of the sediment and water flow was conducted separately. Also, insufficient attention was paid to sediment source, sinks, and sediment movement to beaches and riparian zones. These elements are now realized to be of central importance because they were the focus of other portions of GCES.

Future work by the Department of the Interior should seek to

- **look for connections between research disciplines in the planning phases of the study**
- **initiate studies of tributary processes because they are the main source of sediment in the Colorado River mainstem**
- **include in future hydrologic research empirical approaches as well as modeling approaches**
- **link sediment studies to biological and hydrological monitoring and research**
- **institute geomorphic studies to supplement the hydraulic studies of the Colorado River system in the Grand Canyon**

Recreation

The committee was well satisfied that the relevant questions in the recreation study were approached given the constraints in the scope of analysis embedded in the design of the GCES research program. The change in recreation value in response to changes in dam operations and in terms of appropriate monetary units of measure was evaluated successfully. The study is notable first for the care that was taken to design a survey research instrument for each of the relevant recreation populations and second for the care with which the statistical inferences were drawn. A great deal of relevant information for management was obtained from these results. The recreation reports provided a new dimension to planning for dam operations and an opportunity for further exploration and testing of the contingency valuation study.

Future work by the Department of the Interior should seek to

- **clarify the costs, benefits, and tradeoffs between power generation and recreation opportunities**
- **broaden the definition of constituencies to include not only those who enjoy the Grand Canyon's recreational opportunities; but all those who care about the future of the resource**
- **avoid reliance on the use of hypothetical flows as the basis for predicting user behavior**

Operations

The material presented in the operations section of the final July 1987 draft GCES report is a major improvement over earlier drafts seen by the committee. This type of information would have been useful in the planning phases of the GCES. However, much of the material presented in the operations section of the final July draft GCES report is more relevant to revenue, customers, and the operation of the entire Western Area Power Administration (WAPA) service area than it is to the operation of the dam itself. The hydropower capacity of Glen Canyon Dam is about 78 percent of the total Colorado River Storage Project (CRSP) capacity, but CRSP is but a small percentage of WAPA. The operations section would have been more useful to the analysis of Glen Canyon Dam operations if it had focused on Lake Powell (or at least on CRSP) to develop economic information useful to decisions on changes in dam operations. Furthermore, a comparison of lost revenues from power production and potential gains from management operation of the dam will be necessary at some time.

The Department of the Interior should

- **accept options 1 and 2 of the final draft GCES report: (1) Initiate a feasibility study of possible changes in dam operations and non-operations alternatives for protecting downstream resources. Such studies comply with National Environmental Policy Act (NEPA) requirements for informing and involving interested and affected publics and agencies. (2) Continue with research and monitoring of resources.**
- **consider all management options (e.g., base load hydroelectric operations, discharge and timing of releases, installation and operation of multiple outlet structures, and strategies for conservation that use less than maximum storage in Lake Powell)**

The Integrated Final Report

The integrated final GCES report that was given to the committee in July 1987 is a readable document for the general public. The committee suspects that this type of document was produced to achieve policy objectives. The GCES scientists, however, have sacrificed scholarly rigor to achieve this brevity and readability. By doing so, they have risked confusing readers who do not take the time to read the supporting reports. The combination of sacrificed scholarly rigor and apparent value judgments increases the risk of misleading managers. This inappropriate use of science could lead to poor policy.

The integration of the results from the biological, sediment, and recreational studies is incomplete. There is little direct cross-referencing, between study components and many policy statements do not consider interactions and indirect effects. In short, it is not clear how the authors arrived at their bold, box-enclosed statements even after inspection of the supporting appendixes.

Unclear Objectives

The goals and objectives presented in the GCES were articulated vaguely, they were inconsistent across individual studies, and they often confused science and policy. They seemed to be more strongly related to the missions of the participating agencies than to understanding how the controlled hydrologic regime of the river influenced downstream resources. For example, the National Park Service emphasized "naturalness," and the Arizona Game and Fish Department emphasized a sport fishery based on trout. The GCES did not carefully identify the resource uses and the boundaries of the study, especially as related to the missions of the agencies responsible for management. Potential management strategies (called operational scenarios) were limited in the original research design and were stated in such a way that the GCES scientists assumed that only one management strategy could be employed without adjustments through time (i.e., management strategy is assumed immutable).

These shortcomings in the early planning stages precluded orderly progress toward integration of information. The problems they caused grew until the GCES scientists experienced great difficulty producing an integrated report at the end of the study.

Future work by the Department of the Interior should seek to

- **establish specific objectives, establish the geographic zone of potential effects, and identify resource uses and values**
- set proper boundaries for the study

Existing Information Not Used In Planning

One feature of early planning that seemed to be missing was the recognition and use of existing research on the Colorado River system. For example, information was available from parallel studies at the impoundment in Flaming Gorge and its tailwater fishery that might have led to early insight about the conceptual scheme for the river below Lake Powell. An early review of this and other information about the river in the Grand Canyon might have led researchers to recognize the need for early planning and the need to understand the interaction of ecosystem components. This might have preempted what turned out to be an over-reliance on the missions of participating agencies, their budgets, their available "pool" of researchers, and so on, as the mechanism of planning that was apparently used by default.

Future investigations should be preceded by

- **a review of existing knowledge in the planning phase, and preparation of a written report of the review as documentation**

Confusion Between Administrative and Scientific Oversight

There was no clear separation of administrative and scientific oversight for the GCES project. Both functions suffered as a result. For example, the GCES project manager was also one of the researchers, the contracts manager, and the report integrator, and was looked to for general oversight by many of the participant researchers. Although the GCES project manager was energetic and enthusiastic about the tasks, the committee believes that no one person should have been assigned such diverse responsibilities for research and management in such a large environmental study.

Furthermore, no senior scientist or group of experienced science advisors were involved in the early planning or in helping the researchers in analysis and integration during the study. Had experienced scientists been involved, the results almost certainly would have been more satisfactory and useful. Such an advisory group could have aided the researchers as their work progressed and might have been able to make smooth mid-course corrections as opportunities arose. The committee was especially aware of this need because of the difficulty it encountered in its advisory capacity at the end of the GCES study period.

Future work by the Department of the Interior should seek to

- **bring senior scientists in at the beginning of environmental studies**
- **establish a scientific oversight group**
- **separate agency administration from scientific oversight**
- **establish a report integration team at the beginning of such a project rather than at the end**

Lack of Contingency Planning

In any environmental study of a river, unexpected events may occur and should be considered in the planning phase of the study. During the 20-year period preceding the study, the flow in the river was controlled, usually with low flows so Lake Powell would fill. Variations in flows reflected variations in demand for hydroelectric power. With the reservoir at full storage capacity, however, the probability of uncontrolled flow (spill or flood) increased dramatically.

Extraordinarily high runoff from spring thaw combined with late snows and rains in 1983 produced an unexpected inflow to an already full Lake Powell. Release of the water required the use of the bypass tubes and the spillways and produced higher flows in the river than had been experienced for at least two decades.

With few exceptions the individual GCES reports refer to the effects of the flooding, and so it is clear that some analyses were conducted as the opportunity forced itself on the project. The flooding was seen by most researchers, however, as a major interference with the stated tasks. Bureau of Reclamation administrators considered the flood to be a potential reason for discontinuing the studies.

The lesson from this experience is that uncertainty characterizes ecosystem processes and the unexpected should be considered in planning. What are the most likely major events that would influence the conduct of the research? What should be done if such an event occurred?

Future work by the Department of the Interior should

- **assume complexity, interactions, and indirect effects in future studies**
- **treat operations as manipulative experiments and, thus, monitoring as experimental data collection**

Need for Peer Review in Project Selection

The individual projects in the GCES were identified at the beginning of the study in the absence of a careful design, specific goals, and well-stated objectives. Project funds were committed early, and planning was added as the project grew. A conceptual scheme to guide the selection of critical research questions and clear identification of the required research skills was needed.

The lead agency for the GCES--the Bureau of Reclamation--apparently did not solicit the talent to conduct the needed research through a peer-reviewed request for proposals. The committee believes that such talent exists outside the agencies directly involved in the project, e.g., U.S. Geological Survey, National Park Service, Arizona Fish and Game Department, U.S. Fish and Wildlife Service. A broad search for the best and most experienced researchers is a necessary effort for such a large-scale environmental study. This applies to scientists that are supported to conduct the work and to the appointment of any scientific oversight group.

Future government research should

- **solicit scientific talent for the work based on a research plan**
- **use merit competition to select researchers, including a peer review system outside the agency or agencies conducting the study**

1

INTRODUCTION

HISTORY OF THE DEVELOPMENT OF THE COLORADO RIVER AND THE GLEN CANYON DAM

The headwaters of the Colorado River and its tributaries drain the mountains of Colorado, Utah, New Mexico, and Wyoming and flow southwesterly, emptying into the Gulf of California in Mexico. It is the second longest river in the United States, the Mississippi River being the longest. The Colorado River has eroded the more arid canyon lands of the Southwest, the most spectacular being the Grand Canyon in Arizona. This erosion from the lower reaches of the basin explains the river's high sediment loads and turbidity. The San Juan River, a large tributary of the Colorado River from the east, drains mountain slopes and plateaus in southwestern Colorado, northwestern New Mexico, and a small portion of northern Arizona, and flows through a canyon in southeastern Utah, joining the Colorado in Glen Canyon now Lake Powell (Figure 1.1).

The potential of the Colorado for irrigation was recognized as early as 1850, and proposals to use the river for generation of hydroelectric power go back more than 80 years. The 1905 floods that destroyed the irrigation works constructed in the Imperial Valley created political pressure for the

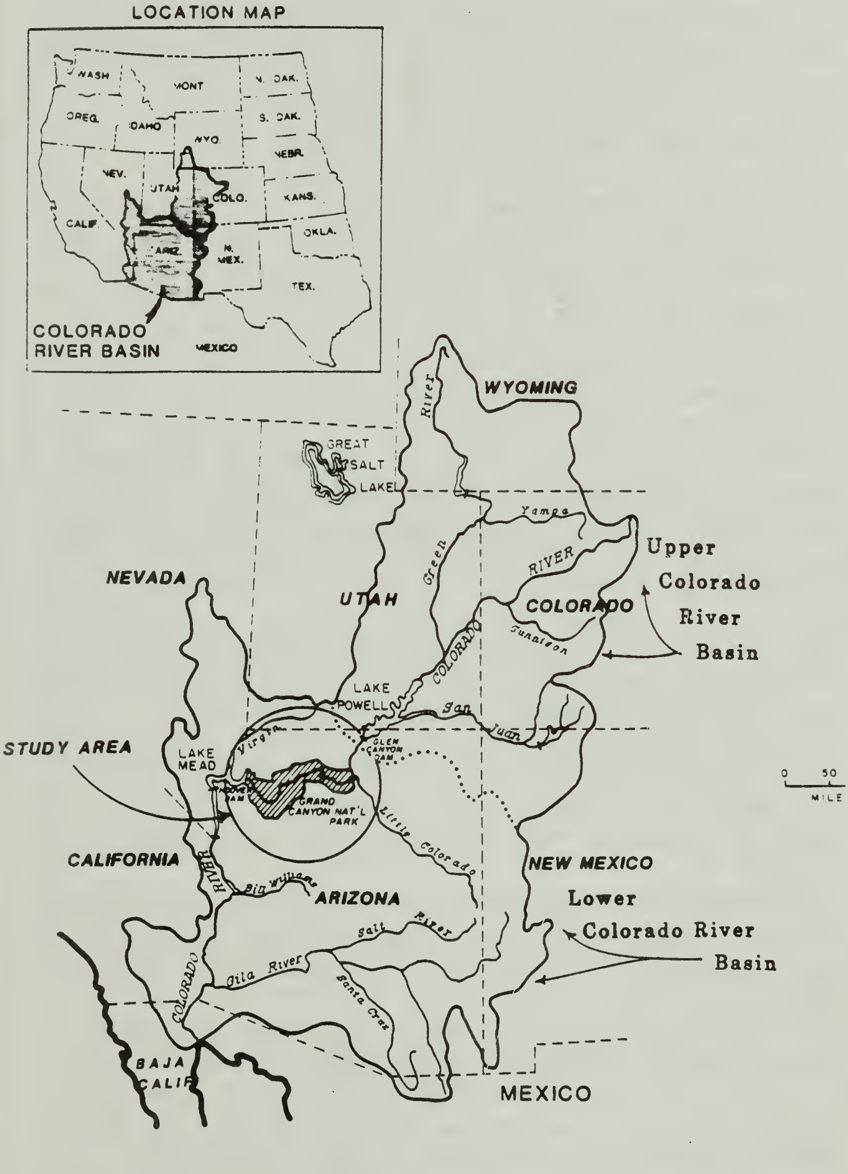

FIGURE 1.1 Location map of the Colorado River basin.

SOURCE: U.S. Department of the Interior, 1987.

the construction of a large storage dam on the river. In 1922 the river was allocated between the upper and lower basins by the Colorado River Compact. Congress passed the Boulder Canyon Project Act in 1928, which authorized the construction of a high dam in Boulder Canyon. Hoover Dam, which formed Lake Mead, the largest of many impoundments seeking to control the river, was dedicated by President Franklin D. Roosevelt on September 30, 1935. In the late 1940s and 1950s the Department of Interior still regarded the Colorado as a "natural menace" (DOI, 1946) to be harnessed to prevent flooding and to provide water resources for the Colorado River basin states. In a 1946 DOI report to Congress titled The Colorado River: A Comprehensive Department Report on the Development of the Water Resources of the Colorado River Basin, the DOI describes the development of the Colorado River basin in terms of harnessing its power for "critical material" (water) to irrigate crops, locating towns and cities within a short distance of dependable domestic and municipal water supplies, and encouraging mining and other industries that would depend on the availability of hydroelectric power. The river basin has since been developed to the point where the Colorado River is known as "the world's most regulated river."

The benefits afforded by the development of the Colorado, including flood control, hydroelectric power generation, municipal and industrial water, recreation, habitat for fish and wildlife, and water for agriculture, cannot be fully satisfied without some conflict. The Bureau of Reclamation has a set of legally defined responsibilities for regulating the flow of the river, defined by the 1922 Colorado River Compact. They coordinate federal, regional, and state agencies, water users, and other interested parties. Current operation of control structures on the Colorado River by the Bureau of Reclamation is based largely on forecast of runoff, available storage, and requirements or demand for water--all according to applicable laws.

When the Colorado River Storage Project Act became law in 1956, it authorized the Secretary of the Interior to construct, operate, and maintain 4 storage projects and 11 participating irrigation projects. One of these was the Glen Canyon Dam. The priority purposes of the storage projects were to (1) regulate the flow of the Colorado River; (2) store water for beneficial consumptive use; (3) provide for the reclamation of arid and semiarid land; and (4) generate hydroelectric power.

Glen Canyon Dam was closed in 1963, and Lake Powell Reservoir was in the filling phase from 1963 to 1980. The storage volume behind Glen Canyon Dam is 27 million acre feet (to an elevation of 3,700 feet). The release of water is controlled by the penstocks to eight generators, capable of releasing 31,500 cfs, two river outlets with a combined release capacity of 15,000 cfs, and two concrete-lined spillways with a combined release of 208,000 cfs.

The construction and operation of Glen Canyon Dam altered the river below Glen Canyon by stabilizing the flow and temperature and reducing sediment loads. Pre-impoundment sediment discharge through the Grand Canyon averaged 140 million tons per year, ranging from 50 to 500 million tons. Most of the sediment is now trapped in Lake Powell. Before the dam was built, there was a wide range in water temperature. Winter lows ranged to near freezing, and temperatures warmed to near 30°C as the annual floods subsided during July and August.

LAW OF THE RIVER AND THE OPERATION OF GLEN CANYON DAM

The operation of Glen Canyon Dam is circumscribed by the "Law of the River." The "law" is often invoked by the Bureau of Reclamation to demonstrate the extent to which it is constrained in its ability to alter release patterns from the dam. To understand the relationship between the Law of the River and the daily, monthly, and yearly operation of the dam and Lake Powell, it is necessary to distinguish between short-term and long-term operations. Both are ultimately related, but the failure to distinguish between the two, as exemplified by the Glen Canyon Environmental Study's evaluation of the law and the operation of the dam, may overstate to a significant degree the legal constraints under which the bureau operates.

The classic Law of the River is a law of mass allocations between the upper and lower basins, the United States, and Mexico, and among the seven basin states and Indian tribes, supplemented by national and international water quality and environmental quality legislation. This law has very little to do with the day-to-day operations of the dam. Beyond ensuring that Lake Powell is filled by July 1 of each year, the bureau has not had to operate the dam to allocate water in response to a long-term shortage on which the classic law is premised. Instead, the bureau operates the dam on a daily basis to maximize power revenues to repay the costs of the dam and reclamation projects in the upper basin. The duty to comply with the law of mass allocations could constrain the daily and monthly operations of the dam, but it is important to realize that to date the bureau has been able to operate the dam within the broadest parameters of the common understanding of the Law of the River. A brief review of the law of mass allocation is necessary for the reader to evaluate the constraints to which the bureau is subject and to understand the deficiencies of the component of the GCES report on dam operations.

1. 1922 Colorado River Compact. In 1922 the lower and upper basin states agreed to a mass allocation between the two basins, with a contingency for the satisfaction of Mexican claims. The upper basin states (Wyoming, Utah, Colorado, New Mexico) agreed to the compact to reserve water for their future use that they feared would be lost to the more rapidly developing lower basin states (Nevada, Arizona, California),

especially California. The upper basin states correctly anticipated that the Supreme Court would apply the law of prior appropriation in equitable apportionment actions between states that follow the doctrine. The lower basin states consented to a limitation on their right to continue to appropriate Colorado River water in order to obtain federal construction of Boulder Dam.

2. 1928 Boulder Canyon Project Act. Congress appropriated money to construct Boulder Dam and required California to limit its use to 4.4 million acre feet of the lower basin's allotment, which set a limitation for Arizona since Nevada has consistently claimed only 300,000 acre feet.

3. 1948 Mexican Water Treaty. The United States agreed to provide Mexico with 1.5 million acre feet per year. Questions about the quality of the water were deferred until the 1970s.

4. 1948 Upper Basin Compact. The upper basin states agreed to a percentage allocation among themselves of the amount reserved by the 1922 Compact. They did this because the Bureau of Reclamation told them that it would not recommend any reclamation projects in the upper basin until each state had a firm entitlement.

5. 1963-1964 Supreme Court decision in Arizona v. California. To the surprise of the basin states, the Supreme Court held that (1) the 1928 limitation on California's use was a congressional exercise of its power under the commerce clause to apportionment of the river among Arizona, California, and Nevada, (2) the Secretary of the Interior has the discretion to apportion water in times of shortage incident to administration of reclamation contracts by whatever formula is chosen, and (3) Indian reservations and federal reservations of public lands may claim federal reserved water rights to fulfill the purpose of the reservation. The result was that Arizona got the firm water right it needed to seek federal funding of the Central Arizona Project (CAP), which has now been completed to Phoenix. The net effect of Arizona v. California was to make the Secretary of

the Interior the River Master and to provide Indian tribes some measure of water parity with agricultural and municipal users.

6. 1968 Colorado River Project Act. This act authorized the Central Arizona Project and partially reversed Arizona v. California because Arizona agreed to subordinate CAP deliveries to 4.4 million acre feet of existing California uses as well as to all present perfected rights in Arizona and Nevada. These are the senior rights around Yuma and the Imperial Valley and the five Colorado River tribes.

7. 1972 and 1977 Clean Water Acts. Reduction of salinity levels became a national commitment.

8. 1973 Endangered Species Act. This federal legislation requires that federal projects be operated to protect listed threatened or endangered species jeopardized by the project. The relationship between flow releases required to comply with the act and prior state and federal allocations is unclear.

There is a potential conflict between use of the dam and reservoir for power generation and use for carryover storage to meet the various mass allocation duties. For example, suppose the upper basin demands that water be stored to meet its future 10-year average delivery obligation but instead the Secretary of the Interior releases water to meet power contracts? A 1964 secretarial decision to release Lake Powell water, while the reservoir was filling, was protested by the upper basin states. The resulting controversy led to the formulation of operating criteria of lakes Mead and Powell that were enacted into law in 1968. The relevant text of the statute provides:

> *In order to comply with and carry out the provisions of the Colorado River Compact, the Upper Colorado River Basin Compact, and the Mexican Water Treaty, the Secretary shall propose criteria for the coordinated long-range operation of the reservoirs constructed and operated under*

the authority of the Colorado River Storage Project Act [43 USCA §620 et seq.], the Boulder Canyon Project Act [43 USCA §617 et seq.], and the Boulder Canyon Project Adjustment Act [43 USCA §618 et seq.]. To effect in part the purposes expressed in this paragraph, the criteria shall make provision for the storage of water in storage units of the Colorado River storage project and releases of water from Lake Powell in the following listed order of priority:

(1) releases to supply one-half the deficiency described in article III(c) of the Colorado River Compact, if any such deficiency exists and is chargeable to the states of the Upper Division, but in any event such releases, if any, shall not be required in any year that the Secretary makes the determination and issues the proclamation specified in section 1512 of this title;

(2) releases to comply with article III(d) of the Colorado River Compact, less such quantities of water delivered into the Colorado River below Lee's Ferry to the credit of the states of the Upper Division from other sources; and

(3) storage of water not required for the releases specified in clauses (1) and (2) of this subsection to the extent that the Secretary, after consultation with the Upper Colorado River Commission and representatives of the three Lower Division States and taking into consideration all relevant factors (including, but not limited to historic streamflows, the most critical period of record, and probabilities of water supply), shall find to be reasonably necessary to assure deliveries under clauses (1) and (2) without impairment of annual consumptive uses in the upper basin pursuant to the Colorado River Compact: provided, that water not so required to be stored shall be released from Lake Powell: (i) to the extent it can be reasonably applied in the states of the Lower Division to the uses specified in article III(e) of the Colorado River Compact, but no such releases shall be made when the active storage in Lake Powell is less than

the active storage in Lake Mead, (ii) to maintain, as nearly as practicable, active storage in Lake Mead equal to the active storage in Lake Powell, and (iii) to avoid anticipated spills from Lake Powell.

This statute tracks the Law of the River. The salient portions incorporated into the statute are the two compacts and prior congressional legislation. The 1922 Colorado River Compact divides the basin between upper and lower states and awards each basin 7.5 million acre feet annually and gives the lower basin the right to increase its uses another 1 million acre feet. The 1948 compact apportions the upper basin's 7.5 million acre feet on a percentage basis among the four upper basin states. The 1948 Mexican Water Treaty guarantees Mexico 1.5 million acre feet per year; the burden is to be borne equally by the two basins if surplus water is not available. The Boulder Canyon Project authorized the construction of Hoover Dam, and authorized Arizona, California, and Nevada to enter into a compact to divide the lower basin such that they would receive 2,800,000; 400,000; and 300,000 acre feet, respectively. No such interstate compact was made, but in Arizona v. California, the Supreme Court construed the act to be a congressional apportionment of the lower basin. Article III(c) of the 1922 compact requires that the upper basin states contribute one-half of the Mexican Treaty obligation, but section 1512 recognizes that the Mexican Treaty obligation is a national one and the upper basin states are relieved of their III(c) duties if the Secretary of the Interior finds that augmented supplies of the Colorado system are available to meet the obligation. In 1968 Senator Jackson successfully sponsored an amendment that prohibited the Bureau of Reclamation from studying augmentation plans for any river system outside the seven basin states, e.g., the Columbia, for 10 years. Article III(d) requires the upper basin states not to cause an aggregate depletion in the river at Lee's Ferry below 75 million acre feet for any 10-year consecutive period "reached in continuing progressive series beginning with the first day of October next succeeding the ratification of this compact." Article III(e) prohibits the upper basin states from withholding water and the lower basin states from requiring the delivery of water that cannot reasonably be applied to domestic and agricultural uses. There is no mention of power generation in the section.

INITIATION OF THE GLEN CANYON ENVIRONMENTAL STUDIES

The physical boundaries of the Glen Canyon Environmental Studies (GCES) extended from Glen Canyon Dam through the Grand Canyon to Lake Mead (Figure 1.2). These boundaries were specified in Commissioner Broadbent's December 6, 1982, memorandum (see Appendix B-2). The study boundary was the Colorado River reach between Lake Powell and Lake Mead, excluding both reservoirs (Figure 1.1).

The Glen Canyon Environmental Studies have their roots in court decisions and public involvement. When it became apparent that operation of the rebuilt turbines in Glen Canyon Dam could increase the fluctuations of water levels downstream in the Grand Canyon, tour operators offering white-water raft trips through the canyon became concerned about the continuing quality and safety of their excursions. Private citizens and environmental preservation organizations were also concerned about the continued vitality of ecosystems in the Grand Canyon that might be subject to alteration by the fluctuations in flow.

In association with several groups, one tour operator, Grand Canyon Dorries, Inc., brought suit against Ronald H. Walker, Director of the National Park Service, and other DOI officials in an attempt to prevent the extreme fluctuations in water levels (Grand Canyon Dorries, Inc., et al. v. Ronald H.

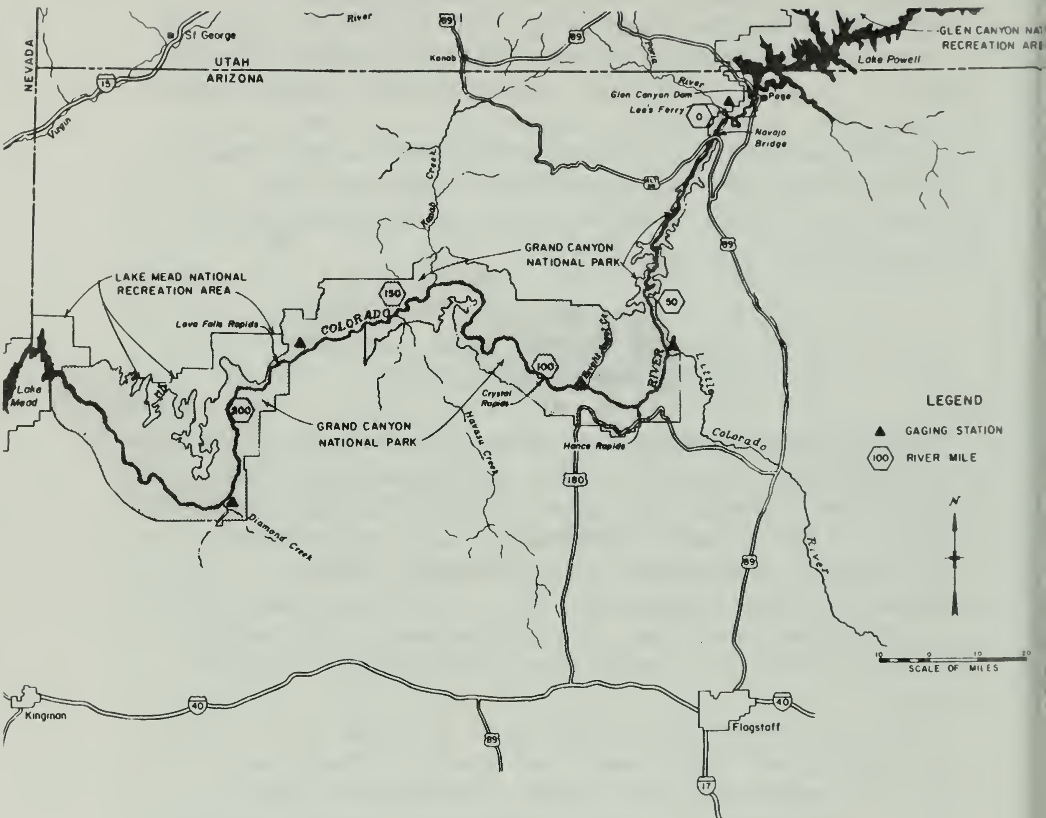

FIGURE 1.2 Glen Canyon Environmental Studies study area.

SOURCE: U.S. Department of the Interior, 1987.

<u>Walker</u>, 500 F.2d 588 1974, see Appendix B-1). Additionally, the suit pointed out that operation of the Glen Canyon Dam properly fell under the requirements of the National Environmental Policy Act, Section 102 of which requires an environmental impact statement for major federal projects that affect the human environment.

The U.S. District Court for the District of Utah ruled that the government did not have contractual obligations to supply river flow to the Grand Canyon in any particular fashion to benefit white-water recreationists, so that the court could not order DOI (and thus the Bureau of Reclamation) to restrict fluctuations. The District Court also ruled that while the National Environmental Policy Act might apply to the operation of Glen Canyon Dam, DOI and the Bureau of Reclamation had not yet exercised their own administrative procedures in the matter. In fact, there was no evidence that the department or the bureau had ever even considered whether or not the operation of the dam required an impact statement. The court was unwilling to interfere with the process until the department and the bureau had made their decisions regarding the issue. In 1974 the Court of Appeals upheld the initial ruling.

The activities surrounding the court case clearly indicated that the department and the bureau would have to make some determination regarding the need for an environmental impact statement for the operation of the dam. If they did nothing, they would be likely targets of another suit for failure to follow their own regulations pertaining to the National Environmental Policy Act. The bureau responded in good faith by soliciting public input through a series of open meetings and mail-based comment processes, which revealed widespread public interest in the issue as well as a variety of opinions about possible downstream impacts of the dam. By the early 1980s it was obvious that the bureau would have to assess those impacts, but it was also obvious that scientific understanding of the possible changes in the Grand Canyon resulting from dam operations was severely limited. The bureau responded to this conundrum by initiating the Glen Canyon Environmental Studies.

Environmental research is not a traditional mission of the Bureau of Reclamation, and so the initiative was somewhat unexpected. Nevertheless, a potential change in the maximum flow through the Glen Canyon Dam's generators accompanied a 4-year program of power plant maintenance and improvement that was completed in early 1987. This established a need for an environmental assessment under the terms of the National Environmental Policy Act, which may have been a crucial influence on the decision to initiate the studies.

REVIEW OF THE GCES AND ITS APPLICATION TO RIVER ECOSYSTEM STUDIES IN GENERAL

The investigation of large rivers requires talents and skills from a wide range of disciplines, many of which have considered rivers less important than other subjects, or too difficult, or both. Most investigations of flowing water have been conducted in headwater streams that are smaller and have less diverse riparian land processes. The development of appropriate ecosystem concepts is, therefore, as uncertain as it is difficult. The opportunity to review the results of a series of studies that set out to delineate river ecosystem concepts promised to be interesting because the information would be useful to conceptual development for future study.

Not only is the matter of integrating disciplines difficult, e.g., hydraulics with sedimentation or water chemistry with biological productivity or water law with recreational values, but the scientific issues in each of these areas alone, in the context of large rivers, reach for new knowledge. No matter how critical this review appears to be, there should be no doubt that the committee has a great deal of respect for the GCES scientists and what they have attempted. The research task was particularly challenging because there were so few pre-dam data describing phenomena in the river that were thought to be affected by dam operations. The products of the study are criticized, of course; some fall short and some are excellent, and the scientists should be applauded heartily for the attempt.

Ecosystem study is complex, and simplification is often part of the planning stage. The more complex the system, the more drastic the simplification measures and the greater the uncertainty of the results. Here are a few cautions of which to be aware.

1. Small headwater streams are more easily considered as part of the terrestrial ecosystem in which they are embedded. Large rivers are not just small streams with greater discharges. They defy categorization as ecosystems or parts of ecosystems because:

a. Large catchments involve climatic and hydrologic heterogeneity. Therefore, they usually contain several, if not many, ecosystem types as characterized by terrestrial vegetation. This large-scale spatial variability may be integrated to some degree by the flow of the river, but the details of this are undocumented. A few examples exist (e.g., Amazon River) where the temporal variability of flow from different regions in the large catchment imparts different characteristics to the water.

b. The boundaries of large river ecosystems are vague. Boundaries of ecosystems are often chosen according to the convenience of investigators. An a priori judgment about minimal fluxes of material or energy, or places where the fluxes might be measured with minimal expense or effort, is a common criterion. Many aquatic ecosystems defined this way consider the shoreline as the most appropriate boundary. Large rivers do not fit this pattern of thinking. What is the shoreline? the active channel? the floodplain? How far upstream must one travel for adequate measurement of the imported water and materials being carried by it?

2. Large rivers are inconvenient units for sampling and analysis. The hydrologic regime should dictate sampling frequency. Tributary and hydraulic patterns ought to dictate sample spacing. The scale of the discharge of large rivers is often beyond the scale of sampling logistics that were developed for smaller streams or for lakes. This makes observation and analysis difficult and expensive. Interpretation will be uncertain because the variance will be high. This is disconcerting because the channel heterogeneity itself may be of critical interest.

3. Large rivers are rarely free of the effects of civilization since rivers have dictated human activity throughout history. Thus, most large rivers are out of equilibrium as they respond to human alterations.

The difficulty of large river study is partly pragmatic. Logistics, expense, and inadequate sampling protocols all present challenges that often preoccupy the attention of investigators. The intellectual challenge of addressing a flowing system at large scale is of much greater interest. The difficulty is not the fault of the river; it lies with the mental construct of the "river ecosystem."

Although the Glen Canyon system is intricate, it can be presented in a conceptual scheme that shows the interactions between components. Such a conceptual scheme provides a way to begin to understand the processes and interactions among the resources of the system. It can provide the baseline and background to understanding the Glen Canyon system currently functioning under human intervention. Human intervention through construction of Glen Canyon Dam has created an altered set of control variables. These can be described as management requirements that lead to operation of the dam.

The conceptual scheme shown in Figure 1.3 was devised by the committee to guide their interpretation as they reviewed the Glen Canyon

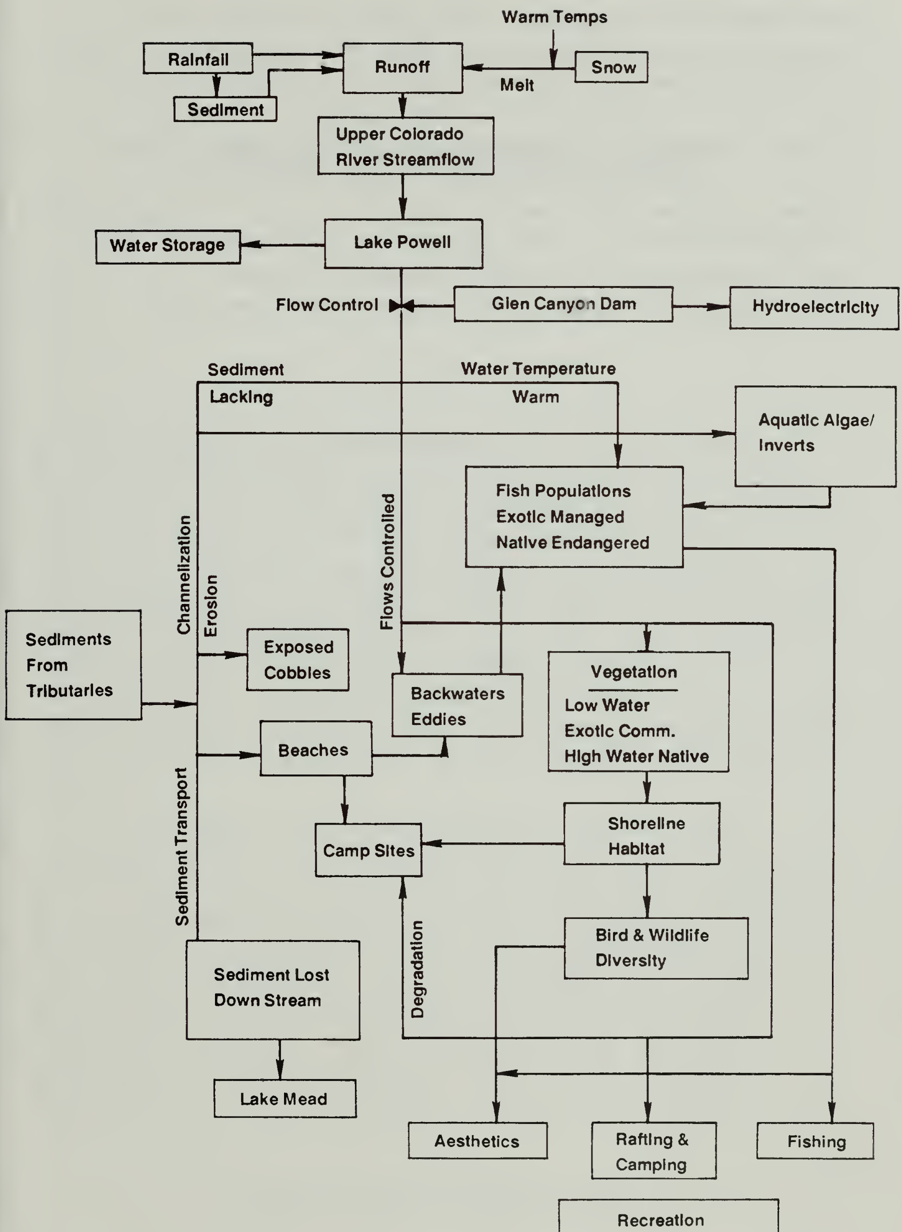

FIGURE 1.3 Conceptual scheme of Glen Canyon ecosystem components and their interactions under present operations of Glen Canyon Dam.

Environmental Studies. The Water Science and Technology Board believes that the request to the National Research Council for advice and review might have resulted in a more useful exchange had it been made at the beginning of the GCES study period. However, the board also believes that a review of the GCES could yield specific insight and recommendations to the Bureau of Reclamation and other agencies that might conduct future environmental studies of large river systems.

2

PLANNING AND MANAGEMENT OF GCES

The planning and management of the Glen Canyon Environmental Studies consisted of three distinct activities that had direct bearing on the validity and usefulness of the outcomes of the project research. First, the definition of objectives determined the scientific direction of the studies; second, the administrative structure established the working relationships among project participants; and third, the selection and organization of researchers created a specific pool of expertise and working relationships for the project.

The strengths and weaknesses of the project planning effort were significant influences on the scientific success of the effort because planning and management determined which questions would be addressed (objectives), how the researchers would work and communicate with each other, and which researchers would contribute to or review the finished products. Good decisions as well as mistakes at the management level were therefore reflected in the scientific output of the project.

DEFINITION OF OBJECTIVES

The definition of research objectives for the studies began with a December 6, 1982, letter (see

Appendix B-2 and Figure 2.1) from Bureau of Reclamation Commissioner Robert M. Broadbent to the bureau's Salt Lake City Regional Director. Broadbent pointed out that although the operation of uprated generators in Glen Canyon Dam offered a variety of discharge options, the maximum releases from the dam were to be limited to the (1982) maximum of 31,500 cfs. This maximum was not to be exceeded until the completion of a decision process that included compliance with the National Environmental Policy Act. This general direction by Broadbent focused attention on relatively low flows.

The December 6, 1982, letter also contained more specific directions that essentially defined the original objectives of the Glen Canyon Environmental Studies. Broadbent instructed the regional director to determine how the present (1982) flow patterns affected the Grand Canyon riverine environment, especially with reference to low-flow effects on recreational river rafting and sport fishing. He further instructed that the studies should consider low-flow regimes of 1,000, 3,000, 4,000, 5,000, and 8,000 cfs. The studies were also to identify the discharge at which material impacts appeared in beach erosion, recreation, and fisheries.

On April 15, 1983, Clifford I. Barrett, Salt Lake City Regional Director of the Bureau of Reclamation, informed Broadbent by letter that he was organizing the Glen Canyon Environmental Studies (Appendix B-3). An additional objective of the studies added by Barrett was to analyze the economic value of the recreational resource of the Grand Canyon.

In the spring of 1983, after Barrett's letter to the Commissioner, Lake Powell filled and the Glen Canyon Dam spillways discharged more than three times the amount of water that was anticipated as a maximum from power plant releases. These high flows were the direct result of the filling of the reservoirs of the Colorado River Storage Project

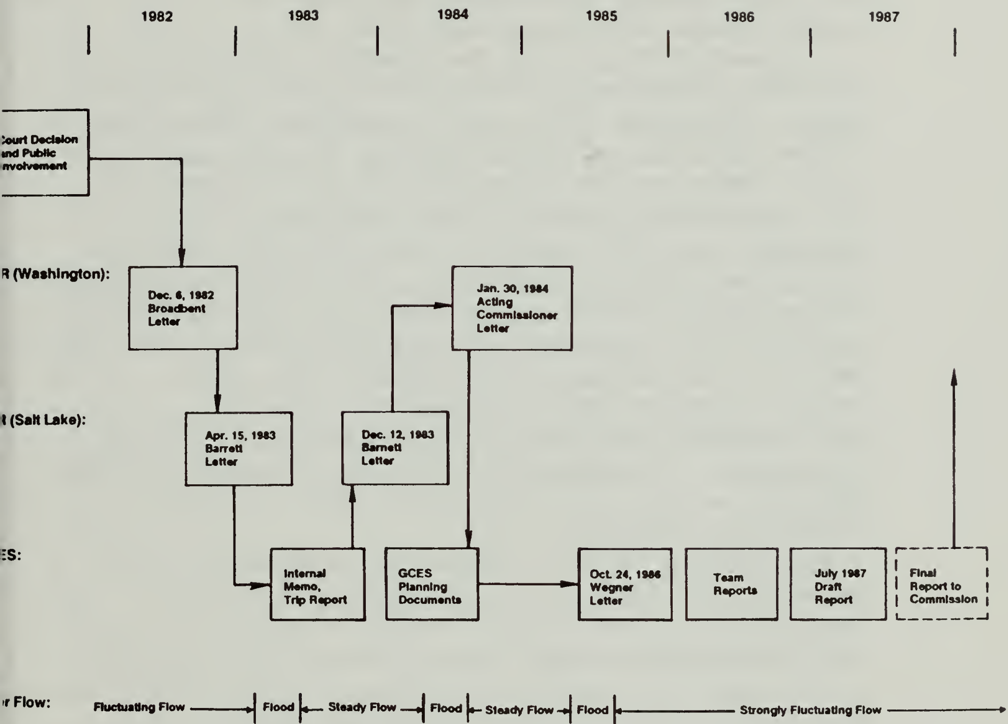

FIGURE 2.1 Steps in the Bureau of Reclamation decision process concerning the Glen Canyon Environmental Studies.

throughout the upper basin. The high, sustained discharges were the first since closure of Glen Canyon Dam and the filling of Lake Powell began in 1963. Apparently, dam operators and study managers had not foreseen such high discharges as possibilities for the early 1980s.

An internal Bureau of Reclamation memo dated July 18, 1983, expressed concern about the implications of the 1983 high flows for the defined objectives of the Glen Canyon Environmental Studies (Appendix B-4). The memo concluded that four alternatives were available to the project manager: (1) continue to study impacts of power plant releases (less than about 31,500 cfs), (2) conduct studies taking into account large flows, (3) terminate the studies, (4) continue the studies assuming that the dam would be operated to minimize high flows. In order to assess the alternatives, the memo recommended a multiagency inspection trip through the canyon. In September 1983 the inspection trip took place at a time when flows were at about 30,000 cfs (Appendix B-5).

The results of the inspection trip appear in a December 12, 1983, letter from Salt Lake City Regional Director Barrett to the Commissioner of the Bureau of Reclamation (Appendix B-6). Barrett wrote that the interagency team concluded that the high flows had not caused "serious damage," and that therefore high flows occasioned by the operation of the new upgraded turbines would be unlikely to have adverse impacts on the canyon environment. He set forth the objectives of the study as including the following points: continue to study the impacts of the present (1983) operating strategy, assume that the Glen Canyon Dam will be operated to minimize risk of spillway releases, assume occasional spills, and collect baseline data on conditions resulting from the 1983 flows. Barrett indicated that the studies were continuing without interruption because of a "commitment to the environmental and recreation communities that a study is being performed," the need to complete these studies prior to the full utilization of the uprated generators, and "consistency" with the original letter from Broadbent, which outlined the need for the studies.

The Acting Commissioner of the Bureau of Reclamation responded by letter on January 30, 1984, approving the continuation of the study with its original objectives, but pointing out that there no longer was a "typical operations pattern" and that there "probably never will be again." The Acting Commissioner advised the Regional Director that any future studies should recognize both flood and drought condition operations (Appendix B-7).

After the late 1983 decision to continue with the Glen Canyon Environmental Studies, the Bureau of Reclamation initiated meetings with the National Park Service, Arizona Game and Fish Department, and the U.S. Geological Survey (Arizona District Office) to consider proposals generated within the agencies for specific projects addressing the general research questions and objectives. Agency representatives evaluated each proposal on a series of three criteria: (1) Did the proposal address the long-term effects of operation of Glen Canyon Dam? (2) Did it address the short-term effects? (3) Did it address issues related to the uprating of the generators or to river impacts downstream? The study manager and members of the subteams or groups decided which proposals to include in the project.

By the time the project was complete in 1987, the study manager, David Wegner, articulated the objectives of the study as being the assessment of the impact of the operating pattern of the dam on the river environment in the Grand Canyon. In summary, the original objectives of the Glen Canyon Environmental Studies were fairly simple: determine how dam operations had affected the canyon environment, and predict how a variety of relatively low flows would be likely to influence the system. High flows in 1983 brought about a new era in the environmental history of the canyon and confused evidence that might be used to achieve the initial objectives. Despite the admonitions of the

Acting Commissioner, the formally stated and actual objectives of the studies remained virtually unchanged, and the individual studies continued as planned without amended research questions or new studies.

The definition of agency objectives and priorities provided an underlying philosophy for many decisions and statements during the project. In many cases, however, the objectives were poorly defined or did not adequately recognize the complexity of the systems involved. For example, the priorities of the National Park Service appear to prize "naturalness," but the environment of the Grand Canyon is highly unnatural (Appendix B-8). It is not clear what point on the continuum of natural to artificial is acceptable to the Park Service.

Research questions and their articulation as project objectives determine the course of any scientific investigation. The original research questions for the Glen Canyon Environmental Studies were reasonable under the circumstances of their formulation. Barring the unanticipated high flows, they would have led to increased understanding of the impacts of dam operations on the canyon environment. Such knowledge would have enhanced predictability of the effects of power plant operations. Nevertheless, objectives were not cast according to existing knowledge of the river ecosystem. That, in part, is why the high flows of 1983 changed the context of the study. After 1983 the collection of field data described a river system that was adjusting not only to impoundment and power plant operations but also to very high, long-duration flows from a spill. After the high flows, the only valid approach to the original research questions was to use historical data from the 1962 to 1983 period, data that showed environmental response to power plant flows alone.

Observations made on the September 1983 inspection trip were irrelevant to planning the research project for two reasons. First, because the trip was made during flows of about 30,000 cfs, changes to the environment could not be accurately observed. Despite the fact that much of the near-channel environment was still underwater and therefore not visible, the Regional Director wrote to the Commissioner that there had been no "serious damage" (Appendix B-6). While upper beaches were available for inspection at this time, channel conditions, sand bars, recirculation zones, and parts of many rapids were not visible and could not be assessed for change. In any case, "damage" is a qualitative term whose meaning had not yet been established. Second, at the project and regional level of the Bureau of Reclamation, there was no satisfactory recognition that the collection of baseline data for a river adjusted to power plant operations alone was now (1983) impossible because the river had experienced high flow from a spill. The river's history had become segmented into three parts: (1) pre-1962, before the closure of the dam; (2) 1962 to 1983, postdam, reservoir filling, no spills, river adjusted to power plant operations; and (3) post-1983, postdam, power plant operations plus occasional spills. The Acting Commissioner clearly recognized the new set of circumstances in his January 30, 1984, letter. While individual investigators had alterations of their plans forced upon them, many turned the unexpected into opportunity. Study managers and researchers failed to make adequate adjustments to the original research questions and plans for synthesis by taking into account the newly established regime. Some of the study's reports therefore address a set of environmental conditions that no longer exist, and for which empirical data are not available.

It appears that, once begun, the project took on a certain inertia in its course toward addressing specified low discharge levels, did not account for spills, and appeared limited to power plant operations. To have seriously altered the research questions after the 1983 flows would probably have partially undermined support for the project within the Bureau of Reclamation. While broadening the study to include predictive efforts accounting for periodic spills might have diluted the original intent to answer critical comments about power plant operations, it would have strengthened the validity of the final products.

The originally stated objectives of the studies as articulated in the December 6, 1982, Broadbent letter did not survive unchanged to the end of the study. Commissioner Broadbent's stated objectives emphasized investigations on how dam operations affected rafting and fisheries, and included a search for how threshold discharges materially affect Grand Canyon resources. At the conclusion of the studies in the July 1987 draft report, however, the stated questions had been transformed into (1) a determination of whether or not the dam "adversely" affected river-related and recreational resources, and (2) whether or not there is a way to operate the dam to "improve" those resources. This shift away from objective questions about system operation to value-laden questions focused on dam operations represents a radical adjustment to the originally stated intent and direction of the studies, and resulted in a lack of internal intellectual cohesion in the project and its reports.

ADMINISTRATION

The Bureau of Reclamation administered the Glen Canyon Environmental Studies through the efforts of a study manager based in Flagstaff, Arizona. The study manager reported to the Salt Lake City Regional Director, who in turn was responsible to the Commissioner of the Bureau of Reclamation in Washington, D.C. Funding for the research came from sales of electrical power by the Colorado River Storage Project of the bureau through the Western Area Power Administration (WAPA). This method of funding reflected the importance of the research to the power generation and sales portion of the bureau's activities, because the uprated and expanded use of the Glen Canyon Dam generators could not occur (according to legal agreements and the direction of the Commissioner) until after the studies were complete.

The study manager administered the efforts of about 50 researchers organized into four subteams or groups, with each group focusing on a limited subject in the total project. Each group had a group leader, a primary researcher who served in a connective role between the group members and the study manager. Group I concentrated on biological concerns including riparian terrestrial and aquatic studies. Group II focused on recreation issues including accident surveys, user preference analyses, and simulations of the effects of flow changes on river use. Group III simulated hydrology and sediment transport, and investigated the dynamics of beaches. Group IV, the operations studies, provided legal and administrative background information on the operation of the dam.

Near the time of final report generation, the study manager formed an "integration team" consisting of group leaders and some key researchers from each group. The purpose of the "integration team" was to attempt to synthesize the results of the study and provide a holistic summary of each group's work, and to enhance the exchange of information between groups.

The project study manager was successful in coordinating the efforts of a large number of diverse researchers in a complicated project. He conducted the managerial functions of the project in a fashion that reflects credit on the bureau. His general understanding of the scientific and management issues permitted the project to move to closure remarkably close to its originally anticipated completion date.

Several adjustments in administration would have improved the project. First, an integration team should have been developed at the beginning of the project rather than at the end. Early establishment of an integration team consisting of representatives from all the groups would have facilitated the transfer of data from one group to another during the research when it would have been most useful. The final report would have then been truly integrative rather than the series of piece-by-piece summaries that emerged inevitably from the attempt to produce a synthesis after individual projects were complete. The recreation studies would have benefited from understanding the beach processes. Perhaps more importantly, the operations section should have been based on findings from all the other reports. The incorporation of the contingency valuation figures from the recreation research would have enhanced the conclusions of the series of studies. Without a prearranged framework, integration of the numerous reports from such a variety of standpoints is loose at best. Another administrative adjustment that would have improved the products of the Glen Canyon Environmental Studies would have been to include a senior environmental scientist or a group of science advisors at the highest levels of project management. This individual or group would not have been specifically attached to any particular agency. Working at the study manager's level in the project structure, this person(s) could have visualized the scientific unity of the project to complement the study manager's vision of the administrative unity and could have generated conceptual models to guide research. A senior researcher would have increased the flow of information from one group to another and could have articulated the need for revised research questions from a scientific perspective.

SELECTION AND ORGANIZATION OF RESEARCHERS AND REVIEWERS

The decision process by which the Bureau of Reclamation obtained proposals for research to be included in the project strongly influenced who actually conducted that research (Appendix B-9). Because proposals for the work came from group members who were employees of the various agencies involved, agency employees or their contractors represented the pool of expertise for the research (Appendix B-10).

The Bureau of Reclamation organized the researchers into the four groups (Biology, Sediment Transport, Recreation, Operations), with each group led by one individual who coordinated group work and acted as liaison with the study manager. Two-day meetings were held every six months with the primary researchers and the study manager to discuss the status of the project. Communications were mostly informal.

In some cases, agency employees took primary responsibility for the work. In the Hydrology and Sediment Transport Group, for example, Bureau of Reclamation specialists in sediment transport and hydraulic engineering accomplished the majority of the basic simulation work. In this effort they made extensive use of engineering techniques developed earlier for other applications by the bureau. The U.S. Geological Survey completed some of the investigations in the hydrology and sediment transport portions of the study, especially those relating to the empirical aspects of the investigation. Like the bureau, the survey used internal researchers in its work, including staff hydrologists and graduate student and intern appointees.

In the Biology Group of the Glen Canyon Environmental Studies, the National Park Service and the Arizona Game and Fish Department used a mixture of a few agency employees and numerous contractors from the private consulting industry. Some graduate students participated in the research in circumstances similar to those in the U.S. Geological Survey.

The process by which individual researchers and specific projects were included in the total study reflected the lack of early planning. Instead of defining the nature of the desired products and general approaches in formal requests for proposals, the decision process accepted proposals from within agencies and from researchers who had been involved in setting objectives. The committee feels that planning served self interest or political expediency to the detriment of coherent integration of the project. Perhaps for some researchers the project became a source of funding that was available to replace declining general support within their agencies. The result was a collection of projects that did not focus on or contribute to the goal of integration and were not completely mutually supportive.

Because there was no apparent effort to advertise the project throughout the scientific community or to solicit for proposals directed to sharply defined research questions, the project did not have a large pool of scientific talent from which to draw researchers. University-based researchers and those in consulting firms that have not traditionally had strong ties with the agencies involved were unaware of the project and had no opportunity to participate in the process or to submit proposals to be evaluated. This process automatically eliminated valuable expertise from consideration for inclusion in the pool of scientific talent for the studies.

Within these constraints, the process identified high-quality researchers at the junior and early-intermediate levels of their careers who were associated with the agencies involved. Use of many junior staff members lacking experience in complex problem analysis may have also contributed to the difficulties encountered in integrating the studies.

The review process for reports generated by the Glen Canyon Environmental Studies consisted of two components: internal and external reviews (Appendix B-10). Internal reviews were those conducted on reports by group members from the same group as the report authors. This internal process meant that in the case of the Biological Studies, for example, the same reviewer read and commented on the majority of the reports generated by the group. External reviews were those conducted by individuals outside the group that generated the report. In the case of the Biology Group, external reviews included a diverse set not in the group but from within the Bureau of Reclamation, as well as U.S. Geological Survey personnel, a variety of university professors, and a private consultant. On the other hand, of the 35 external reviewers for reports of the Hydrology and Sediment Transport Group, more than half were from the Bureau of Reclamation or the U.S. Geological Survey. With two exceptions, the remainder were from the National Park Service.

Much of the success and credibility of scientific research lies in the review and referee process. Review requirements were inconsistent in the studies. Technical and editorial reviewers examined and commented on U.S. Geological Survey reports, but some other reports did not receive such thorough reviews. Generally, with the exception of the Biology Group reports, the technical review process for products of the Glen Canyon Environmental Studies did not involve enough experts sufficiently removed from the work. Agency personnel with potential intellectual or policy-related conflicts of interest were common participants of the review process. Selection of reviewers from agencies not involved in the work (such as the Corps of Engineers), or from universities and consulting firms not under contract elsewhere in the studies, would have been appropriate.

3

BOUNDARIES OF THE GCES

GEOGRAPHIC BOUNDARIES

Tributaries between Glen Canyon Dam and throughout the Grand Canyon were included in the GCES in terms of their input to the river mainstream, but only the lowermost reach of the little Colorado River was studied explicitly (see Figures 1.1 and 1.2). These tributaries are unregulated, and thus the study area was the Colorado River reach between Lake Powell and Lake Mead, excluding both reservoirs.

In any response of a system to various inputs, the boundaries of the system and the inputs need to be uniquely identified and characterized. The physiographic boundaries and the inputs and outputs of the Glen Canyon/Grand Canyon ecosystem are schematically shown in Figure 3.1. The inputs include those from Lake Powell, the identifiable tributaries, the nonpoint inputs along the banks, and ground water and atmospheric inputs. The output is flow to Lake Mead and possible deposition within the channel. Within the ecosystem, many different hydrological, chemical, and biological processes take place. The objective of the GCES was to study those processes and their relationships to the operations of the Glen Canyon Dam.

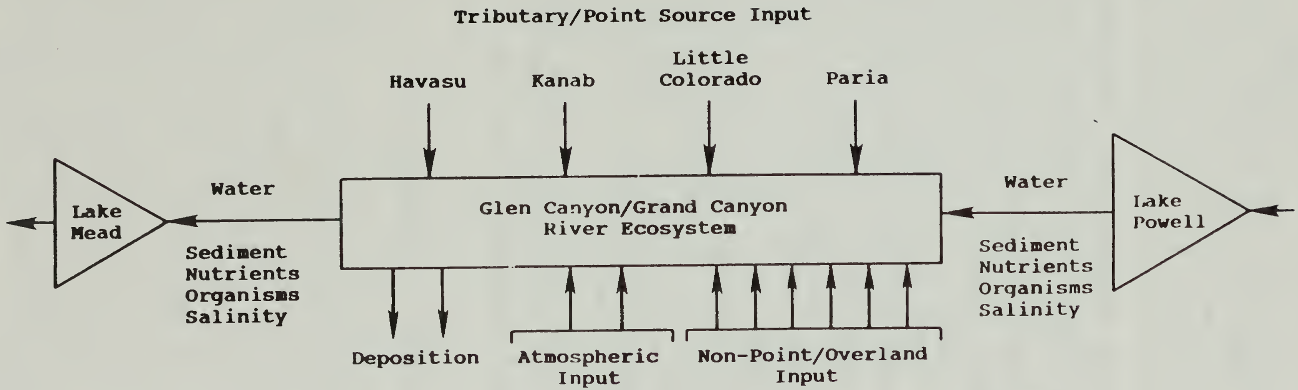

FIGURE 3.1 Inputs and outputs of Glen Canyon/Grand Canyon River ecosystem.

The upstream/downstream boundaries of the GCES were selected with two crucial assumptions: (1) that only at Glen Canyon Dam could the flow rate be controlled and (2) that the effect of outflow from the Grand Canyon on water quality and quantity in Lake Mead was inconsequential. The GCES boundary was chosen therefore to be the rectangular box in Figure 3.1. These two assumptions, although defendable on the basis of the mandate for the GCES (Appendix B-2), are unnecessarily and unreasonably restrictive. They preclude examination of three significant management options for the Glen Canyon ecosystem: (1) the control of water quality in the Glen Canyon/Grand Canyon ecosystem by selective withdrawal and release of water from Lake Powell using alternative withdrawal levels, (2) the minimizing of salinity in Lake Powell by selective withdrawal, and (3) the correction of nutrient deficiency in Lake Mead.

Therefore the committee believes that future ecological investigations in this area should include consideration of selective withdrawal from Lake Powell and impacts of Colorado River water quality on Lake Mead. Because of the obvious connection and important influence that Lake Powell and the Colorado River below have on Lake Mead, any future studies should consider all three.

HISTORICAL BOUNDARIES

The study was mandated on December 6, 1982, and was completed by July 1987. The study began at the end of a long period of water resources and hydropower development on the Colorado River: Flaming Gorge Dam, 1963; Glen Canyon Dam, 1964; Blue Mesa Dam, 1967; Navajo Dam, 1968; Morrow Point Dam, 1970; and Crystal Dam, 1978. In response to this development, the river regime has been in transition in terms of runoff volumes, runoff distribution, and sediment transport. To place the GCES in a proper time frame, one can distinguish the following periods:

1. Before closure of the Glen Canyon Dam (November 1963).
2. After closure of Glen Canyon Dam (completed in 1964) and during filling of Lake Powell (1963 to 1980).
3. Postfilling (since 1980).

The river flow and sediment regimes during each of the three periods are undoubtedly different. It is unlikely that the river has already reached an equilibrium since the post-filling period began in 1980. Was the river in equilibrium before Glen Canyon Dam was built? To answer this question, one must look at a longer time frame (Figure 3.2). The river could not have been said to be in equilibrium, under a rigorous definition of that word, while the watershed was being modified and put to use by settlers on the Upper Colorado River tributaries. However, their impact was slower and possibly much smaller than the impact during and after the construction of Glen Canyon Dam. The conditions prior to Glen Canyon Dam construction may therefore be accepted as a quasi-equilibrium condition.

A very different kind of temporal boundary was imposed by the "time window" within which field research teams could be at an actual study site. These periods were often short and controlled by schedules of participants, difficult and limited accessibility to the sites, food and water supply, and financial resources among others. As a result, some of the researchers had to collect whatever observations were possible and available at the time of their visit, which often lasted for a few hours or a few days under flow conditions uncontrollable by the researchers.

The GCES were commissioned to begin in 1983, and to terminate in 1986. This study period coincided with a strong transition in river regime immediately after the filling of Lake Powell. Unanticipated drastic changes in flow rates occurred and changed the course of some of the studies. Additionally, unusual precipitation in

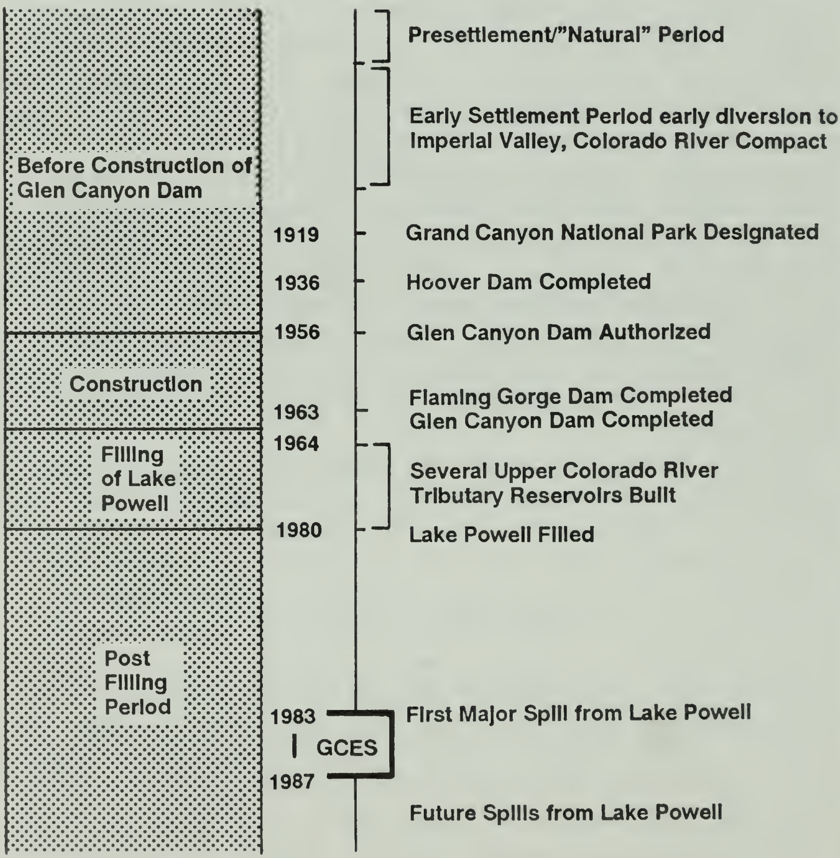

FIGURE 3.2 Historical perspective of Glen Canyon Dam and Lake Powell.

the headwaters was blamed for these events, but the filling and mode of operation of the reservoir also may have had much to do with these events.

EVALUATION OF GCES BOUNDARIES

Since the Colorado River is millions of years old and 1,450 miles long, the GCES represented a quick glimpse through a small window. The glimpse was 4 years long, the window 223 miles wide, and the price $6 million. However, the glimpse is the most detailed view ever taken of the river ecosystem in the Grand Canyon. Where the boundaries of a study are set often influences or biases the outcome or results. The space and time scales chosen for the investigation of any system, be it natural (physical or ecological), economic, or sociopolitical, usually have major consequences for the selection of methodologies and the results. At a geological time scale (millions of years), the events in the Glen Canyon/Grand Canyon over the next 10 to 100 years may have little impact, yet this was precisely the main interest of the GCES. Natural systems have natural time scales and space scales. Many of the time scales are related to climate: long-term trends between ice ages and tropical periods measured in thousands or millions of years, seasonal time scales measurable in months, short-term patterns measurable in hours and days related to the movement of atmospheric weather systems, and finally diurnal time scales measurable in hours related to the rotation of the earth. Artificial time scales are introduced into downstream river flows by the operation of reservoirs and dams. Flows released from Glen Canyon Dam can vary within minutes and hours by magnitudes rarely possible in a natural setting.

The largest space scales of a natural system are determined by the size of the entire system. Subsystems have decreasingly small scales, down to the subatomic level at the most extreme. The scales of a study must be appropriate to the scales of questions and objectives that the study is to answer. Linking the results of a study at different scales is one of the most demanding contemporary challenges. The selection of the appropriate time and space scales is therefore directly related to the selection of the boundaries of an ecosystem study and to the purpose of the study. Boundaries have to be narrow for certain subsets of questions, e.g., studies of individual rapids or tributary subreaches, or wide, e.g., for recreational use studies.

Flow releases imposed by current power production, by recreational users in the canyon, and by dam safety affected the conduct of the GCES strongly. Operation of the dam was not modified to satisfy study needs.

Similarly, the uncontrollable inputs to the river from the tributaries, by overland flow and from the atmosphere, resulted in significant constraints to the GCES. A schematic of the system boundaries and the inputs and outputs through those boundaries is shown in Figure 3.1.

INSTITUTIONAL BOUNDARIES

Glen Canyon Dam was built to serve two primary purposes: (1) to provide carryover storage and (2) to generate power to repay a portion of its cost. Both purposes are mandated by law. The upper basin states have a legal duty to deliver 75 million acre feet of water every 10 years to the lower basin states under the terms of the 1922 Colorado River Compact. Power generation is authorized by the 1956 Colorado River Project Storage Act to repay a large portion of the costs of the dam and to finance other water projects in the upper basin. Nonirrigation and municipal and industrial uses such as flood control and recreation have been viewed as incidental to the two primary purposes. They are, however, significant as they are nonreimburseable, and thus they help to lower the percentage of the project that must be repaid.

Concern over the downstream effects in the Grand Canyon of the operation of the dam eventually triggered the GCES and raised questions about changing the operation of the dam. Different monthly and daily releases, releases from different reservoir strata, and a modest reduction in the amount of water stored in Lake Powell may be desirable to protect and promote endangered species, establish beach stability (rejuvenation), and enhance recreational white water rafting through the canyon.

The most curious deficiency in the GCES report is the absence of any logical connection between the main body of the report and the institutional analysis. A number of significant downstream effects from the construction and operation of the dam are identified by the scientific studies, but the institutional analysis is primarily designed to show why the bureau's operating policies cannot be modified. The operation of Glen Canyon Dam is subject to legal constraints, but the discussion fails to distinguish between external and self-imposed constraints.

Management of the Colorado River is designed to minimize effects of a long-term drought. The bureau's operating rules for the filling of the reservoir and schedule of releases thus seek to guarantee that the agency can respond to compact delivery requirements during a drought. In practice, however, the bureau has been able to control releases in order to generate the maximum amount of power, because power generation storage and releases do not conflict with carryover storage and delivery obligations. In short, the agency's hourly, daily, and weekly release patterns are not mandated by the legal obligations discussed in the bulk of the institutional analysis sections but are discretionary decisions seemingly taken to generate the maximum possible amount of power. This is significant because the GCES report seems to have placed overly constricted limitations on the discussion of alternative operations strategies. The GCES project has, however, produced a major benefit for future studies of the management of the Colorado River by describing in some detail the operating rules in both a long-term (annual and monthly) and a short-term (daily and hourly) time frame.

The GCES July 1987 report properly recognizes that the Bureau of Reclamation is not totally free to change the operation of the dam in response to new demands on the use of the Colorado. The bureau is subject to the web of constraints that make up the "Law of the River." The bureau, however, overstates the extent to which the Law of the River prevents it from modifying the operation of the reservoir to respond to GCES recommendations. The conflict between the Law of the River and the possible operations changes may be less than the operational section of the GCES report indicates. To understand the force of the complaints, it is necessary to distinguish (as the GCES report does not do) among three different levels of constraint. The distinctions are in the binding force of the constraint, and not all constraints are equally binding and difficult to modify. The bureau is subject to:

1. Constraints imposed by law, which include interstate compacts, acts of Congress, treaties, and other international agreements and Supreme Court decrees and decisions
2. Constraints imposed through firm power contracts
3. Constraints imposed by case law that make the bureau responsible for flood damages incurred within the flood zone.

The bureau is, of course, not free to ignore the delivery obligations imposed in the 1922 Compact, but this may be largely irrelevant to the issues raised by the GCES. The operations section of the report seems to assume that any project modification to address the downstream impacts or manage downstream resources by GCES or follow up studies will be permanent. This need not be so.

It seems quite feasible to develop a set of canyon management strategies that will operate most of the time but be subject to modification during periods of extreme drought, or high water, when flow modulation strategies are ineffective. To ignore operation strategies because they will not work in a worst-case situation blinds the bureau to operational modifications that have a likelihood of responding to the problems identified in the July 1987 report and will not conflict with the Law of the River.

The bureau has more discretion to modify policies than it has adopted since the dam was filled. It is important to reemphasize that the delivery obligations imposed by the Law of the River have not in fact constrained the bureau in its operation of the dam. It has been free to operate the dam as a "cash register" but it is not bound to do so (i.e., to generate money).

The bureau is subject to the power delivery obligations in the contracts between WAPA and its customers, but power contracts are subject to modification. WAPA markets power on both a long- and short-term basis. Short-term sales can be adjusted to competing demands for the use of the water. There is no legal obligation to maximize short-term power revenue. Long-term contracts present a greater constraint, but they are subject to periodic renegotiation, and conditions that reflect possible operational changes should have been incorporated into the new contracts that were being negotiated during 1987.

The institutional boundaries of the study were set up by the agencies jointly conducting the study: the Bureau of Reclamation had the lead and was joined by the National Park Service, U.S. Geological Survey, and U.S. Fish and Wildlife at the federal level and Arizona Department of Game and Fish on the state level. These agencies made all key decisions on the way in which the studies were conducted. Legal constraints were not as significant for the conduct of the study as they are for water use. Compliance with the requirements of the National Environmental Policy Act (NEPA) obviously influenced the design and scope of the study, but the significance of NEPA cannot be fully determined until the study is completed and adverse impacts and operational strategies are identified. At this point, NEPA, the Law of the River, and other legal constraints must be fully assessed.

Political entities were the Upper Colorado River Basin Commission and Lower Colorado River Basin Commission, state of Arizona, California, Colorado, New Mexico, and Utah. National and international interests in the Grand Canyon and Colorado River recreational and water resources were represented solely through the federal agencies. The Arizona Department of Game and Fish represented state and local interests. The Indian population of the study area was not represented in a formal way. The conduct of the field studies was constrained by rules and regulations that are enforced by several of the agencies e.g., the prohibition of helicopters for access to the river by the NPS, or the restrictions on the use of motorboats at certain times of the year. Flow rates could not be altered for the purpose of the study supposedly because of WAPA requirements.

4

PRODUCTS OF THE GCES

BIOLOGY

Aquatic Biology

Studies of aquatic resources in the Colorado River between Glen Canyon Dam and Lake Mead were conducted principally between 1984 and 1986. The results of these studies are summarized and interpreted in the report by Maddux et al. (1987) and Appendix II of the GCES final report, although supporting information is also found in other reports (Anderson et al. 1986, Blinn et al. 1986, Haury 1986, Liebfried and Blinn 1986). The aquatic studies focus on two specific resources that have been identified by management agencies, regulatory authorities, and the public as having predominant importance in the Colorado River: (1) the exotic trout fishery (a direct benefit of construction of Glen Canyon Dam), which is based on a combination of naturally reproducing and stocked rainbow trout, supplemented with small amounts of other trout species and (2) nongame native fishes, including the humpback chub, an endangered species. The GCES studies provide substantial new information on these resources.

Changes in the aquatic resources of the Colorado River following construction of the Glen Canyon Dam are primarily explained by four physical factors: (1) increase in water transparency below Glen Canyon Dam resulting from sediment removal by Lake Powell, (2) reduction in the seasonal amplitude of river discharge, (3) increase in the daily amplitude of discharge, and (4) reduction in mean water temperature and seasonal amplitude of water temperature (Dolan et al. 1974, Stanford and Ward 1986). The GCES studies, which build upon numerous previous studies, contribute to our understanding of the present aquatic resources and to the ways in which those resources are regulated by the four major physical changes in the river after construction of the dam. Although this information is useful, the mechanisms that link physical changes in the river to the changes in aquatic resources are still only partly understood.

The conclusions of the GCES studies concerning aquatic resources seem well founded but are of limited scope. The summary report concludes that aquatic resources of the Colorado River have been significantly altered by the presence of Glen Canyon Dam. While this may always have been obvious to managers of aquatic resources, it may have been less so to operators of the dam. The GCES studies are thus useful in clarifying and documenting the great extent to which aquatic life has been affected by the dam. In addition, the studies leave little doubt that specific management options for the dam carry with them specific and often significant effects on aquatic resources below the dam.

The GCES studies also contain some more specific conclusions that are well supported by the studies. The GCES studies leave no doubt that the overall effect of short-term fluctuations in flow is detrimental to aquatic resources, and that steady flow in the intermediate range of discharges is more likely to be beneficial to trout than the lowest or highest discharges.

Even though the conclusions of the GCES studies concerning aquatic resources seem well founded, and should serve as a basis for serious consideration of changes in operations, the conclusions are in these respects incomplete. First, the mechanisms controlling aquatic resources are not yet well understood. Examples of control mechanisms that require further study will be discussed below, along with the analysis of individual study components; a number of these are also identified in the report by Maddux et al. (1987). Second, the forecasting of resources under varying operation regimes has not yet been placed in an integrated framework stressing overall optimization of aquatic resources given a full range of operation capabilities. The deficiency is in part unavoidable because of the limited knowledge of mechanisms controlling the resources, but in part also reflects design of the study around a preformulated set of operation alternatives rather than an optimization approach. A third deficiency, which also is inherent to the overall design of the studies, is failure to consider a full range of management options. While management options under consideration during the studies involved only alterations in the degree of short-term fluctuations in flow, the full range of management options would be much broader. Specifically, the possibilities for temperature manipulation by installation of a multiple withdrawal structure or for minimizing flood flows by operating Lake Powell at lower mean lake levels have not been considered. While it can be argued that these possibilities are not within the scope of traditional operations, full assessment of aquatic resources is unrealistically narrow without consideration of these options.

Despite some severe shortcomings in scope and integration of the aquatic studies, individual components of the studies of aquatic resources were in general well designed and well executed, and therefore can be used now and in the future in the interpretation of factors affecting aquatic resources. Program components that seem particularly outstanding deal with the abundance and distribution of fishes, physical habitat characteristics, growth and condition factors in fishes, and fish feeding habits. As acknowledged by Maddux et al. (1987), some of the studies were handicapped by changes in the flow regime of the Colorado River that resulted in unusually steady high flows between 1982 and 1984. The persistence of these conditions through most of the study interval reduced the possibilities for field observations on the effects of fluctuating flows. Even so, the data provided numerous useful insights concerning regulation of the aquatic resources.

In analyzing the aquatic studies in more detail, it is convenient first to consider separately four of the study components: (1) habitat characteristics, (2) growth and yield of fish, (3) stocking for maintenance of game fish, and (4) aquatic food chains. This is followed by a consideration of possibilities for broadening the data interpretation and future study on the basis of a more comprehensive set of management options.

Habitat Characteristics

The studies of aquatic habitat characteristics by Anderson et al. (1986) and the associated information on distribution of fishes provide a good foundation for identifying specific habitat features that are critical to individual fish taxa. In the report by Maddux et al. (1987), this information is used effectively in demonstrating several important principles that apply to the fishes of the Colorado River. The Colorado River offers only small amounts of backwaters, side channels, or eddies where current velocities are low. The total area of velocity refugia may have been reduced by physical changes in the river following impoundment (Dolan et al. 1977). Because of the inability of most fishes to live continuously with high current velocities, these areas of low current velocity are expected to be of critical importance to aquatic life in the river.

The endemic fishes of the Colorado River in the vicinity of the Grand Canyon were probably dependent on backwaters for food and maturation (Minckley 1973, Valdez and Wick 1983). The GCES studies demonstrate that this importance of low-velocity areas below Glen Canyon Dam is greatly enhanced by the continuously low water temperature maintained by hypolimnion release from Lake Powell. Low-velocity areas and tributaries are the only portions of the aquatic system that rise into the range of summer temperatures to which warmwater fishes and other native aquatic organisms are adopted. Thus the low-velocity areas and tributaries are not only velocity refugia, but also thermal refugia.

Although the new information improves our understanding of the physical limitations on individual species in the Colorado River, the data base and data analysis need to be extended to a sufficient degree to support predictive modeling of critical habitat space for fish species in both the adult and larval stages. This seems feasible given the demonstrated strong association between important fish species and specific habitat characteristics. This extension of the work on physical habitat would include both further data collection and development of models. The present data base is deficient in several ways for the support of modeling, even though it is an adequate basis for the general conclusions that were drawn from the studies.

One limitation has to do with the restriction of empirical data on physical habitats to two flow conditions (4,800 cfs and 28,000 cfs). Management options calling for stabilized flow, as might be desirable for enhancement of certain uses, will almost certainly involve discharges intermediate between these extremes. Consequently, the empirical quantification of habitat types should be extended to intermediate discharge conditions.

A second deficiency is the absence of quantitative estimates of areal coverage for specific habitat types such as backwaters and eddies. It is not clear from the data in the reports whether the underlying information would support estimates of this type, but it appears that most habitat features were counted rather than measured. The use of aerial photography and/or satellite imagery is applicable for purposes of quantifying the habitat area. Support capacity of the river can be judged best on the basis of areal coverage for critical habitat features. This will involve the estimation not only of the number, but also of the sizes of individual backwaters, eddies, and other critical habitat features. The areal coverage can then be quantified as a function of river discharge. The underlying principles of this approach are inherent in standardized Habitat Evaluation Procedure (HEP), Habitat Suitability Index (HSI), and Physical Habitat Simulation (PHABSIM) approaches that are used by the U.S. Fish and Wildlife Service and other agencies. For the specific case of the Glen Canyon, it may be possible to avoid some of the complexities and extrapolations inherent in these standardized procedures by constructing a simpler set of empirical relationships between the habitat areas and the discharges based on direct observations under varying flow conditions. This is particularly feasible in the case of the Glen Canyon because discharge can be regulated over short intervals of time for study purposes while measurements are made. Survival of larval fish, particularly of the humpback chub, is of special interest in relation to habitat requirements. The present data suggest a close relationship between low current velocity and presence of larval fishes. It is possible that modeling of habitat space for larval fishes could be based simply on the use of current velocity as an indicator of suitable habitat space, rather than identification of backwaters by more subjective and complex criteria. Other such simplifications may be possible on the basis of field experience that is now at hand.

An additional piece of information that needs to be obtained and developed through modeling is the distribution of temperatures in aquatic habitats off the main channel. It has been well demonstrated in the recent surveys that side channels and backwaters develop higher water temperatures than the main channel. Some quantitative or semiquantitative procedures for estimating the temperature characteristics of backwaters and side channels in relation to the temperatures and flows in the main channel need to be developed, particularly since the water temperature appears to be critical to the success of some fish species, including the humpback chub. It would be best if such a model were general enough that it could be applied to hypothetical changes in the temperature of water in the main channel, as would be brought about by the introduction of a multiple outlet structure, even though such a structure does not now exist.

The associations between physical habitat features and species requirements are surprisingly weak for rainbow trout. The trout accessible to fishermen just below the dam appear to occupy the entire breadth of the river, and thus are not specifically associated with large, discrete habitat features such as eddies or backwaters. However, more subtle habitat features such as presence of pocket water behind obstructions to the current may be critical. If trout support capacity is to be understood and projected across various operating regimes, the association of trout with habitat features in the river needs to be studied more thoroughly.

Growth and Yield

The data collected on rainbow trout seem to provide a sound basis for estimating present and past growth rates of this key fish species in the Colorado River. Two important matters are unresolved, however. The first of these is related to the possible difference in growth rates for stocked and native fish, and the second has to do with the potential optimum yield of rainbow trout.

As indicated in the report by Maddux et al. (1987), the growth rates of rainbow trout in the portions of the Colorado River just below the Glen Canyon Dam are higher than the growth rates of rainbow trout below Little Colorado River. However, interpretation of this trend is complicated by the fact that stocked trout tend to predominate just below the dam, whereas trout originating from reproduction in the river predominate downstream. Differences in growth rates could conceivably be based on genetic differences in the two groups of fish, even though both groups ultimately derive from stocking. Alternatively, the slower growth rates of fishes downstream might be explained by less abundant food resources below the Little Colorado River. On the basis of present evidence, the latter possibility seems most likely, but the issue is sufficiently important that it needs to be resolved experimentally. One possible approach is to measure the growth rates of the two fish stocks under controlled conditions, or to make a rigorous comparison of comparable sizes of fish at specific locations, and thus to build a stronger case for the importance of food resources in regulating trout growth.

A second open issue of great importance is the potential yield of the trout fishery. The potential yield is in part under control of the fisheries managers through fishing regulations and stocking rates. However, the growth rates of the trout also affects the yield. While the growth rates of trout have been measured, and have been compared in an informal way to growth rates at other locations, no quantitative analysis has been made of the deviation of the growth rates from the expected growth rates under optimum conditions for rainbow trout. Estimations of this type are useful in demonstrating unrealized potential for fish production. If this unrealized potential is great, then management approaches can be used in any attempt to realize additional potential.

Calculations of the potential yield are particularly relevant to the Colorado River near Glen Canyon Dam because of the low water temperatures. Whereas water temperatures are typically in the vicinity of $8^{o}C$ to $12^{o}C$, trout growth is likely to be highest between $15^{o}C$ to $20^{o}C$ (Scott and Crossman, 1973). Consequently, some impairment of growth could be occurring. An estimate of this impairment should be made so that potential benefits of temperature control at the dam can be evaluated. The potential value of temperature regulation is well illustrated by improvement of the trout fishery below Flaming Gorge Dam by installation of a multiple outlet structure capable of raising the summer water temperature from $4^{o}C$ to $13^{o}C$ (Larson et al. 1980).

Stocking

The GCES fisheries studies make a convincing case for the predominance of stocked fish in the heavily fished areas near Glen Canyon Dam. Furthermore, the dependence of fishing quality on stocking is evident from the depression of yield that occurred following an interruption in the stocking program. It appears from the data at hand that approximately 75 percent of the fish yield is based on stocking.

At present, there is no basis for balancing the overall costs and benefits for stocking as opposed to natural reproduction of rainbow trout. Natural reproduction saves the cost of stocking, but it may impose restrictions on water temperature for spawning and protection of redds that are contrary to the enhancement of other components of the fisheries resource, including maximum realized growth for adults or enhancement of habitat for warmwater fishes. Consequently, it is important in the future that the fisheries managers quantify the costs of stocking in relation to fish yield. The costs of stocking may have to be adjusted for differential growth rates of stocked and unstocked trout in the short-term and the genetic diversity of the trout population in the long-term.

Another aspect of the comparison between stocked and unstocked fish is the relative appeal of these two types of fish to the fisherman. Stocked fish are sometimes considered an inferior base for a sport fishery. This objection is typically most valid when fish are caught shortly after stocking. Managers of the Colorado River fishery need to take a position on this, so that future valuation of the fishery can take into account the relative values of fishes from the two sources. If fishes from the two sources are functionally identical, then the valuation of the fisheries resource can be based on the cost of stocking weighted against the cost of maintaining conditions for natural reproduction. If the rainbow trout that originate in the river are of special value, then the valuation procedures become more complex, but are still possible and advisable.

Aquatic Food Chains

The quantitative analysis of food chains supporting fish populations is difficult even under the best circumstances. A good beginning has been made toward the understanding of food chains leading to the production of trout and native species in the Colorado River. However, there are still a number of serious deficiencies in the understanding of these food chains. Some of these deficiencies are acknowledged in the final GCES reports, while others may not be clear from the reports.

The nutrition of larval fishes often is a population bottleneck for fish populations. Even in cases where adult fish are very well nourished, recruitment from the larval stages can be seriously affected by deficiency in quantity or quality of food. This phenomenon is difficult to study because of the short interval over which larval fish are present in most aquatic systems.

The feeding habits of larval fishes and the food densities required to support larval fishes in the Colorado River below Glen Canyon Dam have not yet been satisfactorily quantified. Additional studies are needed of larval fishes just past the yolk absorption state. At this stage of life, many species of fish are dependent on zooplankton. The dependence of larval fish on zooplankton is an important issue in the Colorado River below the Glen Canyon Dam because the amounts and kinds of zooplankton are related to the depth of water withdrawal from Lake Powell. Management options involving multiple outlet withdrawal would include the possibility of manipulating plankton concentrations in water drawn from the reservoir. Deficiencies in the supply of zooplankton food to early life stages should be identified so that efforts to maximize production will not be rendered ineffective by poor recruitment through the larval stages. This is particularly important for the humpback chub, but also for the rainbow trout and other species.

The final GCES reports identify the importance of midge larvae or Gammarus, which appears to be a major food resource for trout. However, production rates for Gammarus are yet to be measured in the field; factors controlling the production of Gammarus should be studied. Maximizing the food yield from a specific source such as Gammarus requires a detailed understanding of the life history and the maximum production capabilities for the food species that extend well beyond what is now known for the Gammarus populations below Glen Canyon Dam.

The final reports suggest that increased ingestion of Gammarus during periods of fluctuating flows indicates a desirable effect of discharge fluctuations on the availability of a critical food resource for the rainbow trout. This appears to be correct, although the present evidence is limited.

However, the substitution of steady flows for fluctuating flows will not necessarily reduce the sustained yield of the Gammarus population to the fish. Temporary increase in vulnerability of Gammarus to fish predations may be offset by decreased vulnerability due to lower population sizes when stable flows are restored. Consequently, the difference in yield of Gammarus to the fish between stable flow and fluctuating flow conditions may not be so great as suggested by the data.

Perhaps the most serious deficiency in the studies of fish food resources is the absence of any meaningful information on the growth and distribution of Cladophora (algae), except for studies of limited scope dealing with desiccation and temperature. Because Gammarus, a critical food resource, appears to be explicitly dependent on Cladophora and its epiphytes, the study of Cladophora is as important as the study of Gammarus itself.

Some simple approaches to the study of Cladophora might provide considerably more information on this important resource base than is now available. The distribution of Cladophora should be analyzed for pattern with respect to depth, current velocity, and substrate characteristics. Such patterns might provide a basis for predicting the support capacity of the river for Cladophora under varying conditions. In addition, light requirements of Cladophora need to be determined. Operations of the dam involving steady flow may affect Cladophora either beneficially or detrimentally, depending on the combination of water depth, transparency, and light requirements of Cladophora. Suitable habitat for Cladophora can be modeled in relation to varying flow regimes if the light requirements are known and if substrate or current requirements can be identified.

In general, the studies of fish feeding habits demonstrate insufficient extension into underlying food chains. Food chains ultimately rely on specific sources of organic carbon, which in this case appear to include Cladophora and its associated periphytic diatoms.

Limited studies of Cladophora described in the report by Blinn et al. (1986), although interesting, may not be broadly applicable to management issues in the Colorado River below Glen Canyon Dam. While the ratio of stalked to unstalked diatoms taxa appears to change in relation to temperature under controlled conditions, there is at best weak evidence that the absolute abundance of stalked forms changes with temperature. Furthermore, the diatom growth rates, which indicate ability to support grazing, might increase at higher temperatures, thus affecting changes in the proportion of stalked forms. Finally, replacement of the diatom flora by an entirely new flora based on physiological strains more adapted to high temperatures, or by entirely different taxa more tolerant of high temperatures, could easily invalidate conclusions based on short-term experiments. Clearly, the question of temperature effects on resource quality for Gammarus is complicated. In fact, it may be so complicated that it is not possible to approach such a question over a short period of time on the basis of laboratory experiments. More informative might be an examination of Gammarus and epiphytic diatom populations in western tailwaters of differing temperatures. Comparison of the diatom flora and the Gammarus abundances in these systems might be informative.

Scope of Management Options

Implicit in the studies of aquatic resources is a series of management options around which the data collection programs have been oriented. With respect to variables that are under the control of management, the primary emphasis has been on the effect of short-term fluctuations in discharge on aquatic resources. Only a minor amount of attention has been given to changes in mean temperature. Manipulation of temperature, which could be made possible through the installation of a multilevel outlet structure, would allow for greater management control over the aquatic resources than is now possible through the regulation of discharge alone. The potential effects of temperature changes, and of many of the associated management possibilities, thus need to be explored more fully.

The limits with which water temperature below Glen Canyon Dam could be adjusted at any given time of the year would depend on the heat distribution in Lake Powell. Models that could identify in the range of possibilities need to be constructed, so that the latitude for adjustment of temperature can be considered in relation to management options for aquatic resources.

Temperature manipulation (and attendant food manipulation) is of particular interest in the Colorado River because of the documented inability of the humpback chub, an endangered species, to complete its life history at temperatures that are characteristic of the main stem of the Colorado River below Glen Canyon Dam (Hammon 1982). Thus temperature appears to limit the population of humpback chub in the river, and to induce a heavy dependence on a single tributary (the Little Colorado River). In addition, there is notable suppression of other warmwater taxa in the river as result of the continuously cold temperatures. Prior to construction of the dam, water temperatures consistently reached 25°C to 29°C in July and August (Paulson and Baker 1981), whereas the present maximum is about 12°C.

The trout fishery below Glen Canyon Dam is an important resource. Preservation of this resource clearly is a high priority for resource managers. Schemes for temperature manipulation that might be beneficial to the humpback chub therefore cannot be considered without simultaneous estimation of the effects of temperature alteration on the trout fishery. However, preliminary evidence suggests that higher temperatures in the Colorado River below Glen Canyon Dam, particularly at certain times of the year, might actually enhance the yield of trout. Consequently, temperature manipulation might well expand the habitat suitability for humpback chub and other warmwater species while at the same time enhancing the yield of the trout fishery. This combination of benefits would give much more weight to the feasibility of temperature manipulation through installation of a multiple withdrawal structure. Disadvantages to higher temperatures, which might include change in the balance of species detrimental to trout or chub, need also to be considered, but cannot be evaluated on the basis of information that is now available.

Temperature manipulation opens up the possibility not only for enhancement of growth among warmwater species currently in the system, but also for reintroduction of former resident species, particularly endemic species that have been lost but that are still available from other areas or from cultured stocks (Minckley 1973, 1979, Hammon and Inslee 1982, Miller et al., 1982, Valdez and Clemmer 1982). The reestablishment of lost populations of endangered species might thus add considerable value to the capability for temperature manipulation, but has not yet been considered in relation to operations.

Regulation of flow, which would not necessarily require manipulation of temperature, should also be considered more fully than it has been up to this point. It is currently possible to operate the reservoir in such a way as to reduce the severity of floods, which might be advantageous from the viewpoint of beach stabilization in support of recreation, and possibly for aquatic life as well. Clearly it is physically possible to stabilize short-term fluctuations in discharge, although stabilization would be likely to cause some loss in power revenue. Because both long-term (flood) and short-term stabilization are feasible, resource managers should attempt to identify optimum combinations of conditions for support of aquatic resources. While the report by Maddux et al. (1987) does make an initial step in this direction by commenting on each one of a number of possible operating alternatives, a more appropriate approach might be to view flow regulation as an optimization exercise for management of fisheries resources, without regard to preformulated schemes or other constraints. The optimum combinations for aquatic resources could then be compared to optimum combinations in support of other uses.

Conclusions

The studies of aquatic resources have built a good foundation for understanding the effects of reservoir operations on fishes and their supporting food chains. However, numerous important gaps still remain to be filled if the required degree of understanding and predictive capability is to be developed for aquatic resources. Numerous functional mechanisms of great importance to sport fisheries and endangered species have not yet been studied sufficiently. Consideration of management alternatives involving temperature manipulation have been unnecessarily constrained, especially since these options would provide for the Colorado River below Glen Canyon Dam some of the most powerful potential management tools. Expansion of the knowledge of aquatic resources in relation to management options will be essential if the aquatic resources below Glen Canyon Dam are to be most effectively maintained and enhanced in the future.

TERRESTRIAL BIOLOGY

The analysis of the effects of dam operations on terrestrial resources of the Glen Canyon Colorado River ecosystem is supported by seven individual GCES technical reports. The Biology Subteam report (see Appendix A, Document 45) describes five of these that investigate vegetation change and both long-term and short-term response to floods. One concerns the effects of flood waters on breeding riparian birds, and one provides preliminary information about the use of the canyon by diurnal lizards. References are made to several other studies conducted in the canyon, both before and simultaneous with the GCES project.

The majority of the individual terrestrial GCES research projects were carefully executed, and the results contribute valuable and useful information to our understanding of the resources concerned. The studies were conducted under difficult field conditions that imposed considerable constraints on data collection. However, the lack of any linkage of the riparian systems of the mainstem and tributaries to the aquatic resources is a major deficiency. Some researchers took advantage of the 1983 flood by formulating questions about the effects of this unanticipated event. The team is to be commended for their dedication and for the enthusiasm they brought to their task.

The studies of riparian bird and shrub population dynamics were particularly well done. The lizard study was well conceived and provides valuable baseline information, although the data are not extensive. The two studies using aerial photography, although useful for indicating general trends, were conducted with less rigor. Neither report discussed the reliability of the analysis techniques used, so that it is difficult to apply the quantitative information provided. Without a discussion of the margin of error involved in making maps and digitizing the information, it is difficult to judge the accuracy of any trends noted. In addition, the Brian report, 1983 (see Appendix A, Document 1) appeared to miscalculate an "average percent change" statistic. In order to extrapolate the vegetation trends documented in the reports over the entire GCES study area, it would be necessary to understand to what extent the sites "represent" the vegetation as a whole, that is, are proportional to the region. Neither report addresses this issue directly, although they imply that the investigated areas cover the diversity of the system.

The Biology Subteam report indicates that studies were formulated to address two primary questions:

1. Do dam operations significantly affect the living systems downstream of Glen Canyon Dam?
2. Does the potential exist to operate the dam in a manner that would enhance or protect biological resources?

These questions appear to be consistent with the charge originally expressed by Commissioner Broadbent (Appendix B-2).

As discussed in earlier sections of this report, in order to accomplish their goals the research team would need to address the following issues:

1. What are the biological resources in question, and why are they significant?
2. How are these resources affected by the river?
3. What are the desired levels of the resources (management targets), and why are these levels significant?
4. How do dam operations affect the resources?
5. How can the dam be operated so as to achieve the desired resource conditions?

It would seem appropriate to examine the GCES investigation of terrestrial biological resources with reference to each of these points.

Choice of Resources and Determination of Significance

The resources investigated by the terrestrial biology are identified in the final report as being: (1) terrestrial vegetation, (2) riparian nesting birds, (3) reptiles (lizards), and (4) phytophagous insects (studied in terms of 1983 flood effects). The reasoning behind this categorization is unclear and inconsistent.

There are usually two ways in which ecosystem resources are identified and defined for investigation in a biological management project such as the GCES: (1) the resource is valued by or essential to one or more users of the area and in that sense is a management "target" and (2) the resource influences or is affected by one or more of the target resources. The biology report is not clear about the identity or goals of the users of the terrestrial resources of the canyon; therefore the identification of proper management "targets" was difficult. The report does indicate that the National Park Service was one of the groups that participated in the initial development of the GCES, and in the draft final report it is stated that it was this collection of agencies and individuals that selected the resources for study. No obvious link was made, however, between the choice of resources to be studied and the goals and values of the users, i.e., the National Park Service.

In discussions with the researchers and agency representatives during the course of the NRC's involvement with the GCES, the implication was that terrestrial resources were included in the project because the Park Service in particular was interested in protecting the "naturalness" of the canyon. If this is the case, the biology report is incomplete because it does not directly address the meaning and implication of this goal. The term "natural" in ecological literature has various meanings, but it usually refers to conditions in the absence of intervention of the forces of modern civilization. Does "naturalness" in the Colorado River System mean that the resources of the canyon should be managed to resemble conditions prevailing before human intervention in the area? If this is the case, then separation of the resource categories "terrestrial vegetation" and "riparian birds" into "exotic" and "native" components in much the same way "fish" were divided into "humpback chub," "native fishes," and "trout" would have been appropriate. As this separation was not made, undefined "naturalness" results in confusion in the analysis.

The report is more explicit as to why riparian birds and diurnal lizards were selected for study. The report indicates that time and budgetary constraints made it impossible to look at all resources. The researchers also point to the fact that the existence of previously collected information on bird populations adds to the value of any bird data to be collected by the GCES. Given the relative lack of previously existing data, this is an important consideration. The implication, however, is that, given the goal of "naturalness," any terrestrial species or guild would be an appropriate object of study. Although this assertion is not made explicitly in the report, it would have been appropriate and would have served as an important reason for the choices.

The logic finally used to single out riparian birds and lizards seems to involve the ease of studying these populations and the idea that these groups will serve as "indicators" of the response of all types of vertebrates to the changing river environment. The first idea is certainly appropriate. The assumption, that birds and lizards can indicate general suitability of wildlife habitat is not validated. More discussion and examples need to be given to give support to this idea. In fact, there is an implication in the individual bird reports that the riparian species do not respond to conditions as a group; therefore, it is less certain that birds and lizards can truly "represent" mammals.

The report does not directly address the second category of study resources, that of items included in the analysis because they affect the "target" resources. In a sense, if the goal of "naturalness" is the driving influence, this step is unnecessary as all resources would be potential targets. However, it might have helped to explicitly consider the influence of other resource types or uses (fish, boaters, and so on) at this point in order to more clearly understand the potential interactions.

Once the target terrestrial resources were identified, it might have helped the study to determine how important they were to particular user groups. Recognition of the relative significance of the terrestrial resources might have changed the nature of the research, perhaps redirecting efforts to the study of other portions of the ecosystem or even channeling more money to the terrestrial studies. This is not to imply that the terrestrial resources are in any way unimportant. In fact the lack of careful treatment of the native-exotic plant species, particularly in the riparian zone, and how the different species mix affect the aquatic resources. However, their significance as compared to that of aquatic resources, recreation, and so on, is not addressed.

Effect of the River on the Resources

In order to devise a management plan, it is important to understand the interactions of the components that can be manipulated and those that will be affected by the manipulations. The biology report exhibits a general understanding of the influence of the river on the terrestrial vegetation, and, given the effect on the vegetation, the indirect effects on birds and lizards. Much of the outline of this interaction with regard to vegetation was available to the researchers prior to the initiation of the GCES. The individual technical reports add detail to the general outline, but because of the limited time available and the fact that the researchers had relatively little chance to effect changes in the flow, the information is not as extensive. Most data document influences of the 1983 flood.

The report does not clearly present an interactive conceptual understanding of the system. Had they done so, the researchers could have provided more insight into linkages between system components (e.g., riparian and aquatic resources) and user groups. For example, changes in river discharge influence the use of the campsites by recreationists. As recreationists have a potential impact on terrestrial vegetation in areas to which they have access, a change in their behavior would affect vegetation.

The report does not always differentiate between information obtained from previous studies of the canyon, that obtained from the GCES, and trends that are predicated on assumptions rather than data. The researchers acknowledge that their conclusions are based on all of these sources, but it would have improved the report had they more carefully referenced this information. That the abundance and diversity of wildlife in an area depend on the areal extent, species diversity, and structural heterogeneity of vegetation is assumed. This is perhaps valid but different species respond to different aspects. For example, many birds respond to vegetation structure, not species composition. The researchers make a distinction between short- and long-term effects of the river and attempt to identify "vulnerable" stages in the life cycle of particular species, i.e., the time at which they are most likely to be affected by river operations.

The occurrence of the 1983 flood forced the terrestrial team to focus on the effects of high water. They viewed floods as a disturbance in a steady flow system and viewed the response of the resources as the reaction of systems to a "disturbance." This assumes that the pre-1980 conditions are "normal" and, as discussed below, that the resultant terrestrial resource levels created by the steady flow are the desired levels.

The final draft report made little reference to the individual technical reports, and on the occasions when data are cited, there are some inconsistencies. For example, the results of studies documenting the loss of vegetation due to the 1983 flood are reported as: (1) 40 to 50 percent loss (page 25), (2) 50 percent (page 27), and (3) large areas (page 31). If the draft reports provided to the committee, the data are as follows: Brian report: 35 percent loss; Pucherelli report: 31 percent loss (112 to 77 acres).

The report makes little reference to information available from studies in the canyon prior to 1982 and to information about the interaction of the river system and terrestrial riparian resources available from studies of other systems. Information from such studies may contribute to conclusions and assumptions, but this is not made clear. The Carothers et al. (1976) study is apparently used extensively.

Desired Resource Levels (Management Goals)

Once the interactions of the components of the system are understood, the next step is to identify the desired levels or conditions of the target resources. These goals must be established in order to determine the management strategy. The biology report establishes goals for the terrestrial resources, but it does not clearly explain or justify them. Values are assumed rather than explicitly derived, and the reasoning behind the choice of management goals is not expressed.

The management goals for terrestrial resources involve maximizing density and diversity. These terms are used by the researchers to refer to numbers of individuals and numbers of species. The assumption appears to be that the increase in woody vegetation and breeding birds that occurred between the closure of the dam in 1962 and the filling of the lake in 1983 has been a positive event, and that management should attempt to continue this trend. No indication is given as to what population levels are ultimately desirable.

The discussion of the goal of "naturalness" earlier in this review is also important here. There is an important distinction to be made between exotic and native biota. Much of the increase in vegetation in the canyon has been due to the spread of exotic species. The biology report mentions this, but there is no discussion of the point of view that a management goal that maximizes the density of exotic species is in fact contradicting the goal of naturalness.

The goal of maintaining high bird population density and diversity also is a position that results in advocating the expansion of species not natural to the river corridor. The reasoning behind this goal is explained by the idea that riparian bird populations are decreasing elsewhere in the Southwest due to lack of habitat so that the new habitat in the Colorado River is a positive effect.

Similarly, there is little or no discussion of what problems might occur because of the shift from "natural" predam conditions. Have any species been lost from the canyon? Are native terrestrial species declining in population? These and other implications of the chosen goals need to be addressed.

Effect of Dam Operations on the River

Two types of dam operations are considered by the researchers: (1) daily fluctuations and (2) the release of flood waters. First, the researchers state that daily water fluctuations do not directly affect the terrestrial riparian system, because vegetation is established above the level of the high water line. Yet later on, in discussing alternative management strategies, they state that a proposed elimination of fluctuations would allow vegetation to extend its range. The second statement implies that the strategy of daily fluctuating flows affects the vegetation. In a sense, both statements are based on conjecture rather than on direct research results.

Second, the researchers approach the study of management alternatives using a "static model." They pose management scenarios that imply that the dam will be operated according to a chosen scenario. Changes might occur given high or low water situations, but the seasonal release patterns would be similar. In contrast, many resource managers adopt a more eclectic strategy in which the management pattern is evaluated at regular intervals in the context of the behavior of the target resources. Although the terrestrial researchers stress the need for continuous monitoring of the resources and indicate that management decisions might need to change in response to resource changes, they do not incorporate this idea into the development of a dynamic management system in which water release patterns might change from year to year. Such a resource-response-driven scenario allows for flexibility as goals change in response to new attitudes and additional knowledge. It also allows for experiments to understand the river-resource link.

Recommended Management Strategy

The conclusions with regard to the analysis of dam operations on the terrestrial resources are highly influenced by the fact that the 1983 flood occurred and that the data collected by the researchers document effects of this event. The researchers take a position with regard to floods and seem to ignore other effects of the river on the grounds that the effects are unknown or not important to the terrestrial resources. It is true that the data collected in the individual research reports relate primarily to the effects of the flood. It might have been better to have stated that their management suggestions relate to flood control and not to other options because that is what their data allow.

The researchers take the position that floods are bad, given their assumptions about desired resource levels. Their data indicate that, at least in the short term (defined variously in the different reports), the flood waters removed vegetation, destroyed bird nests, and perhaps instigated a change in species composition in the New High Water Zone (NHWZ) through differential effects on reproduction. The evidence is not conclusive as to the long-term effects of a single flood.

The researchers acknowledge the fact that flood frequency is an important consideration, and they even discuss possible periodicities based on a repetition of recent history. In the end, the impression they leave is that floods are to be avoided (page 38, 39). This statement appears to be based on the idea that steady flows led to the development of the resources as they were in 1982 and on the assumption that these are the levels to emulate. While this recommendation cannot be said to be inherently "wrong," it is supported by indirect rather than direct evidence. The data collected in the GCES are in some senses incidental.

Conclusions

The terrestrial researchers were faced with the difficult task of collecting enough data in a short period to be able to make river management decisions. Relatively little information about the terrestrial resources of Glen Canyon was known prior to the initiation of GCES, and data acquisition during the project was affected by limited access to the study sites and the existence of flooding conditions.

The report suffers from a confusing mixture of values and science. It is often difficult to determine the basis on which judgments were made. Although it is useful to remove references and lengthy explanations from the body of a report, in this instance the text became more confusing because assumptions, values, and "facts" were not documented and/or explained. Little direct use seems to have been made of the results of studies of other river systems. An effort seems to have been made to make simple conclusions and recommendations. Although sometimes appropriate, this process was carried too far in this instance (decisions to recommend one "static" water release pattern, for example).

Most of the specific information collected during the course of the individual study projects will prove to be quite useful in adding to our understanding of the "controlled" Colorado River ecosystem. However, the conclusions about which management scheme to follow with regard to terrestrial resources are tentative. The wording of the management suggestions is stronger than the data can support. It is difficult to judge long-term trends from a few years of data. The recommendation made by the researchers to continue monitoring the resources is important, and a willingness to change the flow pattern in response to resource changes is the key to successful management of the system.

SEDIMENT TRANSPORT AND HYDROLOGY

According to the sediment and hydrology subteam report, seven objectives were established in 1983 for the research program in sediment and hydrology studies, as follows:

1. Identify the reaches of the river that are losing, gaining, or in equilibrium with respect to sedimentation.
2. Identify the source of sand in transport.
3. Determine the present net sand outflow from Grand Canyon into Lake Mead.
4. Identify specific campsite beaches that are gaining, losing, or in equilibrium.
5. Determine potential management actions to reduce or halt campsite beach erosion.

6. Estimate what the river morphology would be like up to 100 years from now based on operational alternatives.
7. Expand and refine the water-flow routing model, particularly in riparian habitat areas.

These objectives certainly lead to valid scientific questions concerning sediment and water movement through the Grand Canyon. It would have been appropriate in 1983 to formulate testable hypotheses and then devise appropriate efforts in fieldwork, modeling, and so on, to resolve the various competing hypotheses. The sediment/hydrology work has an easily discernable, straight-line relationship to all other environmental components of the GCES. Sediments represent a nearly-finite resource in the Glen/Grand Canyon system, considering loss of input from the above-dam watershed. It would have been more useful to integrate the findings of the sediment/hydrology work as other research was being conducted, rather than leaving such integrative thinking until the end of the project. The major concern in 1983 was to divide various sediment/hydrology studies assumed to be relevant to the objectives into compartmental investigations to be pursued by the technical staffs of the U.S. Geological Survey and the U.S. Bureau of Reclamation.

The lack of an objective, initial overview of the sediment/hydrology research is apparent in the contrast presented by the sediment and hydrology subteam's final report and the 10 technical reports prepared prior to the final integration effort. The final draft report emphasizes the overview of sediment-dependent resources, the storage of sediment in pools and recirculation zones, the sources of sand into the system, observations of change during varying flow conditions, and the important functions of rapids and tributary debris flows. It is obvious that the observational data base provides a more credible basis for predictions concerning future sediment-dependent resources than does the modeling (which fails to predict observed channel bed changes).

It should have been easily foreseen at the start of the studies, and readily demonstrable in their early stages, that the present source of sand entering the Colorado River through the Grand Canyon is tributaries, notably the Paria and Little Colorado rivers and Kanab Creek. Because of the lack of an objective scientific overview in 1983, nearly all sediment analyses were focused on the main-stem Colorado River. The role of tributary sediment sources was identified as a high-priority future research project at the end of the GCES project.

The bulk of the sediment/hydrology research initiated in 1983 was directed into an immense effort to mathematically model the sediment and water movement through the main channel of the Colorado River from Glen Canyon through the Grand Canyon. This effort included a phenomenal survey of cross sections, side-scan sonar records of the stream bed, and continuous measurement of water and sediment at five gaging stations. Combined with computerized flow routing and continued development of a BOR model used in alluvial rivers, the bulk of research was directed at formulating and calibrating an idealized concept of sediment transport in the system. Five of the ten technical reports in the sediment/hydrology GCES series were devoted to this topic:

1. "Unsteady Flow Modeling of the Releases from Glen Canyon Dam at Selected Locations in Grand Canyon."
2. "Sediment Transport and River Simulation (STARS) Model Development."
3. "Sediment Data Collection and Analysis for Five Stations on the Colorado River from Lee's Ferry to Diamond Creek."
4. "Results and Analyses of STARS Modeling Efforts of the Colorado River in Grand Canyon."

5. "Sonar Patterns of the Colorado River Bed in the Grand Canyon."

Problems with the overemphasis on mathematical flow modeling should have been apparent in the early phases of the study. The report "Trends in Selected Hydraulic Variables for the Colorado River at Lee's Ferry and near Grand Canyon for the Period 1922-1984" shows that considerable data were available on long-term channel bed changes in relationship to various flow conditions. These data are not consistent with the predictions of the flow models.

Two of the stated 1983 sediment/hydrology study objectives related to the critical sand deposit/campsite beaches. Despite extensive analyses of the recirculation zones containing these deposits, including studies of effects of flood flows, monitoring of changes, and so on, the critical source of sand input from the main channel was studied, not as part of a linked system, but essentially as an independent effort in sediment transport modeling. The linked character of sediment sources, main-channel transport, recirculation zones, and so on, could have been anticipated from published literature available at the time of study initiation and/or from reconnaissance fluvial geomorphological process investigations of the Grand Canyon system. The need for such preliminary work would have been apparent to an objective scientific oversight of the project by a panel of experienced scientists without bias about which specific research projects would be funded. Such review panels are commonly used in complex federally funded environmental projects involving agency competition for research funds.

As discussed in Part VII of the sediment and hydrology subteam final report, the major product of the modeling effort succeeded in the identification of numerous deficiencies in the analysis. These include inadequacies of the sampling period and the data input and in the one-dimensional character of the model.

The irony of the mathematical modeling effort expended in this project is that there was and there remains a critical need for mathematical sediment modeling to resolve GCES issues. However, the most pressing need is to model the sediment transfer between the main channel and the recirculation zones, where the impacts of dam operations are critical for those recreational, wildlife, and beach stability issues that are central to the study.

A report entitled "Sandy Beach Area Survey Along the Colorado River in the Grand Canyon National Park" provided some inventory data on sand resources in the system. However, it should have been clear from the early phases of the project that resolution of the objectives required a linked understanding of the beach processes to main-channel sediment and water movement and to feedback relationships with vegetation.

The report "Recent Aggradation and Degradation of Alluvial Sand Deposits, Colorado River, Grand Canyon National Park, Arizona" presents the first descriptive model of alluvial sand deposit (camping "beach") formation in zones of flow separation along the Colorado River. This report addresses scientific issues central to the objectives. Unfortunately, the research on processes of alluvial sand deposition was not strongly linked to the sediment transport modeling. Therefore, the connection between the two efforts has been left as a future research need.

The report "The Rapids and Waves of the Grand Canyon, Arizona" provides a detailed hydraulic analysis of specific rapids on the Colorado River in the Grand Canyon. It represents an outstanding step in producing scientific understanding of flow physics in the complex rapids environments that are critical to the recreational use of the Canyon. It also identifies the role of rare, infrequent floods in contributing to the canyon environment.

The report "Debris Flows from Tributaries of the Colorado River in the Grand Canyon" demonstrates the critical role of debris flows in defining local hydraulic conditions on the Colorado River in the Grand Canyon. The report also raises important questions about the role of infrequent events on small tributaries in the introduction of sediment into the river system. It is interesting that this one study on tributary systems, whose importance should have been realized in 1983, was not done until 1986.

The river system in the Grand Canyon changed from a system in quasi-equilibrium prior to construction of Glen Canyon to one in a transition toward a new quasi-equilibrium during the filling stage. Now that Glen Canyon has filled, a new system will develop. That system should be studied as a geomorphologic system, not solely as a hydraulic one. The reach from the dam to the Paria River will continue to be sediment deficient. The reach downstream will scour between major sediment input events from the Paria, and the distance of the degradation of the bottom and the removal of sands from the channel will continue until a new input of sediment occurs. The Paria and the Little Colorado will introduce slugs of sediment which will be deposited in the Colorado and move as waves through the system. The manner in which this new system operates or will operate and what influence it will have on the fish, fauna, and flora in the Canyon has not been addressed. Many of the data collected for the mass sediment movement model are useful for establishing a baseline for the study of the geomorphologic changes in the system.

In summary, the sediment/hydrology research effort has produced some excellent new understanding of certain critical components of the complex system of water and sediment movement through the Grand Canyon. Important in this regard is the information about the operation of sand erosion and deposition in recirculation zones, observations of sediment changes on the river bed in relation to flow conditions, physical studies of flow dynamics at rapids, and analysis of the role of debris flows. Unfortunately, the critical linkage of sediment/water flow in the main channel was pursued predominantly as an exercise in its own right, largely divorced of concerns about sediment sources and sinks and with inadequate attention to modeled sediment movement to beaches, riparian habitats, and so on.

No attention was given to the broad questions of changes in the system response in a geomorphic sense. Much of the expected changes in beach occurrence and of sediment deposition and erosion from those beaches perhaps could be predicted from geomorpologic response models. Those geomorphologic response models could then be used to identify critical sites to study and critical hypotheses to test in more detailed hydraulic models. These and other inadequacies in the sediment/hydrology research seem to derive from overemphasis on agency capabilities for pursuing studies presumed to be relevant to overall GCES goals. This approach precluded research on topics that have now been recognized as more relevant to those goals than much of the original research.

Recommended Future Studies

Much of the monitoring work undertaken for input to the sediment transport model will be necessary for any system overview. That monitoring should be continued. Changes in the composition of the bed and the size distribution of the bed material should be determined periodically to help track slugs of sediment input from the tributaries. The future distribution of flows as a result of different dam operation plans and different inflows to Lake Powell should be determined, and the response of the system--in a broad geomorpologic overview--to those operation plans and inflows should be studied. Sediment input from the tributaries and movement through the Canyon should be monitored.

Detailed hydraulic studies should be undertaken of the mechanism of sediment deposition and erosion on selected critical beaches. Those studies should include the mechanism of sediment interchange between the main channel system and the beaches, as well as the movement of sediment on the beaches in response to varying flows. Minor tributary inputs of sediment as a result of debris flows should be monitored, and any major event should trigger a detailed analysis of the buildup and subsequent erosion of the rapid created by or added to by the event. The sediment and water are an integral part of the Canyon system. Without them there would be not beaches, there would be an entirely different fauna and flora. They are the foundation upon which the rest of the building is constructed. Their continuing study is required in order to understand the overall system.

RECREATION

The recreation reports adequately address the questions raised:

1. What is the public's willingness to pay for angling and rafting opportunities through the Grand Canyon?
2. How are these values related to flow regimes?
3. How does the incidence of accidents correlate with river flows?

Use of the contingency valuation technique to address question one is a bold application of this promising method. The researchers, who are well known for their development of the technique, have ably and creatively analyzed the satisfaction of recent recreationists. They provide a clear explanation of the technique and its opportunities and constraints. While the contingency valuation method is not meant to suggest that anglers and rafters will happily pay much more than is currently being charged for a particular set of experiences associated with various discharges, it does add importance to consideration of recreation users in dam operations decisionmaking. Prior to this carefully prepared study, operations managers, while aware of the recreational value in a theoretical sense, had no direct quantification of this value to include in the power generation calculations. The potential values were therefore officially ignored. The researchers identify potential sources of conflict between the anglers, the commercial white water boaters, and the private white water rafters. Preference for flows and access to the river at various times of the year are valued differently by these groups. This information may aid planning in other instances of user conflict. These findings deserve application to future recreation plans for the Colorado River and elsewhere. It would have been helpful, for example, if these calculations had been used in the operations report. Why was the scope so narrowly defined in the accident study? The results indicate that rafting on the Colorado River through the Grand Canyon is not very hazardous. Discussion with the subteam indicates that as far as National Park experience goes, accidents related to river flow regimes constitute a relatively small percentage of the accidents reported annually. The high water of 1983, difficulty in accurate recording by commercial operators, problems with volunteer surveyors poised at dangerous rapids, and the fact that there are not many accidents reduce the usefulness of this report for policymaking. In addition, the researchers show that in high water the commercial operators are careful to walk boats through the most dangerous rapids. These faults are very clear now. However, at the time the reports were proposed perhaps the researchers thought that accidents were a far greater problem than they turned out to be.

The recreation reports provide a new dimension to planning for dam operations and an opportunity for further exploration and testing of the contingency valuation study. It is unfortunate that although these researchers were able to so comprehensively attack their well defined problem, there was no effort to integrate the results into the broader scheme of operations or questions of the future of the beaches.

Glen Canyon Dam helped create a recreation industry based on white-water boating along the Colorado River and created trout fishing opportunities at Lee's Ferry. The dam changed the sport fishing qualitatively and quantitatively. Previously, this had been a modest fishery for native warmwater fish. Subsequently a significant trout fishery developed; for a time there existed a premier trophy fishery. The number of angler days of the fishery rose from about 6,500 in 1965 to a peak of almost 53,000 in 1983. The number declined to about 20,000 in 1985 and perhaps 15,000 in 1986. The third major recreational activity is day-use rafting at Lee's Ferry. The dam facilitated the development of this popular activity. According to the GCES draft report the current annual scales of these activities are as follows:

	Trips	User-Days
White-water boating	15,000	150,000-170,000
Fishing	6,100	15,000
Day-use rafting	8,500	8,500

These recreational activities--especially the last two--are direct by-products of the dam. The constituencies that represent these activities played an active role in opposing the Bureau of Reclamation's plan to install additional turbines at Glen Canyon over the period 1978 to 1982 and led to the initiation of the GCES.

The fact that both of the major recreation resources identified by GCES are controlled by agencies other than the BOR has two very important implications. First, since there is a natural limit to the carrying capacity of each of these resources, there is an upper limit to the economic benefits that can be attributed to direct use of these resources in any year (other types of economic benefits, discussed below, are not necessarily subject to such a limit). This can be seen very clearly in the case of white-water boating. If no more than 16,000 persons can run the river per year, and if the maximum benefit per person is about $900 for a commercial boat passenger and $700 for a private boat passenger as stated in the GCES report, then the maximum annual use benefit of white-water boating recreation is about $14.4 million. To the extent that river flows are less than optimal, or that fewer than 16,000 persons run the river, the actual use benefit will be lower. These sums are the aggregate amounts that persons who run the rivers would be willing to pay for the experience over and above what they actually do pay (which averages out to $1,406 per person for commercial passengers and $557 per person for passengers on private boat). In the case of fishing at Lee's Ferry, a more complex calculation is required to determine the maximum use benefit because by varying its management policy Arizona Game and Fish can create different types of recreational resources (e.g., a put-and-take fishery versus a trophy fishery). At this time there does not appear to be sufficient information available to perform those calculations.

The second implication is that the impacts of the dam itself, or of alternative flow regimes, cannot properly be assessed without reference to the management policies of these other agencies. Their policies can mitigate or exacerbate the effects of any operating regime for the dam. It would have been difficult politically and administratively to identify alternative management options for these agencies as objects of study for the GCES program, alongside the alternative flow scenarios, but with the benefit of hindsight the committee believes that it would have been extremely desirable to do so.

It would have been appropriate to initiate the economic analysis by considering the following questions: What would current usage be without Glen Canyon Dam? Who are the people that could be affected by changes in the operation of Glen Canyon Dam? In what ways might they be affected? The answers to such questions would generate a taxonomy of possible impacts that could have been explored in designing additional economic studies for the GCES program. A plausible listing of the potential "constituencies" is as follows:

1. People who actually visit Glen Canyon National Recreation Area and Grand Canyon National Park to engage in some recreational activity that is directly affected by river flows--white-water boaters, day-use rafters, and anglers as studied in the GCES. These people care about flow regimes not only because of the impact on the quality of their recreation experience but also for other motives unrelated to their current use of the resource, including existence value, option value, and/or bequest value.
2. People who visit Glen Canyon or Grand Canyon for some other recreational activity, perhaps indirectly affected by changes in river flow--e.g., sightseeing, hiking, or nature photography. These people may consider the quality of their recreation experience to be affected by the river flow and/or they may care about flow regimes for other motives similar to those of the rafters and anglers.
3. People who do not currently visit Glen Canyon or Grand Canyon, but may want to in the future.
4. People who will never visit Glen Canyon or Grand Canyon, but still care about it.
5. People who directly or indirectly earn their livelihood from recreation activities at Glen Canyon or Grand Canyon who may be affected by changes in flow regimes.

The GCES program focused exclusively on the use values associated with the persons in group 1. The GCES report explicitly acknowledges this restriction. The benefits to others compared to those considered by the GCES are unknown. They could possibly be much larger, because of the upper limit on the use benefits of boating and fishing mentioned above. However, whether or not the nonuse benefits are of legitimate concern depends on an issue that is not clearly resolved in the GCES report--the extent to which the consequences of alternative flow regimes are ephemeral, at one extreme, or very long-lasting, at the other. On the whole, the report appears to assume that the effects are relatively ephemeral--low flows in the river today may reduce the quality of today's boating or fishing but not tomorrow's, assuming these are highest flows tomorrow. As long as this is true, a narrow focus on the use of benefits of current boaters and anglers is justified. On the other hand, if a change in the operation of the dam substantially alters the fishery or white-water boating for a period of years or longer (e.g., by eliminating beaches or certain terrestrial or aquatic biota), then the effects are more widespread and the impacts on groups 2 through 5 must be considered. Changes in flow measurement, whether diurnal, weekly, monthly, seasonal, or annual, would also affect study results.

If research is extended to groups 2 through 5, a broader data collection effort would be required, Dealing with 2 through 5 requires surveys of much larger populations, while dealing with 5 requires the use of an input-output model. Another question is "what are the subsidies involved"? Such subsidies are usually well hidden, but are almost always involved in public projects, such as dams when small select groups stand to benefit extensively. Also, what are the contingency calculations concerning lawsuits? One significant, successful lawsuit could easily offset marginal cost-benefit calculations.

The economic benefits of (peak) power generation were excluded from the analysis. This omission makes it impossible to analyze tradeoff between power generation and the recreation and environmental resources of the GCES study area. Given the constraints on the scope of analysis embedded in the design of the GCES research program, the committee considers the economic analysis that was performed to be highly competent and creditworthy. With the benefit of hindsight, comments on several technical issues follow.

The first concerns the two alternative approaches in the contingent valuation survey to estimating how people's willingness to pay for white-water boating varies with the flow regime. Ultimately, only one of them is employed in the GCES draft report, but the contrast is of some interest. The first method was to elicit from respondents their willingness to pay (over and above their actual cost) for the boating trip that they actually took in 1985, and to correlate this with actual flow conditions during the trip. The second method was to ask respondents for their willingness to pay for each of several hypothetical trips with different flow regimes from that actually experienced. Both methods raise several issues. The main problem with the first method is the range of variation in flows during the 1985 white-water boating season; for commercial trips the average low and high flows were 25,200 cfs and 31,600 cfs while, for private trips, these averages were 21,800 cfs and 29,200 cfs. Thus, it appears that actual flows fill in a relatively narrow range. The willingness to pay was extrapolated to lower and higher flows by fitting a statistical model to the survey responses that was quadratic in flow. Inevitably, however, estimates of the value of boating with low flows (e.g., 5,000 cfs, 13,000 cfs) or very high flows (e.g., 40,000 cfs) involve projecting the fitted equation beyond the range of data from which it was estimated. In this context, it is interesting to note that the peak-value flows (33,000 cfs for passengers on commercial trips, 29,000 cfs for passengers on private trips) are located near the upper limit of the flows in the actual data set. There might be some extraneous factors that confound the relationship between the actual flow conditions on a trip and the respondent's valuation of the trip. For example, could it have happened that richer people, or more avid boaters, took trips at times when flows were higher, so that the increase in value per trip over the range 20,000 to 30,000 cfs is not really indicative of a preference for higher flows?

The elicited values for hypothetical trips with different flow regimes were not actually used in the GCES draft report, but it is interesting to compare them with the flow-value function based on actual trips. The main limitation of the hypothetical scenarios is that they were restricted to flow conditions different from those actually experienced--5,000 cfs, 13,000 cfs, 22,000 cfs, 40,000 cfs. Except for the 22,000-cfs scenario, there was no overlap between the actual flows in the sample and those in the hypothetical scenarios. The absence of an overlap makes it impossible to determine from the responses to the hypothetical scenarios whether values peak anywhere. In the case of passengers on commercial trips, it is encouraging to note that the two functions, actual and hypothetical, appear to agree reasonably well for flows below about 15,000 cfs (Bishop, et al., 1986, Figure 5.2). For passengers on private trips there is less argument (Bishop, et al., 1986, Figure 5.3). Finally, notwithstanding the limitations in the data, the responses to the hypothetical scenarios could have been pooled to obtain a single, flow-dependent, statistical model or pooled along with the actual trip responses in order to obtain a formal, statistical test of whether or not the two sets of responses were different.

Another set of issues concerns the problem of extrapolating from the statistical models based on the sample responses to the contingent valuation survey to the larger populations of anglers and boaters in the GCES study area. (As already noted, for boating the statistical model was based on actual trip questions; for angling a flow-dependent value function could be obtained only for the responses to hypothetical flow scenarios.) The sample responses provide estimates of the value <u>per</u>

trip associated with each type of flow regime. In order to estimate the total impact of a given regime, it is necessary to know the total number of trips, and also to be sure that the value per trip does not vary among important segments of the recreation "market."

Starting with the latter point, it does not appear that the GCES researchers devoted substantial effort to investigating whether the flow-specific values per trip vary with significant attributes of the individual respondents. There are two qualifications to this blanket statement: (1) in the case of boating, separate value functions were estimated for passengers on commercial and private trips, and these differed significantly; (2) for both types of boating and for angling, the respondent's actual expenses on his boating or fishing trip were found to have a significant positive impact on his willingness to pay for the trip. The latter result could be an indication that market segmentation phenomena are occurring: respondents with higher incomes or living further away from the Grand Canyon (both of which could imply higher expenditures) may value their recreation experience there more highly (in dollars). If this is so, it would have been useful to know it more explicitly. Moreover, it is interesting to compare the present study with an earlier (1982) survey of recreational fishing at Lee's Ferry by Richards et al. (1985). The earlier study employed a different methodology--the "travel cost" method, as opposed to contingent valuation. In the present context the Richards et al. group was able to distinguish two types of angler in their sample--trophy fishermen and nontrophy (or "meat") fishermen. Among their 3,500 respondents, they classified 27.5 percent as trophy anglers and 72.5 percent as nontrophy. They estimated that the value of fishing at Lee's Ferry averaged about $380 per trip (in 1982 dollars) to the trophy anglers, and $270 per trip to the nontrophy angler (the former made about eight trips per year, however, while the latter made only four trips per year).

By contrast, the GCES researchers did not observe a distinction between trophy and nontrophy anglers (in the attitude survey, for example, 57 percent of the respondents cited "not catching a trophy fish" as an attribute of a poor fishing trip, while 63 percent cited "not catching your limit"), and their estimate of willingness to pay per trip was $104 to $130. Given the deterioration in the fishery between 1982 and 1985, as well as the difference in research methodology, these two studies are not necessarily comparable. But, because there is now (1987) a requirement for artificial lures at Lees's Ferry, which may repel nontrophy anglers, it would have been useful to know if there were distinct segments of the angler market with different flow-specific values.

The total impact of any flow regime depends on the size and composition of the recreationist population. In the case of boating the size of the recreationist population may not be an issue as long as the number of National Park Service permits is a binding constraint. In the case of the fishery it is, because Arizona Game and Fish does not directly control entry. For fishing, the model of flow-dependent values needs to be supplemented by a model of participation in the fishery.

OPERATIONS

The Operations appendix in the final integrated report includes (in Section II), a good discussion of the operating rules for annual, monthly, and hourly time periods (although it does not always distinguish between physical/legal constraints and policy). The first GCES objective asks for the identification of adverse effects of current operations taking 1982 as a baseline; whereas the Commissioner asks how the current operations affect the total riverine environment. The latter is unclear as to whether any baseline (predam or postdam) is intended. The former, in raising the issue of adverse effects, sets the stage for value judgments. The conflict is further confused by the committee's observation that the GCES report is not consistent in maintaining 1982 as a baseline for identification of adverse effects.

The most curious deficiency in the GCES final draft report (July 1987) is the inconsistency between the main body of the report and the institutional analysis. A number of significant adverse downstream impacts from the construction and operation of the dam are identified by the scientific studies, but the institutional analysis is primarily designed to explain why the bureau's operating policies cannot be modified because of legal constraints. The operation of Glen Canyon Dam is subject to legal constraints, but the report fails to distinguish between external and self-imposed constraints. As the report reflects, management of the Colorado River is driven by the specter of a long-term drought, and the bureau's operating rules for filling and scheduling releases seek to guarantee that the agency can respond to downstream calls during a drought. In practice, the bureau has been able to fulfill the primary objectives of storage and delivery and still generate large amounts of power. The consistency between power generation and storage and delivery has given the bureau the flexibility to schedule hourly, daily, and weekly releases is response to system demand for power. As a result the GCES report blurs important distinctions among different orders of constraints that effect the operation of the dam. In turn, this has led to an overly constricted discussion of alternative operations strategies.

As stated elsewhere in this report, the bureau has more discretion to alter dam operations for power generation than it does with respect to its storage and delivery obligations. The GCES have, however, greatly contributed to future studies of the management of the Colorado River because they show clearly how the "Law of the River" in fact gives the bureau great discretion to manage the dam for power generation.

Another serious remaining deficiency is Section III's discussion of flood releases. This discussion is limited to the risk of floods given the assumption that the January 1 maximum storage target of 22.6 million acre feet is inviolate. That criterion is, of course, simply a policy decision, which should have been subjected to sensitivity analysis. In the discussion it is freely admitted that the 22.6 criterion results in frequent spills (1 in 4 years).

The logical next step that would be responsive to Commissioner Broadbent's charge to examine possible modification to operating criteria would be simulation of flood volume frequency and the likelihood of meeting downstream flow commitments resulting from various other January storage criteria. A rather simple model developed by a reviewer, for example, agrees roughly with the frequency of spills resulting from the 22.6 million acre feet criterion but also predicts higher turbine flows (and revenue), fewer spills, and reduced flood peaks at lower January 1 storage criteria. Because both economic and environmental benefits (fewer and smaller floods) would result from additional flood storage, it is difficult to understand why changing this policy was not examined. This is particularly surprising given the executive summary conclusion in the July 1987 GCES Draft Report (page iii) that "we would recommend that flood releases be avoided until the tolerable frequency can be better defined"--implying that a 22.6 million acre feet criterion should be reduced.

Surely as part of a $6 million research program the tolerable frequency could have been defined. The existing Bureau of Reclamation simulation model is capable of calculating both the frequency and the volume of spills as a function of various flood storage rules; therefore no new model development was required. Volume is a much more important indicator than frequency because it differentiates between a 0.1 million acre feet spill and a 10 million acre feet spill. In future studies, the volume as well as frequency of spills should be analyzed.

Economic/Environmental Tradeoffs

The GCES executive summary recommendations imply that modified operations are feasible (operationally) and would result in desired environmental benefits. The operations section, however, does not support these recommendations by discussing the impact of such changes on power production and revenue and the availability and cost of alternative power sources. Nor does it discuss the political feasibility of proposed changes. The report should have pointed out the implication of operational changes--for example, an increase in minimum flow during the night will produce a corresponding decrease in maximum flow during the day and a significant loss in revenue to the Colorado River Storage Project (CRSP) due to reduction in short-term sale of surplus energy during peak hours and perhaps event inability to meet firm power contracts.

Power in kilowatts of capacity is proportional to the product of flow rate and head (Q•H) on turbines. Total energy produced during a particular month may be reasonably calculated as a function of <u>average</u> flow since head from this large (25 million acre feet) reservoir is relatively constant over a month. Given a target monthly release and an initial surface elevation, monthly energy can be calculated (kilowatt hours) quite independently of daily variations in flow because total volume released must meet the water delivery target regardless of diurnal variations. In the world of energy marketing, the time of day during which energy is produced is crucial for the following reasons: (1) firm power contracts require a large fraction of energy deliveries during peak hours and (2) the opportunity to sell energy surplus to firm power contracts at much higher prices occurs during daily peaks--not at night. The operations report does not discuss the implication of these facts. For example, if a policy of much higher minimum flows were to be adopted: (1) the existing firm power CRSP contracts could likely not be met (there would be excess capacity at night and inability to meet firm contracts during daily peaks). (2) Costs to CRSP customers would increase by perhaps 3 times the lost revenue to CRSP because customers of WAPA would have to meet the peak period energy shortfall with much more expensive fossil fuel plants.

Although it was obviously not the intent of the Bureau of Reclamation to produce a full-blown multiobjective planning analysis within the GCES research program, it would have been very useful to produce at least an order of magnitude estimate of the impact on revenue and on mobility to meet long-term contracts of various levels of change in minimum flows--rather than simply deferring the question to a future study while simultaneously negotiating new 15-year contracts. Otherwise, the scientific studies remain outside of reservoir management.

In addition to total costs (losses), the study needs to delineate how these costs will be distributed, i.e., who wins and who loses. Will certain economies be hit hard? Is adequate substitute energy available? The answers to these questions will help determine the political feasibility of any changes.

Operational Constraints and Policies

Prior to discussing alternative operating policies for Glen Canyon Dam, the physical and legal constraints, contractual commitments, and current Bureau of Reclamation operating policies should be clearly understood and differentiated.

Physical Constraints: Physical constraints concern active storage and power plant releases.

Active Storage: The Glen Canyon Dam can store 25 to 27 million acre feet depending upon whether radial gates are open or closed. Because 6 million acre feet is inactive storage (cannot be drained from reservoir), 21 million acre feet of active storage is available for management.

Releases: Power plant releases are physically limited at 31,500 cfs (now 33,100 after generator uprating). When necessary, additional controlled releases can be made by opening the dam's river outlets, thereby adding 15,000 cfs, thereby totaling 48,100 cfs of controlled release capacity. This occurs only when the dam storage is 25 million acre feet or greater.

Legal Constraints: Legal constraints include the following:

Yearly Releases: The Colorado River Compact requires delivery of water at the Compact Point (just below Glen Canyon Dam) of 75.0 million acre feet for any 10 conservative years. A subsequent Mexican Water Treaty adds an additional 0.75 million acre feet of water to the upper basin states' release commitments. Subtracting the 0.02 million acre feet contribution of the Paria River, which drains the upper basin but enters the canyon just below Glen Canyon Dam, yields a 10-year release commitment of 82.3 million acre feet.

Lake Powell Active Storage versus Mead Active Storage: The Colorado River Basin Project Act specified that on September 30 of each year if the Lake Powell active storage is greater than the Lake Mead active storage then minimal releases greater than power plant capacity (31,500 to 34,100 cfs) equalize active storage in both lakes.

Bureau of Reclamation Operating Policies: The Bureau of Reclamation has set several storage and release objectives for operation.

Monthly Storage: The Bureau of Reclamation operates Glen Canyon Dam in the fall to try to reach a storage of 22.6 million acre feet by January 1 and in the spring to try to reach a storage of 25.0 million acre feet (full) by July 1.

Releases: Seasonally, the Bureau of Reclamation attempts to provide a minimum release of 1,000 cfs in the nonboating season and 3,000 cfs in the summer. To the maximum amount possible the BOR tries to release all water through the power plant.

Lastly, to reflect the demand for power and maximize power revenues, the Bureau of Reclamation maximizes hourly releases from 7:00 A.M. to 11:00 P.M. and minimizes them between 11:00 P.M. and 7:00 A.M. subject to other constraints and objectives.

Need to Focus on Glen Canyon

Much of the material presented in the Operations appendix has to do with the revenue, customers, and operation of the entire WAPA service area and is therefore no help in analyzing the operation of Glen Canyon Dam. The Glen Canyon hydropower capacity is about 78 percent of the total CRSP capacity, but CRSP is a small fraction of WAPA. The operations report should have focused more on Lake Powell, or at least on the CRSP, in order to develop useful information on how much change in operation would affect energy production and ability to meet CRSP firm power contracts.

The bureau is subject to the power delivery obligations in the contracts between WAPA and its customers, but power contracts like any other contracts are subject to modification. WAPA markets power on both a long- and short-term basis. Short-term sales can be adjusted to competing demands for the use of the water. What is at stake are lost power revenues, not a legal obligation. Long-term contracts present a greater constraint, but they are subject to periodic renegotiation and conditions that reflect operational changes and can be incorporated into the contracts.

The balance between power generation and other uses of the river is a complex one, but the GCES report does not contain a sufficiently sophisticated discussion of the constraints to allow an informed decisionmaker to balance the competing demands. A more detailed discussion of the relationship between the proposed changes and present and future WAPA marketing policy, as reflected in its contracts, is especially necessary. Power not water delivery is the key to the operation of Glen Canyon Dam.

5

THE ROLE OF MONITORING IN THE MANAGEMENT PLAN

Monitoring is an integral part of resource management and provides a basis for prediction and projection of resource characteristics. Management is based largely on prediction or projection of resource characteristics. Prediction requires data to calibrate and to validate models or expectations based on experience. These principles apply to the Glen Canyon Dam and to associated uses of the Colorado River.

The Colorado River from Glen Canyon to Lake Mead is in a constant state of change. The filling of Lake Powell caused a period of low, controlled flows. Apparently, the GCES study plan assumed that flows would always be controlled to the same extent as they had been prior to the beginning of the study. However, flows in 1983, the first high-water year after the filling of the reservoir, demonstrate the possibility of reduced control following filling. In fact, more years of flood flows are certain in the future under present operational plans.

If a management plan is to be developed for the Glen Canyon Dam, the plan should be integrated with and based upon a sound understanding of the effects of operations on environmental resources. The predictions of effects should be viewed as working hypotheses about river processes; these hypotheses can be tested by use of monitoring data.

The monitoring program should include a rapid research mobilization plan for future high-water flows, so that the system responses to the exceptional flows can be documented as they occur. The more knowledge we have of the Colorado River system, the less additional data will be required to verify our knowledge. Even so, because discharge through the Glen and Grand canyons is related to stochastic sedimentary phenomena, perfect knowledge of the system would not yield perfect predictions; there will always be some level of uncertainty.

Decisions about what to monitor and where or when to monitor should be integral parts of the management plan for the future. Furthermore, a data management system with a repository for the data in well-documented and retrievable form is an essential feature of any management plan.

Sediment is a major concern for recreational uses and fisheries resources downstream of the dam. Formation and erosion of rapids, beaches, and riparian vegetation are related to the sediment input, storage, and movement through the canyon. Fisheries are affected by current, which is in turn regulated in part by sediment distribution in the canyon. Sediment movement is determined by (1) the supply of sediment to the system from the tributaries, and (2) water discharge. Thus, sediment input and water discharge should be one major focus for monitoring. The sediment input will vary from year to year, as the tributary flows vary. An assessment of the sources of sediments, the volumes expected on the average from each source, and the uncertainty associated with each source are important subjects for early focused analysis. Allocation of effort can then be made in terms of expected reduction of uncertainty in assessment of sediment input.

Very little sediment will come from the main Colorado River above the junction with the Paria and the Little Colorado, because sediment is deposited in Lake Powell. However, tributary sources of sediment below the dam should be measured. In addition, the pools and their scour and fill should be monitored. The following sites should be continuously monitored: Lake Powell just above the dam, Paria River, Little Colorado River, Kanab Creek, Colorado River at Bright Angel Creek, and Colorado River above Lake Mead. For logistic purposes, as well as for subsequent analysis, it makes sense to conduct biological measurements at these points as well.

Sediment inputs from the major tributaries will move as waves through the Canyon. The Canyon reach just downstream from the Paria and the Little Colorado will be in a continuous state of disequilibrium as it is alternately scoured by clear flows released from Lake Powell and filled by sediment from the tributaries. The length of this reach of disequilibrium should be monitored, and the movement of major waves through the Canyon should be tracked. The transient effect of the sediment waves on the growth and decay of beaches should be monitored, and bed sediment distribution upstream from, on, and downstream from the sediment wave should be determined. These data are necessary for any geomorphic or hydrodynamic analysis of the interaction of the beaches with the River, particularly in the upper reaches of the Canyon.

Lake Powell should be monitored for temperature, water quality, and plankton near the dam. Vertical profiles of temperature, oxygen, nitrogen phosphorus, and phytoplankton and zooplankton concentrations should be obtained at least on a monthly basis, and might be further modified to include sampling during unusual dam operations. At some point the question of multiple dam outlets is almost certain to arise. Without the data base on Lake Powell, it will not be possible to model the downstream impact of changes in the temperature, nutrient content, and plankton composition of outflow water. Additional monitoring should be planned at the discretion of the scientific leadership of the monitoring team in order to provide an adequate scientific basis for future decisions. The monitoring program should include:

1. Sediment data from the temporary monitoring sites used during the GCES for continuity and from any additional sites considered necessary for completeness.
2. Beach deposition and erosion, as related to the sediment stored in and passing through the river in the vicinity of specific beaches.
3. Tracking of sediment waves which may be created by major inputs by the tributaries which are deposited in the channel of the Colorado River.
4. Systematic samples of bed material, particularly in the reach of the Colorado River immediately downstream from the Paria and Little Colorado, which will be in a state of continual disequilibrium.
5. Transverses of bottom elevation indicative of bed resistance and pool scour and fill, plus any further transverses required for a geomorphic analysis of the system, independent of the hydraulic analysis.
6. Transverses of fauna and flora. These should consider the transverses established during the study for continuity, but also should be coordinated with and should influence the location of the sediment transverses for completeness of a data set at a cross-section.
7. Fixed photo sites should be established throughout the Grand Canyon so that the impact of major events can be recorded over time.

Flows in the Glen Canyon-Boulder reach should be modeled for stochastic characteristics, so that the probability of future spills can be estimated. This information can be used in assessing the possible variation of outcomes associated with different management plans. The stochastic characteristics should include the effect of dam operation plans, (and they should be used to provide a geomorphic overview of the system and its response to different regimes of flow.)

An annual assessment should be made of sediment input from the minor tributaries, and major events on a tributary should be investigated in detail to determine its impact on the canyon downstream from its sediment input to the canyon. In particular, growth in size of rapids and the rate of removal of material from them should be monitored.

The current method of operating the dam for conservation of water guarantees that spills will be a common occurrence in the future, unlike the immediate past. A mobilization plan should be based on an assessment of data that would be especially useful immediately after a major flood. The elevation of the water resulting from the largest flood of record should be estimated, and all transects should be extended beyond that elevation. The high-water mobilization plan should include hypotheses concerning impacts, and monitoring of those impacts should be anticipated. Team members should be chosen in advance and their duties during the high flow year should be detailed, so that no time is wasted in mobilization once the high flow event occurs. The apparent stress on sediment monitoring should not be interpreted to preclude the needed biological and botanical monitoring which are strongly influenced by the sediment movement through the Canyon. Team members should include hydraulicians, geomorphologists, botanists, biologists, and fisheries scientists who are familiar with the transects sampled in the past, and who are prepared with a check list for where to go, what to do, and who to coordinate with. Such a detailed procedure is an integral part of any monitoring plan under uncertainty, because it will help alleviate the expected confusion and panic which results from an unusual event.

It cannot be stressed too strongly that detailed understanding of the Grand Canyon ecosystem requires a well-planned monitoring program.

6

APPLICATION OF ECOSYSTEM SCIENCE TO RIVER MANAGEMENT

This chapter is provided as a general guideline for the Bureau of Reclamation in the performance of any future environmental studies which may be conducted on river systems. Environmental studies that are now either required or expected prior to alteration or management of the natural environment often must encompass large units of the landscape. For reasons that have already been explained, it is usually not realistic to attempt to restrict such environmental studies to the immediate vicinity of the structure or activity whose effects are being considered. Both theory and experience show that the effects of human intervention can be propagated well beyond the immediate location where they first occur, and one of the first tasks of those who would study these effects is to define the boundaries of the system within which the effects can be expected. Logical boundaries are typically determined by the tendency of the landscape to be divided into identifiable functional units that can be treated as ecosystems. Consequently, environmental studies are actually ecosystem studies, and will be most effective if they are conceived and designed from the beginning as ecosystem studies.

Ecosystem science is not very old, and thus does not show the stability of approach or method that is typical of more mature sciences. However, a consistent distinguishing feature of ecosystem science is that it has as its priority an understanding of systems, even though this must sometimes be achieved by combining and integrating knowledge from disciplines that have not been previously very strongly joined. Because ecosystem studies must identify and deal with any physical, chemical, or biological phenomena that may govern the overall system properties, a carefully considered study design is essential.

No formal protocol is used by ecosystem scientists in designing ecosystem studies. However, the most successful studies often incorporate many of the same principles. The committee has identified six such principles, which are presented below in a sequence that might be logical for application to a managed river system.

LEARNING THE BACKGROUND

It may seem obvious that the persons who design a specific ecosystem study must first assemble and assimilate all of the existing background information that is relevant to the system. Even so, poor use of background information is often a critical failing of applied ecosystem studies. It is essential that managers and administrators allow the designers of such a study time to make this preparation, and it is essential that the scientists realize the importance of background preparation.

Study designs often reflect deficiencies of two different types in dealing with the background information. First, the designer of the study may give excessive weight to subjects that are most familiar. The result may be a study that emphasizes biological phenomena but deals inadequately with the physical controlling variables, or vice versa. The full range of background information on a particular site must be the basis for the study design, and this may require the study designer to call on outside expertise in some disciplines, and to give special consideration to unfamiliar disciplines. Major lakes, rivers, or watersheds have typically been studied far more extensively than might be apparent at first. Design of a study without benefit of such background information is inefficient, and may seriously handicap a study from the beginning.

A second common type of deficiency in background preparation has to do with the relevance or value, through comparison or analogy, of previous studies elsewhere. Very few management problems or ecosystems are entirely unique. A careful review of the sequence of events at other sites, or of the difficulties and shortfalls of previous studies at other sites, is likely to make the design of an ecosystem study both easier and more effective.

The background information that serves as a basis for study design should be synthesized as part of the rationale for a particular study design. This background document can then serve as a reference for members of the study group.

DEVELOPING CONCEPTUAL SCHEMES AND MODELS

The proper role of models has been a subject of controversy in ecosystem science. The potential usefulness of models seems obvious, especially given the persistent use of them in other disciplines, such as economics or meteorology, that deal with systems consisting of large numbers of interacting components. Taking this principle to its logical extreme, some ecosystem scientists foresaw as much as 25 years ago the need for quantitative systems models. In the subsequent decades, the construction and use of these systems models have been extensively explored. This period of exploration has revealed a number of fundamental problems that have impeded the development and application of quantitative models of ecosystems, including excessive complexity, lack of realism, high cost, and poor general applicability across systems. As a result of these findings, ecosystem science has now largely turned away from the development of quantitative systems models as a unified approach for the study of ecosystems.

Even though quantitative systems modeling proved to be of more limited use than expected, ecosystem studies still persistently incorporate models. Perhaps the strongest tendency in current ecosystem studies is to develop an overall conceptual scheme (sometimes called a model) showing compartments and interactions between compartments for the system. This conceptual scheme then serves as a basis of organization for study of the ecosystem. Subsequently, certain segments of this conceptual scheme are developed in a quantitative way wherever it is deemed appropriate and feasible to do so. If this approach is used, investments can be focused on the development of quantitative predictive capabilities for a few critical phenomena, rather than for the entire system. This approach is much more economical and generally more reliable as a means of providing specific types of critical information to managers or planners.

The first version of a conceptual scheme should be as complete as possible. It is logical to begin constructing such a scheme by considering the list of abiotic factors that influence the living components of the system. Linkages between these abiotic factors and the biotic compartments are then established, and biotic compartments are related to each other through food chains or other kinds of biotic interactions such as competition.

Identification of compartments, particularly within the living part of the system, requires considerable experience and insight. Compartments should lump species of organisms as extensively as possible without sacrificing the ability of the scheme to resolve major properties of the system. For example, it is common in aquatic ecosystems to treat phytoplankton, attached algae, and rooted aquatic plants as three compartments because the factors that regulate organisms in these compartments differ considerably, whereas the factors that separate species within these compartments are more likely to be minor from the perspective of the ecosystem.

SIMPLIFYING THE CONCEPTUAL SCHEME

Conceptual schemes that portray all compartments and suspected interactions in an ecosystem are typically complex. It is scarcely ever the case that time or financial resources allow a detailed consideration of all compartments and all interactions. Fortunately, it is almost always possible to simplify greatly the scope of study in light of (1) the specific purposes for the study, (2) the known principles applying to specific compartments and their interactions, and (3) the specific background information on the site.

For managed ecosystems, the major basis of simplification would be two separate but related lists of factors: (1) a list of values (or designated uses, in regulatory jargon) and (2) a list of management options or management imperatives. The designated uses should be considered very broadly; i.e., they should include not only the uses directly connected to management, such as water supply or power production, but also other uses that are recognized by custom or by law. In aquatic environments, these other uses typically include the broad categories of recreation and support for aquatic life. In order to be of greatest value in simplifying a scheme, each of these general categories of use needs to be defined as specifically as possible for a particular site. For example, protection of aquatic life typically can be simplified by identification of the aquatic life classification of a water body through the state regulatory agencies, and recreational uses can be identified by present and historical use patterns.

Management or development schemes that motivate environmental studies typically have some very specific direct effects. Although it is often relatively easy to list these effects, and to specify their projected magnitudes on the basis of engineering or planning studies, failure of persons planning environmental studies to do so has often resulted in inappropriate designs for the study of managed ecosystems.

When the designated uses and the expected range of management alternatives are considered in relation to the ecosystem scheme, certain compartments and certain control pathways can be identified as having unquestionable significance for the overall analysis of ecosystem responses to management. This subset of compartments and interactions form a simplified scheme that serves as a direct basis for the design of the study. Such simplifications can result in the exclusion of large components of the system, and thus allow the effort of the investigators to be diverted toward specific goals. For example, it is well known that all natural systems contain microbial decomposers. Some studies of managed ecosystems might require that these decomposers be considered as part of an overall scheme designed to analyze and forecast the effects of management practices. For instance, enrichment of a lake with nutrients raises its productivity. Higher productivity results in the deposition of greater amounts of organic matter in the deep waters of the lake, which in turn stimulates microbial decomposers, resulting in accelerated oxygen depletion. Accelerated oxygen depletion is connected to beneficial uses of the lake because of its potential effect on fisheries and internal nutrient cycling. In the case of a river, however, similar connections to designated uses might not exist. A rise in the productivity of a river may have numerous effects, but oxygen depletion through decomposition is offset by reaeration of the moving water except in the most severe instances of enrichment. Consequently, a simplified scheme for such a system might disregard the microbial decomposers, and thus focus on factors that are likely to be important to the designated uses.

The necessity for simplifying conceptual schemes of ecosystems is frequently disregarded. This shortcoming inevitably results in the collection of data that cannot be used in any meaningful way to advance the understanding of the system as a whole, and the omission of data collection in some areas that are absolutely critical for an understanding of the system.

A corollary of the simplification process for ecosystem studies is that the staffing of such projects should not be completed until the final simplified plan is available. If the staffing of projects occurs before the plan for study of the system has fully evolved, the project will almost inevitably be staffed with an inappropriate mixture of expertise to answer the critical questions.

CREATING A DATA COLLECTION PROGRAM

The simplified system scheme indicates which compartments and which interactions have the highest priority for study. From this blueprint it must be determined how much original information should be taken. Broadly speaking, the original information may be obtained in two different ways, which may be termed descriptive and experimental. Where an interaction between compartments is suspected, but the nature of the interaction is poorly known from previous experience or from the literature, an ideal approach would be experimental. In practice, however, the number of experimental approaches that can be undertaken through a single system study spanning a few years is quite low. The experimental approach is more certain to yield novel insight than descriptive studies, but produces results very slowly, and at great cost. Consequently, the experimental component of ecosystem projects must be focused very carefully on issues that cannot be approached in any other way. Experiments involving manipulation of system components or of the entire system within the range anticipated under future management are likely to be the most useful, but more fundamental experimental approaches may also be justified.

Descriptive studies are likely to form the bulk of information that is both necessary and feasible to collect for an ecosystem study that must be completed within a specified amount of time on a moderate budget. Description might include determination of the kinds, abundances, and distributions of organisms, and of the means and amplitudes for critical environmental variables. For environments that have not been thoroughly studied, descriptions of this type, although unexciting in concept, may provide novel and revealing insights, especially when considered together. However, it is essential that the collection of descriptive data be motivated entirely by the system scheme, and not by the convenience or precedence for certain types of data collection.

Descriptive data collection frequently can serve as the basis for quantitative approximation of effects and interactions. Many individual environmental processes have been studied to such an extent that they can be modeled quantitatively with reasonable confidence, particularly if adjustments can be made to local conditions. Examples include production of plant biomass in response to variation in nutrients, chemical changes in water in response to the presence of various kinds and densities of organisms, dose-response relationships between organisms and toxic substances, habitat requirements for certain categories of organisms, and certain types of biotic interactions. Frequently, modeling of this type is based on a few key pieces of information, and the ecosystem study must consistently provide information of this type as part of its descriptive data base.

The descriptive data collection program supporting an ecosystem study should have a common organizational basis across all ecosystem compartments. For example, physical, chemical, and biological studies should be coordinated in time and space because the ultimate aim is to use these data sets in relation to each other.

Stratified data collection schemes are frequently very useful in ecosystem studies because they allow the investigators to cover adequately a range of different temporal and spatial scales within the realistic limits of resources that are available for a study. For example, the spatial component of studies for a large ecosystem might consist of three elements: (1) information collected very frequently at a single index site, (2) information collected less frequently at a small number of important sites suspected of being different in some meaningful way, and (3) infrequent synoptic studies in which a few critical variables are measured at a large number of stations. The same principle can be applied to the resolution of events on a temporal scale.

Very few natural systems can be characterized in a single year because of interannual variation in various forcing functions such as EL NINO weather events. Consequently, management should realize that studies having a duration of less than 2 or 3 years are not acceptable in many instances. At the same time, the return on information after 2 or 3 years is slower, and it is often reasonable to reach conclusions after this amount of time. Even so, some categories of problems cannot be resolved in 2 or 3 years, and will require commitment to long-term studies of smaller scope following the completion of the main effort.

MAKING MID-COURSE ADJUSTMENTS

Only a very poor ecosystem study would fail to turn up sufficient novel information about a system to warrant changes in the study plan. Consequently, mid-course corrections should be part of the plan itself. It would not be surprising if 20 to 25 percent of the resources and effort expended in the course of the study were directed toward problems that were not foreseen in the initial study design.

Mid-course corrections require mid-course data evaluation. There is a strong tendency for data to be collected in one step and analyzed in a second step. To some extent this may be inevitable because of limitations on time and resources. However, an effective system study plan should incorporate a mechanism, such as an annual synthesis, that formalizes the requirement for data evaluation before the resources of the project are entirely expended.

EVALUATING AND SYNTHESIZING THE DATA

Major amounts of time must be budgeted for final evaluation and synthesis of information. Typically, this final evaluation and synthesis can occur in three stages. First, the information for individual components of the program, which are typically associated with specific investigators, must be summarized statistically and accompanied by a written interpretation of the immediate and obvious conclusions and trends that have emerged from the study. It is especially important here to point out in written form departures from the expected or differences and similarities in relation to other similar studies.

At a second level, components of the ecosystem that can be unified or combined in a meaningful way with reference to the conceptual scheme should be joined. This may occur by the application of a recognized type of scheme, or by a less quantitative set of interpretations where modeling is considered unrealistic or unnecessary.

The final and most critical phase of interpretation is done at the level of the system, and reflects the ecosystem scheme as modified by experience. At this stage, some final simplification may occur if the studies have demonstrated that certain linkages or compartments considered initially to be of concern actually are not. For the evaluation of management options, for example, it is often possible to identify the most vulnerable or most critical component of the system, and to base much of the forecasting and interpretation on the behavior of this component, which may then be the most important in setting limits on management.

Evaluation of an ecosystem must consistently be accompanied by the appropriate degree of reservation, especially where predictions are made outside the framework of experience, as in the case of construction projects that have not yet occurred or manipulations that are not yet in place. As a rule, the degree of uncertainty in ecosystem prediction is approximately the same as the degree of uncertainty that could be expected from predictions associated with schemes that deal with national economies or with weather patterns. Like economic predictions and weather forecasts, ecosystem forecasts are likely to be most satisfactory if they are applied over a relatively short span of time and near the framework of experience. However, ecosystem schemes, like economic and meteorologic schemes, can be made more reliable if they are adjusted on the basis of local experience. Consequently, an ecosystem study should be coupled to a long-term study program based directly on the earlier, more intensive studies.

REFERENCES

Anderson, L. S., L. Lucas, M. McGee, M. Yard, and G. Ruffner. 1986. Aquatic habitat analysis for low and high flows of the Colorado River in Grand Canyon. GCES Technical Report, Bureau of Reclamation, Salt Lake City, Utah.

Bishop, R. C., K. J. Boyle, M. P. Welsh, R. M. Baumgartner and P. R. Rathbun, 1986. Glen Canyon Dam Releases and Downstream Recreation: An Analysis of User Preferences and Economic Values. Heberlein-Baumgartner Research Service.

Blinn, D. W., H. D. Usher, G. C. Hardwick and W. C. Liebfried. 1986. Cladophora Glomerata and its Diatom Epiphytes in the Colorado River through Glen and Grand Canyon, October 1986: Distribution and Dessication Tolerance. Department of Biological Sciences, Northern Arizona University, Flagstaff, Arizona.

Carothers, S. W. and S. W. Aitchison (eds.). 1976. An ecological survey of the riparian zone of the Colorado River between Lees Ferry and the Grand Wash Cliffs, Colorado River Technical Report No. 10. Grand Canyon National Park, Grand Canyon Arizona.

Dolan, R., A. Harden, A. Howard and R. Johnson. 1977. Environmental management of the Colorado River in the Grand Canyon. Envir. Mangmt. 1:391-400.

Dolan, R., A. Howard and A. Gallenson. 1974. Man's impact on the Colorado River in the Grand Canyon. Am. Scient. 62:392-401.

Hammon, R. L. 1982. Spawning and culture of humpback chub. Progressive Fish Culturist 44:213-216.

Hammon, R. L. and T. D. Inslee. 1982. Culture of endangered Colorado River fishes. In W. J. Miller, J. J. Valentine, D. L. Archer, H. M.

Haury, L. R. 1986. Zooplankton of the Colorado River from Glen Canyon Dam to Diamond Creek. Glen Canyon Environmental Studies Technical Report, Bureau of Reclamation, Salt Lake City, Utah.

Larson, E. B., E. Bonebrake, B. Schmidt and J. Johnson. 1980. Fisheries investigations of the Flaming Gorge tailwater. Utah Department of National Resources, Salt Lake City, Utah. 57 pp.

Liebfried, W. C. and D. W. Blinn. 1986. 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, Bureau of Reclamation, Salt Lake City, Utah.

Maddux, H. R., D. M. Kubly, J. C. DeVos, Jr., W. R. Persons, R. Staedicke, and R. L. Wright. 1987. Effects of varied flow regimes on aquatic resources of Glen and Grand Canyons. Final report to the GCES. Arizona Game and Fish Department, Phoenix, Arizona.

Miller, W. J., J. J. Valentine, D. L. Archer, H. M. Tyus, R. A. Valdez and L. Kaeding (eds.). 1982. Colorado River Fishery Project. Final report, part 1. Fish and Wildlife Service, Bureau of Reclamation, U.S. Department of the Interior, Salt Lake City, Utah. 42 pp.

Minckley, W. L. 1973. Fishes of Arizona. Arizona Game and Fish Department, Phoenix, Arizona. 283 pp.

Minckley, W. L. 1979. Aquatic habitats and fishes of the lower Colorado River, southwestern United States. Final Report. U.S. Department of the Interior, Washington, D.C. 478 pp.

Paulson, L. J. and J. R. Baker, 1981. Nutrient interactions among reservoirs on the Colorado River. In V. D. Adams and V. A. Lamarra (eds.), Aquatic Resources Management of the Colorado River Ecosystem. Ann Arbor Scientific Publishers, Ann Arbor, MI. pp. 457-474.

Richards, M. T., D. Brent Wood, D. A. Caylor. 1985. Sporting at Lees Ferry, Arizona: User Differences and Economic Values. Final Report to Northern Arizona University, Organized Research Committee.

Scott, W. B. and E. J. Crossman. 1973. Freshwater fishes of Canada. Fisheries Research Board of Canada Bulletin 184.

Stanford, J. A. and J. V. Ward. 1986. The Colorado River system. In the Ecology of River Systems. B. R. Davies and K. F. Walker (eds.). Dr. W. Junk Publishers, Dordrecht, the Netherlands.

U.S. Department of the Interior. 1946. The Colorado River: A Comprehensive Department Report on the Development of the Water Resources of the Colorado River Basin. U.S. Department of the Interior, Washington, D.C.

U.S. Department of the Interior. 1987. Glen Canyon Environmental Studies Draft Report. Bureau of Reclamation, Flagstaff, Arizona.

Valdez, R. A. and G. H. Clemmer. 1982. Life history and prospects for recovery of the humpback and bonytail chub. In W. H. Miller and H. M. Tyus (eds.), Fishes of the Upper Colorado River System: Present and future. Proceedings of the Western Division Meeting, American Fisheries Society.

Valdez, R. A. and E. J. Wick. 1983. Natural versus man-made backwaters as native fish habitat. In V. D. Adams and V. A. Lamarra (eds.) Aquatic Resources Management of the Colorado River Ecosystem. Ann Arbor Scientific Publishers, Ann Arbor, MI. pp. 519-536.

APPENDIX A

DOCUMENTS REVIEWED BY THE COMMITTEE

1. Aerial Photography Comparison of 1983 High Flow Impacts to Vegetation at Eight Colorado River Beaches, by Nancy J. Brian, Division of Resources Management and Planning, Grand Canyon National Park, Arizona, National Park Service (Executive Summary).

2. Aerial Photography Comparison of 1983 High Flow Impacts to Vegetation at Eight Colorado River Beaches. Final Report, Terrestrial Biology of the Glen Canyon Environmental Studies, by Nancy J. Brian, Division of Resources Management and Planning, Grand Canyon National Park, Arizona, National Park Service. May 1985.

3. Effects of Post-Dam Flooding on Riparian Substrates, Vegetation, and Invertebrate Populations in the Colorado River Corridor in Grand Canyon, Arizona. Final Report, Terrestrial Biology of the Glen Canyon Environmental Studies, by Lawrence E. Stevens and Gwendolyn L. Waring. Glen Canyon Environmental Studies, GCES Report No. A2. April 15, 1986.

4. Effects of the Post-Glen Canyon Dam Flow Regime on the Old High Water Line Plant Community along the Colorado River in Grand Canyon. Terrestrial

Biology of the Glen Canyon Environmental Studies, by L. Susan Anderson and George A. Ruffner. Glen Canyon Environmental Studies, GCES Report No. A3. October 31, 1986.

5. The Effects of Fluctuating Flows on Breeding Birds, by Bryan T. Brown and R. Roy Johnson, National Park Service, P.O. Box 41058, Tucson, Arizona 85717 (Executive Summary).

6. Fluctuating Flows from Glen Canyon Dam and Their Effect on Breeding Birds of the Colorado River, by Bryan T. Brown and R. Roy Johnson, Cooperative National Park Resources Studies Unit, University of Arizona, Tucson, Arizona 85721. A Final Report Submitted to: USDI Bureau of Reclamation, Upper Colorado Region, Salt Lake City, Utah. December 31, 1985.

7. Evaluation of Riparian Vegetation Trends in the Grand Canyon using Multitemporal Remote Sensing Techniques, by Michael J. Pucherelli, Environmental Biologist, U.S. Bureau of Reclamation, Division of Research and Laboratory Services, D-1524, Denver Federal Center, Denver, Colorado 80225 (Executive Summary).

8. The Effects of Recent Flooding on Riparian Plant Establishment in Grand Canyon. Final Report, Terrestrial Biology of the Glen Canyon Environmental Studies, by Gwendolyn L. Waring and Lawrence E. Stevens. Glen Canyon Environmental Studies, GCES Report No. A6. November 11, 1986.

9. Herpetofauna in Riparian Habitats Along the Colorado River in Grand Canyon National Park, by Peter L. Warren, Arizona Remote Sensing Center, Office of Arid Lands Studies, University of Arizona, Tucson, Arizona, and Cecil R. Schwalbe. Final report submitted to Non-game Branch, Arizona Game and Fish Department, Phoenix, Arizona. August 1986.

10. Instream Flow Analysis of the Glen Canyon Tailwater. Glen Canyon Environmental Studies. David L. Wegner, Grand Canyon Study Manager. Draft, December 1986.

11. Colorado River Water Temperature Modeling Below Glen Canyon Dam, by Ron Ferrari. Glen Canyon Environmental Studies. Draft, October 1986.

12. The Effects of Steady Versus Fluctuating Flows on Aquatic Macroinvertebrates in the Colorado River Below Glen Canyon Dam, Arizona, by W. C. Leibfried and D. W. Blinn. Glen Canyon Environmental Studies Technical Report, Bureau of Reclamation, Salt Lake City, Utah. Final Report, October 1986.

13. Zooplankton of the Colorado River Glen Canyon Dam to Diamond Creek. Final Report, Aquatic Biology of the Glen Canyon Environmental Studies, by Loren R. Haury, Scripps Institution of Oceanography, La Jolla, California 92093. GCES Report No. B-10. October 1986.

14. Aquatic Habitat Analysis for Low and High Flows of the Colorado River in Grand Canyon, by L. Susan Anderson, Lauren M. Lucas, Marie McGee, Michael Yard, and George A. Ruffner. Final Report, Glen Canyon Environmental Studies, P.O. Box 1811, Flagstaff, Arizona 86001. April 1986. GCES No. B12.

15. Evaluation of Varied Flow Regimes on Aquatic Resources of Glen and Grand Canyons, Draft Report, December 1986, by Henry R. Maddux, Dennis M. Kubly, James C. deVos, Jr., William R. Persons, Richard Staedicke, and Rebecca L. Wright. Prepared for: U.S. Department of Interior, Bureau of Reclamation.

16. Cladophora Glomerata and Its Diatom Epiphytes in the Colorado River Through Glen and Grand Canyons--October 1986: Distribution and Desiccation Tolerance. Submitted by H. D. Usher, D. W. Blinn, G. G. Hardwick, and W. C. Liebfried, Department of Biological Sciences, Northern Arizona University, Flagstaff, Arizona 86011.

17. The Effects of Steady Versus Fluctuating Flows on Aquatic Macroinvertebrates in the Colorado River below Glen Canyon Dam, Arizona. William C. Leibfried and Dean W. Blinn, Department of Biological Sciences, Northern Arizona University 86011. Submitted to James deVos and Henry Maddox, Arizona Game and Fish Department, Phoenix, Arizona 85023. Final Report, October 1, 1986. Glen Canyon Environmental Studies Report Number B-8.

18. Glen Canyon Dam Releases and Downstream Recreation: An Analysis of User Preferences and Economic Values--Draft, by Richard C. Bishop, Kevin J. Boyle, Michael P. Welsh, Robert M. Baumgartner, Pamela R. Rathbun. Heberlein-Baumgartner Research Service. October 15, 1986.

19. Simulating the Effects of Dam Releases on Grand Canyon River Trips, by A. Heaton Underhill and Ronald E. Borkan, Cooperative National Park Resources Studies Unit, 125 Biological Sciences East, University of Arizona, Tucson, Arizona 85721. Glen Canyon Environmental Studies. GCES Report No. C-2. May 1986.

20. Glen Canyon Dam Releases and Downstream Recreation: An Analysis of User Preferences and Economic Values, by Richard C. Bishop, Kevin J. Boyle, Michael P. Welsh, Robert M. Baumgartner, and Pamela R. Rathbun. Draft Final Report and Appendixes. Heberlein-Baumgartner Research Service. November 5, 1986.

21. Reported and Observed Boating Accidents as a Function of River Flows from Lee's Ferry to Diamond Creek, Grand Canyon National Park--Draft, by Curtis A. Brown and Martha G. Hahn-O'Neill. October 17, 1986.

22. An Analysis of Recorded Colorado River Boating Accidents in Glen Canyon from 1980, 1982, and 1984, and in Grand Canyon for 1981 through 1983. Final Report, Recreation Studies of the Glen Canyon

Environmental Studies, by A. H. Underhill, M. H. Hoffman, and R. E. Borkan, Cooperative National Park Resources Studies Unit, University of Arizona, 125 Biological Sciences (East) Bldg. 43, Tucson, Arizona 85721. GCES Report No. C-1. July 1986.

23. Boating Accidents at Lees Ferry. A Boater Survey and Analysis of Accident Reports. Draft Report, by Lawrence Belli and Robert Pilk, National Park Service, Glen Canyon National Recreation Area. November 1986.

24. Unsteady Flow Modeling of the Releases from Glen Canyon Dam at Selected Location in Grand Canyon, by Jerold F. Lazenby, Bureau of Reclamation, Final Report, October 9, 1986.

25. Sonar Patterns of the Colorado River Bed in the Grand Canyon, by Richard P. Wilson, U.S. Geological Survey, Tucson, Arizona. Preliminary Draft--Subject to Revision. October 31, 1986.

26. Aggradation and Degradation of Alluvial Fan Deposits, 1965-1986, Colorado River, Grand Canyon National Park, Arizona, by Jack C. Schmidt and Julia B. Graf. Draft Report, November 1986.

27. Aggradation and Degradation of Alluvial Sand Deposits, 1965-1986, Colorado River, Grand Canyon National Park, Arizona by Jack C. Schmidt and Julia B. Graf. Final Report, March 1987.

28. Topographic Surveys of Selected Sandy Beaches along the Colorado River in the Grand Canyon National Park--Draft. Glen Canyon Dam Environmental Study, by Ron Ferrari, Bureau of Reclamation, Durango Projects Office. November 1986.

29. Sandy Beach Area Survey Along the Colorado River in the Grand Canyon National Park, by Ronald Ferrari. Executive Summary, Glen Canyon Environmental Studies, Durango Projects Office, Bureau of Reclamation. December 1986.

30. The Rapids and Waves of the Colorado River, Grand Canyon, Arizona, by Susan Werner Kieffer, U.S. Geological Survey, Flagstaff, Arizona 86001. Preliminary report submitted for review on October 31, 1986.

31. Sediment Data Collection and Analysis for Five Stations on the Colorado River from Lees Ferry to Diamond Creek, Executive Summary, by Ernest L. Pemberton, Glen Canyon Environmental Studies. October 27, 1986.

32. Trends in Selected Hydraulic Variables for the Colorado River at Lees Ferry and near Grand Canyon, Arizona--1922-1984. U.S. National Park Service. Final Draft, by Durl E. Burkham. October 17, 1986.

33. Debris Flows from Tributaries of the Colorado River, Grand Canyon National Park, Arizona, Draft Report, by R. H. Webb, P. T. Pringle, and G. R. Rink. September 11, 1986.

34. Debris Flows from Tributaries of the Colorado River, Grand Canyon National Park, Arizona, Executive Summary, by R. H. Webb, P. T. Pringle and G. R. Rink. October 14, 1986.

35. Sediment Transport and River Simulation Model, Technical Draft Report, by Curtis J. Orvis and Timothy J. Randle, Bureau of Reclamation. April 1986.

36. Sediment Transport and River Simulation Model. Executive Summary, by Curtis J. Orvis and Timothy J. Randle, Hydraulic Engineers, Bureau of Reclamation, Denver, Colorado. November 1986.

37. Sediment Transport and River Simulation Model, Final Report, by Curtis J. Orvis and Timothy J. Randle, Hydraulic Engineers, Bureau of Reclamation, Denver, Colorado. January 1987.

38. Results and Analysis of Stars Modeling Efforts of the Colorado River in Grand Canyon--Draft by Timothy J. Randle and Ernest L. Pemberton. October 31, 1986.

39. Results and Analysis of Stars Modeling Efforts of the Colorado River in Grand Canyon. Executive Summary, by Timothy J. Randle, Bureau of Reclamation, and Ernest L. Pemberton, Consulting Engineer. November 1986.

40. Results and Analysis of Stars Modeling Efforts of the Colorado River in Grand Canyon, Final Report, by Timothy J. Randle and Ernest L. Pemberton. February 1987.

41. Colorado River Storage Project Constraints and the Operation of Glen Canyon Dam, Arizona, Draft Report, by David L. Wegner, Glen Canyon Environmental Studies, P.O. Box 1811, Flagstaff, Arizona 86002. January 1987.

42. Colorado River Water Law: Its Development and Impact on the Operations of Glen Canyon Dam, Draft Report, by David L. Wegner, Grand Canyon Study Manager. December 1986.

43. Annotated Outline Sediment and Hydrology Subteam Report. Glen Canyon Environmental Studies. January 30, 1987.

44. Sediment and Hydrology Draft Subteam Report. January 30, 1987. Bureau of Reclamation, Salt Lake City, Utah.

45. Biological Subteam Draft Report. January 30, 1987. Bureau of Reclamation, Salt Lake City, Utah.

46. Recreation Subteam Draft Report. February 18, 1987. Bureau of Reclamation, Salt Lake City, Utah.

47. A Synopsis of the History of Recreational River Running on the Colorado River in Grand Canyon

National Park, by Lauren Lucas, Glen Canyon Environmental Studies. February 4, 1987.

48. Longitudinal-Vertical Hydrodynamics and Transport with Chemical Equilibria for Lake Powell and Lake Mead, by John Eric Edinger and Edward M. Buchak, J. E. Edinger Associates, Inc., Wayne, Pennsylvania, and David H. Merritt, Engineering and Research Center, Bureau of Reclamation, Denver, Colorado. July 1983.

49. Development, Verification, and Use of Methods to Model Chemical and Thermal Processes for Lakes Mead and Powell. **Phase IIIa**. Attachment. Computed Weekly Circulation 1974. Prepared for United States Department of the Interior, Bureau of Reclamation, Engineering and Research Center, P.O. Box 25007, Denver, Colorado 80225. Prepared by Edward M. Buchak and John Eric Edinger, J. E. Edinger Associates, Inc., 37 West Avenue, Wayne, Pennsylvania 19087. **November 28, 1982**.

50. Laterally Averaged Reservoir Model--Lake Powell and Mead (LARMPM) Glossary of Variables. Development, Verification, and Use of Methods to Model Chemical and Thermal Processes for Lakes Mead and Powell. **Phase V**. Prepared for United States Department of the Interior, Bureau of Reclamation, Engineering and Research Center, Denver, Colorado 80225. Prepared by Edward M. Buchak and John Eric Edinger, J. E. Edinger Associates, Inc., 37 West Avenue, Wayne, Pennsylvania 19087. **November 8, 1983**.

51. Laterally Averaged Reservoir Model--Lake Powell and Mead (LARMPM) Input Data Description. Development, Verification, and Use of Methods to Model Chemical and Thermal Processes for Lakes Mead and Powell. **Phase V**. Prepared for United States Department of the Interior, Bureau of Reclamation, Engineering and Research Center, Denver, Colorado 80225. Prepared by Edward M. Buchak and John Eric

Edinger, J. E. Edinger Associates, Inc., 37 West Avenue, Wayne, Pennsylvania 19087. **October 12, 1983.**

52. Development, Verification, and Use of Methods to Model Chemical and Thermal Processes for Lakes Mead and Powell. **Phase I.** Model Evaluation and Data Analysis. Prepared for United States Department of the Interior, Bureau of Reclamation, Engineering and Research Center, Denver, Colorado 80225. Prepared by Edward M. Buchak and John Eric Edinger, J. E. Edinger Associates, Inc., 37 West Avenue, Wayne, Pennsylvania 19087. **April 1982.**

53. Development, Verification, and Use of Methods to Model Chemical and Thermal Processes for Lakes Mead and Powell. **Phase II.** Analysis and Development of Carbonate-Bicarbonate Chemical Subroutine. Prepared for United States Department of the Interior, Bureau of Reclamation, Engineering and Research Center, Denver, Colorado 80225. Prepared by John Eric Edinger, Ph.D., and Edward M. Buchak, J. E. Edinger Associates, Inc., 37 West Avenue, Wayne, Pennsylvania 19087, and Joseph S. Norton, Ford, Thornton and Norton Assoc. Ltd., P.O. Box 927, Vicksburg, Mississippi 39180. **June 28, 1982.**

54. Development, Verification, and Use of Methods to Model Chemical and Thermal Processes for Lakes Mead and Powell. **Phase IV.** Lake Powell High and Low Level Comparative Simulations. Prepared for United States Department of the Interior, Bureau of Reclamation, Engineering and Research Center, P.O. Box 25007, Denver, Colorado 80225. Prepared by John Eric Edinger, Ph.D., and Edward M. Buchak, J. E. Edinger Associates, Inc., 37 West Avenue, Wayne, Pennsylvania 19087, and Joseph S. Norton, Ford, Thornton and Norton Assoc. Ltd., P.O. Box 927, Vicksburg, Mississippi 39180. **June 28, 1982.**

55. Development, Verification, and Use of Methods to Model Chemical and Thermal Processes for Lakes

Mead and Powell. **Phase IV.** Lake Powell High and Low Level Comparative Simulations. Prepared for United States Department of the Interior, Bureau of Reclamation, Engineering and Research Center, P.O. Box 25007, Denver, Colorado 80225. Prepared by John Eric Edinger and Edward M. Buchak, J. E. Edinger Associates, Inc., 37 West Avenue, Wayne, Pennsylvania 19087. **August 16, 1983**.

56. Development, Verification, and Use of Methods to Model Chemical and Thermal Processes for Lakes Mead and Powell. **Phase IIIB**. Lake Powell High and Low Level Comparative Simulations. Prepared for United States Department of the Interior, Bureau of Reclamation, Engineering and Research Center, P.O. Box 25007, Denver, Colorado 80225. Prepared by John Eric Edinger and Edward M. Buchak, J. E. Edinger Associates, Inc., 37 West Avenue, Wayne, Pennsylvania 19087. **August 16, 1983**.

57. Development, Verification, and Use of Methods to Model Chemical and Thermal Processes for Lakes Mead and Powell. **Phase IIIb**. Lake Mead LARM Setup, Verification, and Results and Analysis of Surface Discharge Case. Prepared for United States Department of the Interior, Bureau of Reclamation, Engineering and Research Center, P.O. Box 25007, Denver, Colorado 80225. Prepared by John Eric Edinger and Edward M. Buchak, J. E. Edinger Associates, Inc., 37 West Avenue, Wayne, Pennsylvania 19087. **June 20, 1983**.

58. Development, Verification, and Use of Methods to Model Chemical and Thermal Processes for Lakes Mead and Powell. Lake Mead **Phase IIIb** Chemistry Studies. Prepared for United States Department of the Interior, Bureau of Reclamation, Engineering and Research Center, P.O. Box 25007, Denver, Colorado 80225. Prepared by John Eric Edinger and Edward M. Buchak, J. E. Edinger Associates, Inc., 37 West Avenue, Wayne, Pennsylvania 19087. **July 11, 1983**.

59. Development, Verification, and Use of Methods to Model Chemical and Thermal Processes for Lakes Mead and Powell. **Phase IIIa**. Lake Powell LARM Setup, Verification, and Results. Prepared for United States Department of the Interior, Bureau of Reclamation, Engineering and Research Center, P.O. Box 25007, Denver, Colorado 80225. Prepared by Edward M. Buchak and John Eric Edinger, J. E. Edinger Associates, Inc., 37 West Avenue, Wayne, Pennsylvania 19087. **November 28, 1982**.

60. Glen Canyon Environmental Studies Draft Report. U.S. Department of the Interior, Bureau of Reclamation, National Park Service, Fish and Wildlife Service. July 1987.

TECHNICAL REVIEW COMMENTS ON GCES

National Park Service Review Comments on the Glen Canyon Environmental Studies. From Superintendent, Grand Canyon. To Project Manager, Glen Canyon Dam Environmental Studies. January 20, 1987.

Review of draft technical report, Glen Canyon Environmental Studies--BR. From Field Supervisor. To Dave Wegner, Study Manager, GCES, Bureau of Reclamation, Flagstaff, Arizona. January 8, 1987.

Boating Accidents at Lees Ferry: A Boater Survey and Analysis of Accident Reports by Gary Traub, U.S. Coast Guard (G-BP-1). December 12, 1986.

A brief review of the Draft Report and Appendix, "Glen Canyon Dam Releases and Downstream Recreation: An Analysis of User Preferences and Economic Values." December 15, 1986. From Robert K. Lanky, Chief, Division of Planning Technical Services.

Review Comments--Colorado River Storage Project Constraints and the Operation of Glen Canyon Dam, Arizona (David L. Wegner). From Superintendent, Grand Canyon. To Study Manager, Glen Canyon Environmental Studies.

Review Comments--Colorado River Storage Project Constraints and the Operation of Glen Canyon Dam, Arizona (David L. Wegner). From Superintendent, Grand Canyon. To Study Manager, Glen Canyon Environmental Studies.

Waring and Stevens Glen Canyon Study Critique. R. Roy Johnson. December 9, 1986.

Anderson and Ruffner Glen Canyon Study Critique. R. Roy Johnson. December 9, 1986.

Pucherelli Glen Canyon Study Critique. R. Roy Johnson. December 9, 1986.

Bryan Brown's review of Larry Stevens' and Gwen Waring's final report. July 28, 1986.

Laurie J. Vitt's review of the herpetofaunal study. November 20, 1986.

Martin M. Karpiscak's review of "Impact of Post-Dam Flows on Western Honey Mesquite and Catclaw Acacia in Grand Canyon, Arizona." December 2, 1986.

J. Collins' review of the draft technical report, "Herpetofauna in riparian habitats along the Colorado River in Grand Canyon National Park" by P. L. Warren and C. R. Schwalbe. December 1, 1986.

Lewis H. Stolzy's review of "Effects of Post-Dam Flooding on Riparian Substrates, Vegetation, and Invertebrate Populations in the Colorado River Corridor in Grand Canyon, Arizona" by Stevens and Waring. November 20, 1986.

T. T. Kozlowski's review of "The Effects by Recent Flooding on Riparian Plant Establishment in Grand Canyon" by Waring and Stevens. November 24, 1986.

Michael Pucherelli's review of a report prepared by Nancy Brian. March 17, 1986.

Nancy Brian's review of a report prepared by Michael Pucherelli. March 19, 1986.

Donal D. Hook's review on the Waring and Stevens report on revegetation along the Colorado River. December 2, 1986.

Review comments from Beth Manna, Martha Hahn-O'Neill, C. Hunter, P. R. Krausman, and R. D. Ohmart of a report entitled, "Nesting Habitat Relationships of Obligate Riparian Birds Along the Colorado River, Arizona."

Timothy J. Randle's review of the report "The Rapids and Waves of the Colorado River, Grand Canyon, Arizona" by Susan W. Kieffer. January 2, 1987.

Ernest L. Pemberton's review of the report "The Rapids and Waves of the Colorado River, Grand Canyon, Arizona" by Susan W. Kieffer. December 3, 1986.

Ernest L. Pemberton's review of the report "Sandy Beach Area Survey Along the Colorado River in the Grand Canyon National Park. December 12, 1986.

T. C. Pierson's review of the report "Debris flows from Tributaries of the Colorado River in Grand Canyon by R. H. Webb, P. T. Pringle, and G. R. Rink. September 11, 1986.

Edward M. Hallenbeck's review of "Evaluation of Varied Flow Regimes on Aquatic Resources of Glen and Grand Canyons." January 8, 1987.

Charles Liston's review of "Cladophora Glomerata and Its Diatom Epiphytes in the Colorado River Through Glen and Grand Canyons: Distribution and Desiccation Tolerance." January 12, 1987.

Gerald A. Cole's review of L. R. Haury's paper on the "Zooplankton of the Colorado River" (GCES Report No. B-10). January 11, 1987.

Lynn R. Kaeding's review comments on the GCES draft technical report. December 16, 1986.

Acting Field Supervisor's review of the Colorado River Water Temperature Modeling Below Glen Canyon Dam by Ron Ferrari. December 3, 1986.

APPENDIX B

BUREAU OF RECLAMATION DOCUMENTS

1. Grand Canyon Dorries, Inc., et al., Appellants v. Ronald H. Walker, Director, National Park Service, et al., Appellees, No. 73-1853

2. Letter, Bureau of Reclamation (BOR) Commissioner Robert M. Broadbent to BOR Salt Lake City Regional Director, December 6, 1982

3. Letter, BOR Salt Lake City Regional Director Clifford I. Barrett to BOR Commissioner Robert M. Broadbent, April 15, 1983, "Exhibit One"

4. Internal BOR Memo, July 18, 1983, "Exhibit Two"

5. Letter, BOR Glen Canyon Study Manager Dave Wegner to Sheila David, National Research Council, October 24, 1986

6. Letter, BOR Salt Lake City Regional Director Clifford I. Barrett to BOR Commissioner, December 12, 1983

7. Letter, BOR Acting Commissioner to BOR Salt Lake City Regional Director, January 30, 1984, "Exhibit Three"

8. BOR Document, "Agency Priorities for the Glen Canyon Environmental Studies"

9. BOR Document, "Decision Process Used to Determine Probable Studies for the Glen Canyon Environmental Studies Effort"

10. BOR Document, "Glen Canyon Integration Team Biographical Sketches"

11. BOR Document, "Glen Canyon Environmental Studies Review Process"

1

GRAND CANYON DORRIES, INC., ET AL., APPELLANTS V. RONALD H. WALKER, DIRECTOR, NATIONAL PARK SERVICE, ET AL., APPELLEES, NO. 73-1853

GRAND CANYON DORRIES, INC., et al.,
Appellants,
v.
RONALD H. WALKER, Director, National
Park Service, et al., Appellees.

No. 73-1853.

United States Court of Appeals,
Tenth Circuit.
Aug. 20, 1974

Operators of commercial float trips on Colorado River below Glen Canyon dam brought action against various federal officials seeking declaratory and injunctive relief concerning discharge of water from dam. The United States District Court for the District of Utah, Aldon J. Anderson, J., denied relief, and plaintiff appealed. The Court of Appeals, Seth, Circuit Judge, held that even if contractual obligations arose from plaintiffs' concession licenses injunctive relief was not available in a contract action and that application of National Environmental Policy Act to ongoing operation of dam was not ripe for judicial determination in absence of any administrative determination on the matter.

Affirmed.

1. United States 74(7)

Even if there were implied in concession licenses granted operators of commercial float trips on Colorado River below Glen Canyon dam contractual rights concerning release of water from dam,

---

1. The maximum penalty which could have been imposed upon the defendant was a prison term of not more than 15 years and a fine of not more than $25,000, or both. 21 U.S.C. § 841(b)(1)(A). the three-year special parole term was required by 21 U.S.C. § 841(b)(1)(A).

injunctive relief, in nature of specific performance, was not available against the government in the contract action; operator's remedy lay in an action for damages before the appropriate tribunal.

2. Health and Environment 25.5

Although subject of retroactive application of the National Environmental Policy Act is not a matter entirely within agency discretion, it is a matter which must be determined in the first instance by the agency. National Environmental Policy Act of 1969, § 2 et seq., 42 U.S.C.A. § 4321 et seq.

3. Health and Environment 25.10

Issue whether National Environmental Policy Act required preparation of environmental impact statement in connection with continuing operation of Elen CanynL dam was not ripe for deci3ion, in suit by operators of commercial float trips on the Colorado River below the dam complaining that intermittent reduction in volume of water released interfered with safe conduct of float trips, where neither the Department of the Interior nor any of its subordinate agencies had ever considered, let alone decided, whether the National Environmental Policy Act applied to the continuing operation of the dam. National Environmental Policy Act of 1969, §§ 2 et seq., 102, 42 U.S.C.A. §§ 4321 et seq., 4332.

Constance K. Lundberg, Salt Lake City, Utah (Owen Olpin, Salt Lake City, Utah, with her on the brief), for appellants.

Robert L. Klarquist, Atty., Dept. of Justice, Washington, D.C. (Wallace H. Johnson, Asst. Atty. Gen., C. Nelson Day, U.S. Atty., and George R. Hyde, Atty., Dept. of Justice, with him on the brief), for appellees.

Before SETH and HOLLOWAY, Circuit Judges, and TALBOT SMITH,* District Judge.

SETH, Circuit Judge.

The several appellants are operators of commercial float trips on the Colorado River below Glen Canyon Dam. They appeal the dismissal of their action for declaratory and injunctive relief against the Secretary of the Interior and various named officials of the Bureau of Reclamation and the National Park Service. The gist of their complaint is that the ongoing operation of Glen Canyon Dam and particularly the intermittent reductions in the volume of water released below the dam interfere with the safe conduct of the plaintiffs' float trips. Such interference is claimed to be a continuing breach of the contractual rights allegedly implied in the concession licenses which the plaintiffs have been granted by the National Park Service. The plaintiffs' more serious contention, however, is that the continuing operation of Glen Canyon Dam is a major federal action "significantly affecting the quality of the human environment," and therefore the National Environmental Policy Act (NEPA) requires the preparation of a detailed environmental impact statement. 42 U.S.C. § 4321 et seq.

[1] Considering the contractual claims first, we find that the plaintiffs are in effect seeking specific performance of the Government's alleged obligations. Even if it were assumed that such obligations do arise from the plaintiffs' concession licenses, the court could not grant the relief requested. As we remarked in National Helium Corp. v. Morton, 486 F.2d 995 (10th Cir.):

> "We have fully considered the Supreme Court cases which prohibit injunctive relief against governmental officers on account of their upholding the rights of the government arising

* Of the Eastern District of Michigan, sitting by designation.

under a contract. Such a suit is distinguished by the Supreme Court from actions seeking compensation for an alleged wrong and are regarded as actions against the sovereign to which there has not been consent."

Injunctive relief against the Government is not available in a contract action such as this, and the plaintiffs' remedy lies in an action for damages before the appropriate tribunal. See Larson v. Domestic and Foreign Commerce Corp., 337 U.S. 682, 69 S.Ct. 1457, 93 L.Ed. 1628.

The potential application of NEPA to the ongoing operation of a dam planned and constructed prior to passage of the Act could be a substantial issue, but it is not properly before us.

It is readily apparent that both NEPA and the Guidelines promulgated thereunder rely heavily on agency action to achieve their stated objectives. While the action itself is mandatory, the considerations and objectives are stated only in general terms. Thus it is also apparent that great reliance is placed on the proper exercise of administrative discretion and the good faith efforts of each agency. For this reason the agencies are given latitude in weighing the environmental factors to be considered in their decisions. As the provisions in the Guidelines and the Departmental Manual illustrate, this latitude exists also with respect to projects undertaken before passage of the Act.

[2] It is obvious that the subject of the retroactive application of NEPA is not a matter entirely within agency discretion. What we do recognize is that the matter must be determined in the first instance by the agency undertaking or operating the project. It is precisely this administrative determination which has not been made in this case, and for this reason the basic issue is not presented, and we must affirm the dismissal.

[3] In reviewing the record we find neither allegation nor evidence therein that the Department of the Interior or any of its subordinate agencies has ever considered, let alone decided, whether NEPA applies to the continuing operation of Glen Canyon Dam. Nor is there allegation or evidence that the plaintiffs have requested the Department to consider the question. During oral argument the plaintiffs alluded to a number of informal conversations with various Department officials. Even if the record were to reflect these conversations, they would still be insufficient to establish the Department's position.

At this point the court and even the plaintiffs can only speculate at the position the Department might ultimately take. It is possible that after reviewing the situation the Department might decide that an impact statement is feasible and necessary, and that it is practicable to comply fully with section 102. On the other hand, it may decide that by this time it would be unreasonable and impracticable to reconsider the operation. In any event whatever course the Department takes, judicial review must await its action. It is the Department which must in the first instance assemble and weigh the factors relevant to whether and how NEPA should be applied to the operation of the dam. Only which it has exercised the broad discretion conferred by the Act and the Guidelines will the issues be ripe for judicial determination.

We have considered the cases arising under NEPA in this Circuit and many of those arising in other Circuits. In every instance there is specific agency action or a decision that has been the subject for review, even if it was only a determination that the particular action was not subject to the requirements of NEPA. See, for example, Wyoming Outdoor Coordinating Council v. Butz, 484 F.2d 1244 (10th Cir.). We have no such action or decision before us to review in this case.

The problem before us can appropriately be characterized as one of ripeness. We believe this case closely parallels those in which the agency action for which review is sought is not sufficiently formalized to be appropriately considered by the courts. The Supreme Court expressed the controlling considerations in Abbott Laboratories v. Gardner, 387 U.S. 136, 87 S.Ct. 1507, 18 L.Ed.2d 681:

> "Without undertaking to survey the intricacies of the ripeness doctrine it is fair to say that its basic rationale is to prevent the courts, through avoidance of premature adjudication, from entangling themselves in abstract disagreements over administrative policies, and also to protect the agencies from judicial interference until an administrative decision has been formalized and its effects felt in a concrete way by the challenging parties."

Although the facts of this case differ substantially from those in Abbott Laboratories, the considerations set forth therein apply equally well here. Judicial action at this point, without a decision by the Department whether NEPA will be applied would be premature and would perhaps frustrate the very purposes of the Act. The opportunity should be first afforded the Department to utilize the procedures set forth in its departmental manual and to make its initial independent determination of the extent to which NEPA should be applied. Until that determination has been made, or the Department has in some formalized manner indicated its refusal to make it, the case is inappropriate for judicial consideration.

Affirmed.

2

LETTER, BUREAU OF RECLAMATION (BOR)
COMMISSIONER ROBERT M. BROADBENT TO BOR
SALT LAKE CITY REGIONAL DIRECTOR,
DECEMBER 6, 1982

United States Department of the Interior

BUREAU OF RECLAMATION
~~WATER AND POWER RESOURCES SERVICE~~

WASHINGTON, D.C. 20240

GLEN CANYON
RECEIVED ... SSB
OFFICIAL FILE COPY
DEC 12 '82

Date	Initials	To
		150

Subs. Corresp. ____
Date Ans'd ____

IN REPLY REFER TO: 150

742

DEC 6 1982

Memorandum

To: Regional Director, Salt Lake City, Utah

From: Commissioner

Subject: Uprating and Studies of Operational Alternatives--Glen Canyon Powerplant--Colorado River Storage Project (CRSP)

We have reviewed the proposed final Environmental Assessment/Finding of No Significant Impact (EA/FONSI) transmitted with your letter of October 27, 1982.

While we concur with your analysis of the potential environmental consequences of the proposed uprating and alternative courses of action, any decision by you to initiate the uprating program should take into account the following guidance:

1. The evidence presented indicates that the uprated generators are still economically viable if used only during maintenance activities or during emergencies and would provide greater flexibility even without any changes in current operating criteria. Consequently, the additional plant capacity resulting from the uprating will be restricted to present maximum water releases (31,500 ft ^{3}/s) from the powerplant. This restriction on operation of the uprated generators will remain in effect until a decision process with appropriate NEPA compliance, has been completed on a long-term operating criteria for Glen Canyon Powerplant.

2. Studies will be undertaken on the current operation of Glen Canyon Dam to see how the present flow patterns impact upon the total riverine environment in the Grand Canyon and how various low-flow periods affect rafting and the fisheries resources in the river. We anticipate that these studies will evaluate various low-flow patterns, such as, 1,000, 3,000, 4,000, 5,000, and/or 8,000 ft ^{3}/s. We also anticipate that you will evaluate fluctuating patterns as well as periodic high-flow periods to see if there is a point where high flows materially affect beach erosion, recreation, and fisheries.

To: Regional Director, Salt Lake City, Utah

We concur with your initiation of the following studies:

a. Sediment transport-beach erosion studies below Glen Canyon Dam through the Grand Canyon.

b. Biological studies to determine what impacts are occurring based on the above sediment transport studies.

c. Environmental studies of the effects of the present and historic operation of Glen Canyon Dam on the vegetation wildlife, fishery, recreation, and other environmental resources of the Grand Canyon.

These studies are to be conducted as a cooperative effort with the National Park Service (NPS), with the Bureau providing the funding, and being the lead agency. Other appropriate Federal and non-Federal agencies should also be requested to participate with the NPS and the Bureau in the above studies. We will need the assistance of the Fish and Wildlife Service in certain of these studies and a copy of this letter is being sent to the Director of the Fish and Wildlife Service to alert that agency of our decision and the need for its assistance.

3. In conjunction with these studies, you should undertake an analysis of potential alternative operating criteria, consistent with CRSP requirements, to see if there are feasible alternative to our present operating criteria that will address the many concerns raised on our uprating environmental assessment. Should alternatives that meet the above criteria be identified, an environmental impact statement should be prepared. This would lead to a decision process to determine appropriate long-term operating criteria for Glen Canyon Powerplant.

Robert N. Broadbent

Concur:

Mary Lou Grier — 12/7/82

ACTING Director, National Park Service — Date

G. Ray Arnett — 12/7/82

Assistant Secretary for Fish and Wildlife and Parks — Date

David L. Houston — 12/7/82

Deputy Assistant Secretary - Land and Water Resources — Date

3

LETTER, BOR SALT LAKE CITY REGIONAL DIRECTOR CLIFFORD I. BARRETT TO BOR COMMISSIONER ROBERT M. BROADBENT, APRIL 15, 1983, "EXHIBIT ONE"

APR 15 1983

IN REPLY REFER TO: UC-431
651.

Memorandum

To: Commissioner

From: Regional Director

Subject: Program of Uprating Generators at Glen Canyon Powerplant and Studies of Environmental Impacts in the Grand Canyon

We have awarded a contract for the generator upratings at Glen Canyon Powerplan and are proceeding with environmental studies of the Grand Canyon as discussed in your letter of December 6, 1982. These studies are being undertaken to determine how the current operation of Glen Canyon Dam and the resulting flow patterns affect the total riverine environment in the Grand Canyon and how low flow periods affect rafting and the fishery resources in the river.

Attached is a draft program flag action document which displays the significant studies, timing, and cost in relationship to the actual uprate program.

There are three basic components into which our overall effort has been divided; these components consist of a sediment transport and beach erosion study, a biological analysis, and a recreational study. These three components, althoug being handled separately, technically are significantly interrelated. Because of the high degree of interrelationships especially in regard to canyon access for basic data, we are planning to assign a full time study manager to ensure maximum efficiency in data collection and that the objective of the program is met.

Work on the sediment transport component has been coordinated by this office and involves the Sedimentation Branch; E&R Center, the Tucson District Office, U.S. Geological Survey, and our Durango Projects Office. The U.S. Geological Survey will be the primary data collection group and should commence field work in June 1983. It is expected that the data collection effort will continue for about 1 year at a cost of about $750,000. Analysis of the samples together with calibration of a sediment transport model and actual modeling of the canyon will be accomplished by the E&R Center which will bring the total cost of the sediment transport component to about $1 million.

The biological component is being coordinated with the National Park Service, Fi and Wildlife Service, and the Arizona Department of Game and Fish. Although not totally identified to date, the biological studies are expected to continue for about 2 years at a cost of about $200,000 per year.

EXHIBIT ONE

The recreation component is being coordinated through the National Park Service with input from representatives of the Western River Guides Association. It is anticipated that an analysis of the economic value of the recreational resource in the Grand Canyon will be conducted in conjunction with an evaluation of the effect of different minimum flow criteria. These studies are expected to cost about $100,000.

As you can see, the estimated cost of these studies could be as much as $2 million. The spending of revenues in this magnitude will receive much scrutiny from the power customers. We believe we have sufficient data to defend these studies. We will continue to commit personnel and resources, including contracts in a timely manner unless directed otherwise. If you have concerns please let us know.

Clifford I. Barrett

Attachment

bc: UC-431, UC-320

LBR:JNewman:sp:3/31/83

4

INTERNAL BOR MEMO, JULY 18, 1983, "EXHIBIT TWO"

Date: July 18, 1983
Discuss With: WO-700, E&RC
Appropriation Code: UC-750

Issue: What should be the objectives and scope of the environmental studies being conducted on the Colorado River below Glen Canyon Dam now that the unexpectedly large releases have probably considerably altered the hydrologic regime and the biological communities in the Grand Canyon?

Background: During the review of the environmental assessment for the Glen Canyon Powerplant uprating program, many concerns were voiced regarding the environmental impacts on the Grand Canyon that result from the present operation of the powerplant and impacts that will result from releases from the uprated powerplant. The Commissioner, in a December 6, 1982 letter, directed the Regional Director, Salt Lake City, to undertake sedimentation, biological and environmental studies directed towards determining where there are feasible, alternative operating criteria for the power plant that will lessen or eliminate adverse impacts.

Recent flood control releases from Glen Canyon Dam have resulted in flows in the Canyon of up to three times the maximum powerplant release. Preliminary indications are that there may have been considerable adverse impacts to the camping beaches and riparian vegetation from these high, sustained flows.

The UCRSP is currently full and there is a good chance that there will be surplus waters in the Upper Basin for the next several years, at least until the Upper Basin States begin to fully utilize their compact allotment of water, which could take several decades. Thus, there appears to be the potential for a repeat of the 1983 flooding on the Colorado River.

Alternatives:

1. The environmental studies should be continued under the original mandate, i.e. study the impacts of powerplant releases only.
2. The predictive studies should consider a scenario where Glen Canyon Dam spills, say every 10 years.
3. The studies should be terminated because the impacts of powerplant releases are probably insignificant when compared against impacts from periodic spillway floods.
4. The studies should proceed with the assumption that the operational criteria for Glen Canyon Dam will be revised to considerably minimize the risk of future spillway floods, in which case, the environmental studies should be expanded to include the collection of base line data for evaluating the future impacts of the new operational era.

Recommendations:

It is recommended that as soon as the releases from Glen Canyon Dam are back down to powerplant flows, an inspection trip of the Canyon be made by an inter-agency team of engineers, biologists and recreationalists to assess what the impacts of the high flow releases have been. Based on their findings and their judgements about the value of future studies, they can come up with recommendations on how and whether to continue the environmental studies. These conclusions and recommendations can be written up into an issues and options paper that would be sent to the Commissioner for final decision.

5

LETTER, BOR GLEN CANYON STUDY MANAGER DAVE WEGNER TO SHEILA DAVID, NATIONAL RESEARCH COUNCIL, OCTOBER 24, 1986

United States Department of the Interior

BUREAU OF RECLAMATION
~~UPPER COLORADO REGIONAL OFFICE~~ Glen Canyon Environmental Studies
~~P.O. BOX 11568~~ P.O. Box 1811
~~SALT LAKE CITY, UTAH 84147~~ Flagstaff, AZ 86002

REPLY
REFER TO: UC410

October 24, 1986

Ms. Sheila David
National Research Council
Water Science and Technology Board
2101 Constitution Avenue
Washington, D.C. 20418

Dear Sheila:

Enclosed is the information that you requested as Item 5 and 6 in your September 26, 1986 Memorandum to this office. Since these are copies of actual documents that were prepared for the Glen Canyon Environmental Studies, a bit of explanation is required.

The Glen Canyon Environmental Studies were initiated in the December 1982 letter from Mr. Broadbent to the Bureau of Reclamation. As you will recall from that initial letter, the direction was based on the two broad based objectives:

1. Evaluation of the short-term, present flow patterns, impact of the operation of Glen Canyon Dam on the total riverine environment in the Grand Canyon.

2. Evaluation of the impact of the historic operation of Glen Canyon Dam (ie. long-term) on the riverine environment of the Grand Canyon.

As we discussed at our September 24-25, 1986 meeting with the Glen Canyon Environmental Studies Review Committee, a great deal of expansion has been provided to that original directive. What I have included in this letter to you are several of the early documents/letters that were developed that outlined the original direction of the Glen Canyon Environmental Studies.

Exhibit One - Initial Identification of Main Study Components.

Prior to the high water releases in 1983, this memorandum was sent by the Regional Director of the Bureau of Reclamation to the Commissioner in Washington defining the major areas of the study effort. Note, that at this date only the major areas of the studies were identified: Sediment Transport and Beach Erosion Biological Analysis; and, Recreation Studies. These broad areas were defined based on the December 1982 directive and prior discussions with the National Park Service and the other cooperating agencies.

Beginning in May 1983 and continuing through the summer, Lake Powell rose and eventually required the necessity of releasing additional water from Glen Canyon Dam through both the river outlet tubes and the spillways. Based upon this obvio perturbation to the environmental system and the major changes that were occurrin throughout the entire Upper Colorado River Basin, a concern was raised as to the necessity for the continuance or expansion of the Glen Canyon Environmental Studi effort.

Exhibit Two - Redefinition of the Glen Canyon Environmental Studies Objectives.

To address the question of the direction and objectives of the Glen Canyon Environmental Studies, the Bureau revisited the original objectives and tried to assess the impact that the high water releases of 1983 had on those overall goals. Upon review of this document, you will be able to discern that the recommendations were:

1. Conduct a multi-agency inspection trip of the Grand Canyon to determine the impact of the 1983 high flow releases.

2. Determine the value of future Grand Canyon impact studies.

3. Develop recommendations on how and whether to continue the environmental studies.

Based on these recommendations, a multi-agency trip was conducted in the Grand Canyon during September of 1983. The flow level in the Canyon at that time was approximately 30,000 cfs. Included on that inspection trip were representatives from:

* Bureau of Reclamation
* National Park Service
* U.S. Geological Survey
* U.S. Fish & Wildlife Service
* Arizona Game & Fish
* Commercial River runners
* Consultants

This group of 22 technically knowledgeable scientists included expertise in biology, recreation, sedimentation, hydrology, and operations of Glen Canyon Dam. During the course of this 10 day river trip, many discussions were held regarding the determination of the 1983 high water impacts and the types of studies that could be initiated in the Grand Canyon to still address the original objectives of the 1982 directive. Based on the discussions that were held in the Canyon, Exhibit Three was developed.

Exhibit Three - November 1983 Status of the Glen Canyon Environmental Studies.

This memorandum addresses the findings and recommendations from the September 1983 inspection trip in the Grand Canyon and some initial estimates of the cost of completing the project. Attached to Exhibit Three is the Acting Commissioners recommendation for continuance of the Glen Canyon Environmental Studies.

Based upon the Commissioners Office direction, a series of meetings were initiated with each agency involved in the initial meetings to develop specific study plans and objectives. We have supplied you with the original Work Statements for the major studies under seperate cover. Concurrent with the development of the specific work plans, I developed a PROPLAN chart defining the major time scale and critical paths to completion of the effort. This PROPLAN chart is included as Exhibit Four.

The remainder of the early direction of the Studies was defined mainly in notes that were kept during meetings and discussions with the cooperating agencies.

e can provide those other notes if you think they will serve some purpose, owever they will take additional time to pull together and track down from all he associated agencies and groups.

f you require any addtional definition of the enclosed exhibits, please call e and we will be happy to clarify any questions or concerns. We are looking forward o the meetings at the South Rim in November.

Regards,

Dave Wegner

Dave Wegner
Grand Canyon Study Manager

closures
Exhibit One - April 15, 1983 Memorandum.
Exhibit Two - July 18, 1983 internal BOR Issue Statement.
Exhibit Three - January 30, 1984 Memorandum.
December 12, 1983 Memorandum.
Exhibit Four - PROPLAN chart.

6

LETTER, BOR SALT LAKE CITY REGIONAL DIRECTOR CLIFFORD I. BARRETT TO BOR COMMISSIONER, DECEMBER 12, 1983

United States Department of the Interior

BUREAU OF RECLAMATION
UPPER COLORADO REGIONAL OFFICE
P.O. BOX 11568
SALT LAKE CITY, UTAH 84147

REPLY
REFER TO
UC-410
20.1

DEC 12 1983

emorandum

o: Commissioner

rom: Regional Director

ubject: Status of the Glen Canyon Environmental Studies and the Potential Impact on the Grand Canyon

ver the last several months, representatives of the Upper Colorado Region nd other study members have been discussing and analyzing the future irection and magnitude of the Glen Canyon Environmental Studies. As a esult of the high flows of 1983 and the potential for additional months of ontinuous high releases from Glen Canyon, the study team conducted a econnaissance trip down the Grand Canyon in September. The objectives of e trip were to determine if the Grand Canyon environment was severely pacted by the 1983 high flows and to determine if the original study, as fined by your memorandum of December 6, 1982, should continue, terminate, be modified. As a result of the trip, the following conclusions were veloped:

The study team concluded that the high flows did not negate the need r the study. Therefore, the study should continue.

The high flows did not appear to cause as serious damage to the Grand nyon environment as was originally anticipated.

The occurrence of the high flows provided reconfirmation of the conclu- on set forth in the 1982 Environmental Assessment that the impact of the rating and rewind program would be negligible on the Grand Canyon vironment. The focus of the study should be directed at evaluating the pact of the overall Glen Canyon operating criteria and high controlled leases on the Grand Canyon ecosystem.

For a successful study to be completed, the sediment, biological, and creation data must be collected during a typical operations pattern. is may not be possible under the current operating constraints, and these ts of the study may have to be partially deferred for an appropriate riod of time.

Bureau is committed by your letter of December 6, 1982, to complete the dies prior to the full utilization of the uprated generators at Glen yon Dam. We anticipate that this study will be completed by October 30, 6, on schedule with the generator programming. In order to better define the coordination and monetary involvement that will be required to complete this study, an estimated budget and fiscal year breakdown was prepared. Two budget estimates were defined; one for completion of the study under the original time frame; and the second for completion of the study with a 1 year deferral into fiscal year 1987, to include alternative operating criteria and data analysis reports. The revised estimated budget is:

	FY 84, 85, 86	FY 87
A. SEDIMENTATION SUBTEAM		
1. U.S. Geological Survey	- $2,173,400	
2. Sediment Transport Consultant	- $ 80,000	
3. Bureau of Reclamation .		
a. E&R Center, Denver	- $ 73,000	
b. Durango Projects Office	- $ 20,000	
c. Upper Colorado Region	- $ 51,300	
d. Aerial Photography	- $ 50,000	
	$2,447,700	

	FY 84, 85, 86	FY 87
B. BIOLOGICAL SUBTEAM		
1. Fisheries Studies	- $373,050	(+35,610)
2. Terrestrial Studies	- $148,000	(+17,000)
3. Temperature and Backwater Surveys	- $ 70,000	
4. Bureau of Reclamation - Upper Colorado Region	- $ 20,000	
5. Fish and Wildlife Service Consultation	- $ 40,000	
6. E&R Center, Aerial Photography	- $ 60,000	
	$711,050	
C. RECREATION SUBTEAM		
1. Accident Survey	- $ 13,000	
2. Simulation Model	- $ 65,000	
3. CVM Survey and Collection	- $130,000	
4. National Park Service	- $ 4,000	
5. Bureau of Reclamation		
a. E&R Center	- $ 27,000	
b. Upper Colorado Region	- $ 80,000	
	$319,000	(+50,000)
D. COORDINATION		
1. Upper Colorado Region, Wegner		
a. salary (3 yrs.) and benefits (1.6)	- $130,000	(+45,000)
b. travel	- $ 30,000	(+2,000)
	$160,000	

E. TOTALS

1. Project as originally defined - $3,636,400
2. Project with 1 year addition - $3,795,300 (+4.4%)

These costs can be broken down by fiscal year as:

Fiscal year 1983 - $876,900 (already expended)
Fiscal year 1984 - $1,156,400
Fiscal year 1985 - $1,293,000
Fiscal year 1986 - $311,000
Fiscal year 1987 - $158,900

The total estimated study cost exceeds the initial estimate of $940,000 by a large margin. The reasons for the large increase in cost can be summarized as follows:

1. Timing and operating constraints

2. 1983 high water releases from Glen Canyon Dam.

3. Re-establishment of a new environmental baseline due to the high flows.

4. Inaccurate and incomplete initial cost estimates

a. Safety constraints requiring a doubling of manpower at each of the sediment measuring stations.

b. Prototype sediment sampling equipment required.

c. Operational constraints within the canyon.

d. No inclusion of BOR costs (±0.5 million) for manpower and equipment.

5. Inadequate communication between the BOR and the USGS.

We have addressed the problems of the increased costs, program management, and study coordination. We have established a position within the Upper Colorado Region to manage this study. David Wegner, UC-410, has been assigned as the Grand Canyon Study Manager and will be responsible for all program coordination and the preparation and completion of the study reports.

As a result of our investigations, we believe that the studies should proceed under the assumption that the operational criteria for Glen Canyon Dam will be revised to minimize the risk of spillway releases while accepting the possibility of occasional spills. Under this scenario, the environmental studies should be structured to include evaluation of the new environmental baseline conditions caused by the 1983 high flows, in addition to evaluation of the environmental impact of present operating criteria. These data would be used to evaluate future operational impact on the biological, recreation, and sediment components of the Grand Canyon system and to evaluate feasible alternatives to existing CRSP operating criteria.

Due to the significant increase in the total estimated cost of the study since its inception, we felt a need to so advise you. However, we are proceeding with the study as scheduled unless otherwise advised because of:

1. Commitment to the environmental and recreation comments that a study i being performed.

2. The need to complete these studies prior to the full utilization of th uprated generators now under contract.

3. Consistency with your letter of December 6, 1982.

If you have any questions, please inform this office or Dave Wegner, Grand Canyon Study Manager, at FTS 588-6084.

Clifford I. Barrett

7

LETTER, BOR ACTING COMMISSIONER TO BOR
SALT LAKE CITY REGIONAL DIRECTOR,
JANUARY 30, 1984, "EXHIBIT THREE"

United States Department of the Interior

BUREAU OF RECLAMATION
WASHINGTON, D.C. 20240

FEB 2 '84

Date	Initials
2-3	
2-3	DLW

Subs. Corres ___
Date Ans'd ___

IN REPLY REFER TO: 150

JAN 30 1984

Memorandum

To: Regional Director, Salt Lake City, Utah

From: Acting Commissioner

Subject: Approval to Continue the "Glen Canyon Environmental Studies and the Potential Impact on the Grand Canyon" Study Program

It has been over 1 year since approval was provided to you to undertake the subject study. During that time, many events have occurred and conditions contemplated in the study have radically changed making it appropriate for us to reevaluate the original study plan to determine whether or not study needs continue to exist. Our analysis shows that the study objectives discussed in our December 6, 1982, memorandum to you are still valid. Therefore, you should continue the studies, including the modifications and 1-year extension as described in your status report of December 12, 1983 (attached). However, we would like to point out that we are no longer in a "typical operations pattern" and probably never will be again, due to the fact that the reservoirs have been filled for the first time. Accordingly, any future studies should recognize both flood and drought condition operations.

We are pleased with your progress to date and feel you have designed an appropriate set of studies. If you have any questions, call Wayne Deason, Director, Office of Environmental Affairs, at 343-4991.

NOTICE: IF YOU DETACH ENCLOSURES PLEASE INSERT CODE NO. ___

K. A. Olson

Attachment

8

BOR DOCUMENT, "AGENCY PRIORITIES FOR THE GLEN CANYON ENVIRONMENTAL STUDIES"

AGENCY PRIORITIES FOR THE GLEN CANYON ENVIRONMENTAL STUDIES

Bureau of Reclamation

1° Restriction on the operation of the uprated generators at Glen Canyon Dam will remain in effect until a decision process with appropriate NEPA compliance has been completed on a long-term operating criteria for the Glen Canyon Powerplant

2° To undertake studies on current operation of Glen Canyon Dam to determine how present flow patterns impact the total riverine environment in the Grand Canyon, and specifically 1) how low-flow periods affect rafting and fishery resources and 2) how high-flow periods affect erosion, recreation and fisheries

3° Conduct studies as a cooperative effort with the National Park Service, with other Federal and non-Federal agencies requested to participate

4° Undertake an analysis of potential alternative operating criteria consistent with Colorado River Storage Project requirements to determine if feasible alternatives address concerns raised on the uprating environmental assessment

National Park Service

1° Existing Native Aquatic Organisms

2° Pre-dam Alluvial Deposits

3° Riparian Vegetation

4° Riparian Fauna

5° Existing Water Quality

6° Opportunities for River Running at Existing Levels and with Existing Character

7° Trophy Trout Fishery

Note: Critical elements for comprehensive research program to address these priorities include:

1) Hydrology and Sediment Transport
   - Verification and refinement of the predictive flow model
   - Evaluation of the erosion and sediment transport potential of various flow releases

National Park Service - Continued

2) Biology
   - Quantification of the effects of various flow regimes on the aquatic and terrestrial ecosystems of Grand Canyon
3) Visitor Access and Safety
   - Quantification of the effects of various flow regimes on visitor access and the safety of river users
4) Impact Mitigation
   - Identification of strategies for mitigation

U.S. Fish and Wildlife Service

1° To determine the potential impact of warming the Colorado River below Glen Canyon Dam on endangered species (Colorado Squawfish, *Ptychocheilus lucius* and Humpback Chub, *Gila cypha*) and proposed endangered species (Boneytail Chub, *Gila elegans* and Razorback Sucker, *Xyrauchen texanus*)

2° To determine the ecological needs of the endangered species in the Colorado River between Glen Canyon Dam and Lake Mead

3° To determine the methods for reducing or eliminating the known constraining factors of low water temperature and frequent water flow fluctuations on endangered species

4° To determine the relationship between mainstream and tributary habitats and their utilization by endangered species

Arizona Game and Fish Department

1° Sport Fishery
   1) To determine the effect of current and future operations on trout reproduction, recruitment, and spawning habitat from Glen Canyon Dam to Lake Mead

   2) To determine the type and condition of the sport fishery within the study area and the effect of temperature, flow, and nutrient levels

   3) To determine the amount of available sport fish habitat and the effect of temperature and flow

   4) To determine the biomass and distribution of periphyton and invertebrates and the effect of temperature and flows

   5) To determine the movement patterns on sport fish within the study area and the effect of temperature and flow

Arizona Game and Fish Department - Continued

2° Native Fish

1) To determine how the temperature profile within the Grand Canyon and its tributaries affects distribution, abundance, and reproduction

2) Establish the importance of backwater areas

3) To determine the importance of tributaries to the native fish population and spawning success

4) To determine the distribution and abundance of native fish in the mainstream and tributaries

3° Avian Community - To determine if the current operating regime is degrading or reducing the amount of available nesting habitat for birds within Grand Canyon

4° Terrestrial Wildlife - To determine if the current operatin regime is limiting amphibian, mammalian, and avian diversit and biomass.

9

BOR DOCUMENT, "DECISION PROCESS USED TO DETERMINE PROBABLE STUDIES FOR THE GLEN CANYON ENVIRONMENTAL STUDIES EFFORT"

DECISION PROCESS USED TO DETERMINE PROBABLE STUDIES FOR THE GLEN CANYON ENVIRONMENTAL STUDIES EFFORT

After the decision was made in late 1983 to continue with the Glen Canyon Environmental Studies, a series of meetings were initiated to determine the type and extent of studies that would be initiated. Initial meetings were held with:

A. National Park Service - Grand Canyon National Park Resources Management
B. Arizona Game and Fish Department
C. U.S. Geological Survey - Arizona District Office
D. Bureau of Reclamation

Each agency proposed the types of studies that could be used to address both the long-term and short-term impact assessemnts of the impact of Glen Canyon Dam. These meetings were held from November 1983 through February 1984. Continuous feedback was maintained between the Bureau of Reclamation, Grand Canyon Study Manager, and the Resource Management staff at Grand Canyon National Park. Specific proposals were sent to each agency. Specific studies were evaluated by both agencies and refined to define the specific level of effort and type of product that would be provided. Each study was evaluated to determine if it met the following criteria:

1. Did it address the long-term effects of the operation of Glen Canyon Dam?
2. Did it address the short-term impacts of the operation of Glen Canyon Dam?
3. Did it specifically apply to either a major issue of the Peaking Power studies or did it address the river zone?

A priority of questions was developed based on the Peaking Power and public involvement feedback. Studies were defined that addressed the issues. It was known at the beginning of the Glen Canyon Environmental Studies effort that not all interrelationships defining the ecosystem of Grand Canyon could be addressed. However, issues and factors which could be addressed and quantified during the time frame of the overall study program needed to be defined. The decision process of the initial series of studies rested with the individual subteams and the project manager in cooperation with the National Park Service. In September 1983, specific areas of impact were defined and studies were proposed which could address the objectives of the Glen Canyon Environmental Studies ates of Important Events Leading to the Glen Canyon Environmental tudies:

916 National Park Service Act: "... to conserve the scenery and the natural and historic objects and the wildlife therin and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations."

949 Less than 100 people have floated the Colorado River in Grand Canyon

956 Colorado River Storage Program Authority

959 Colorado River annually floated by less than 100 people

963 Glen Canyon Dam construction completed

964 Generation of power by hydroelectric generators at Glen Canyon Dam

965 547 people floated the Colorado River in this year

966 Congressional authority for the Glen Canyon Dam uprating study

972 16,428 people floated the Colorado River this year

973 Initiation by the National Park Service for the Colorado River Research Program to provide specific answers to three questions: 1) In what manner and how rapidly are physical and biological resources of the riparian zone of the Colorado River adjusting to the new river regime?, 2) How is the increased visitation impacting the riparian and aquatic resources?, and 3) What are the sociological effects of different visitor use patterns on the nature and quality of the river running experience?

975 Funding available for the Glen Canyon Dam Uprating Study

976 National Park Service issues Grand Canyon National Park Master Plan: "The goals for management of the Colorado River in Grand Canyon will be to perpetuate the wilderness river-running experience and to attempt to mitigate the influences of man's manipulation of the river."

977 Colorado River Research Program findings published along with future research an monitoring suggestions (see attached information)

979 Public meetings about the Glen Canyon Dam Uprating Study

1979-81 A series of seven newsletters to the public about the Glen Canyon Dam Uprating Study

1981 Scoping meetings about the Glen Canyon Dam Uprating Study

1982 Acting Commissioner letter to Regional Director, Bureau of Reclamation (Salt Lake City) proposal for proceeding wit studies on operation impacts (dated September 16)

1982 Commissioner Broadbent's letter to initiate Glen Canyon Environmental Studies

1983 Meetings with U.S. Fish and Wildlife Service, National Park Service, Bureau of Reclamation

1983 Glen Canyon Dam spilled with releases greater than 90,000 cubic feet per second from June through August.

The Colorado River Research Program (CRRP) was initiated in 1973 to gather base line information on the Colorado River environment. Information from the three year study was necessary to measure environmental changes caused by operation of Glen Canyon Dam and by the ever-increasing numbers of river-runners. The base line data was also used in the formulation of the Colorado River Management Plan by the National Park Service.

Over 50 investigations were addressed by the CRRP:

- sociological aspects of the river-running experience
- economic analysis of the river-running industry
- environmental and ecological elements in the riparian and aquatic environments
- status of endangered and threatened species
- impacts of human use
- campsite inventories
- human carrying capacities
- use scheduling
- environmental quality
- beach development and erosion
- inventories of plant and animal life
- impacts of water flow regulation

Bibliographies of Research Conducted in Grand Canyon National Park, Arizona:

Carothers, S. W. et al. 1974 (also 1973 edition). A preliminary report on the history and bibliography of biological research in the Grand Canyon region with emphasis on the riparian zone. Colorado River Research Report, Grand Canyon National Park. 137 pp.

Ruder, Ruth L. (compiler) 1970. Selected list of references of the Grand Canyon Area. Museum of Northern Arizona.

Spamer, Earle E. et al. (compilers) 1981. Bibliography of the Grand Canyon and the Lower Colorado River 1540-1980. Grand Canyon Natural History Association, Monograph No. 2. 119 pp.

10

BOR DOCUMENT, "GLEN CANYON INTEGRATION TEAM BIOGRAPHICAL SKETCHES"

GLEN CANYON INTEGRATION TEAM
BIOGRAPHICAL SKETCHES

Linda Sue Anderson was born in 1952. She received her Master of Science Degree and Doctorate of Ecology and Evolutionary Biology from the University of Arizona in 1982 and 1984 respectively. Her professional experience has been numerous ecological and environmental organizations. Presently, she is employed by the National Park Serve as an Ecologist.

Bryan T. Brown was born in 1952 and will receive his doctorate in 1987 in Wildlife Ecology from the University of Arizona. The GCES report will be the basis of his dissertation. His professional experience has been as biological technician, Grand Canyon National Park (1976-1979); graduate research assistant, University of Arizona (1980-82); research ecologist, Cooperative National Park Resources Studies Unit/University of Arizona, National Park Service (1983-1986); and research ecologist, Arizona Projects Office, Bureau of Reclamation (1986). He is a member of the Cooper Ornithological Society, Southwestern Association of Naturalists, and the Wildlife Society. His research interests include avian distribution, reproduction and habitats.

Henry R. Maddux was born in 1953 and received his Master of Science in Fisheries from South Dakota State. His professional experience has been as wildlife specialist, Arizona Game and Fish Department (1984-present). He is a member of the Arizona/Nevada Academy of Science and the Arizona/New Mexico Chapter and Fisheries Management Section of the American Fisheries Society. His research interests are in the relationships between temperature, reproduction and distribution of freshwater fishes.

Julia B. Graf was born in 1945 and received her Doctorate in Geology-Sedimentology from the University of Illinois at Urbana-Champaign. Her professional experience has been teaching assistant, Department of Geology, University of Illinois (1969-1972); visiting assistant professor, University of Illinois (1977-78); sedimentologist, Illinois District, USGS, Water Resource Division (1978-1983); and hydrologist, Arizona District, USGS, Water Resource Division (1983 to present). She is a member of the Geological Society of America, American Geophysical Union, Society of Economic Paleontologists and Mineralogists, and International Association of Sedimentologists. Her research interests are sediment modeling and transport.

Jack Schmidt was born in 1950 and is a doctoral candidate in Geography and Environmental Engineering from the John Hopkins University. His GCES report is the basis of his dissertation. His professional experience has been hydrologist, Montana Mine Land Reclamation Department (1975-1976); owner, Earth Resource Consultants (specializing in geomorphology and water resources, environmental and reclamation issues associated with mining development) (1977-1984); and hydrologist, graduate student appointment, USGS (1985-present). He is a member of the American Geophysical Union and Geological Society of America. His research interests are geomorphology and application of the earth sciences in resolving natural resource policy issues.

Ernest L. Pemberton was born in 1922 and received his Bachelor of Science in Civil Engineering from the University of Iowa. His professional experience has been as sedimentation specialist, Bureau of Reclamation (1948-1960); assistant to head, Sediment Section, BOR (1960-1970); head, Sediment and River Hydraulics Section, BOR (1970-1981); sediment consultant, BOR (1984-present). He is a member of the American

Society of Civil Engineers, International Association for Hydraulic Research, and American Geophysical Union. He has authored numerous BOR publications on reservoir sedimentation, sediment transport, scour of natural channels and stability of river channels.

Richard Bishop was born in 1943. He received his Bachelors of Science Degree in Business Administration at Colorado State University in 1965, his Masters of Science Degree in Economics from Colorado State University in 1967, and his Ph.D. in Agricultural Economics at the University of California-Berkeley, in 1971. He has worked at the University of Wisconsin as a Professor in Agricultural Economics since 1983 and as a Senior Resource Economist for Heberlein-Baumgartner Research Services since 1984. Rich has numerous publications to his credit.

Martha G. Hahn-O'Neill was born April 12, 1955. She has received an Associated Arts Degree in General Education from El Camino College in 1976, a Bachelor of Sciences Degree for Forestry and Outdoor Recreation from Utah State University in 1979, and a Masters of Science Degree in Outdoor Recreation from Utah State University in 1982. Her professional experience has included: Outdoor Recreation Planner (1979-1985) with the Bureau of Land Management, UT; and, as a Resource Management Specialist with the National Park Service, Grand Canyon (1985 to present).

Curt Brown was born in 1952 and received his doctorate in Psychology from the University of Colorado. His professional experience has been as psychologist, Planning Technical Service, Bureau of Reclamation (1979 to present). His research interests include decision analysis, measurement of preferences, and policy analysis.

Mike O'Donnell was born in 1952 and received his Master of Science in Landscape Architecture from Utah State University of Logan. His professional experience has been as landscape architect for the Land Management and Recreation Branch of the Bureau of Reclamation, Upper Colorado Region (1976-present). He is involved with recreation planning and administration. He is the Recreation Sub-Team leader for the Glen Canyon Environmental Studies.

Reed Harris was born in 1946 and received his Master of Science in Fishery Science from Utah State University. His professional experience has been as Federal Fish and Wildlife Biologist (1970-1977) with the U.S. Fish and Wildlife Service and National Marine Fisheries Service, Utah and Alaska; planning biologist for Upper Colorado Region, Bureau of Reclamation (1977-1980); and Chief, Biological Studies Branch, Bureau of Reclamation (1980-present). He has served as a member of the Colorado River Fishes Recovery Team and Interagency Task Force for Implementation of Upper Colorado Basin Endangered Fishes Recovery Plan. He is the Biological Sub-Team leader for the Glen Canyon Environmental Studies.

Jerold F. Lazenby was born in 1935 and received his Master of Engineering in Hydraulic Engineering from the University of California at Berkeley. His professional experience has been as associate engineer with International Engineering Company (1958-1959); civil engineer with the Bureau of Reclamation in Sacramento (1959-1960); hydraulic engineer with the Bureau of Reclamation in Sacramento (1961-1962); hydraulic engineer with the Bureau of Reclamation in Salt Lake (1966-1981); and supervisory hydraulic engineer and branch chief at the Water Resources Branch, Planning Division (1981-present). He has served as a hydrologic consultant to Taiwan and the World Bank. His research interest are water operation studies, drainage, water rights, stream gaging programs, consumptive use determination, hydrosalinity, and projects of water depletion in the Colorado River

Basin. He is the Sediment Transport and Hydrology Sub-Team leader for the Glen Canyon Environmental Studies.

11

BOR DOCUMENT, "GLEN CANYON ENVIRONMENTAL STUDIES REVIEW PROCESS"

Glen Canyon Environmental Studies Review Process

REPORT	INTERNAL REVIEWERS *	EXTERNAL REVIEWERS *
I - 1	Reed Harris, BOR Michael Pucherelli, BOR E&R Susan Anderson, NPS	Lee Swenson, BOR
I - 2	Reed Harris, BOR Bryan Brown, NPS	Lewis Stolzy, Univ. Cal. at Riverside Raymond Turner, USGS
I - 3	Reed Harris, BOR	Martin Karpiscak, Univ. of Arizona Raymond Turner, USGS James Brown, Univ. of Ariz. Lee Swenson, BOR
I - 4	Reed Harris, BOR Michael Pucherelli, BOR, E&R Steve Hodapp, NPS	Steve Carothers, Environmental Consultant Lee Swenson, BOR
I - 5	Reed Harris, BOR Nancy Brian, BOR	T. T. Kozlowski, Univ. of Wisconsin Donal Hook, Univ. of Clemson
I - 6	Reed Harris, BOR	Lee Swenson, BOR
I - 7	Reed Harris, BOR	Laurie Vitt Jim Collins
II - 1	Henry Maddux, Arizona Game and Fish Dept. Frank Baucom, USFWS	Bob Williams, BOR Tom Burke, BOR Ken Bovee, USFWS
II - 2	Frank Baucom, USFWS Henry Maddux, Arizona Game and Fish Dept. Bill Vernieu, BOR	Robert George, BOR

Alphabetical list of Reviewer Code Affiliation: BOR = Bureau of Reclamation; E&R = Engineering and Research Center, Denver, BOR; HBRS = Heberlein Baumgartner Research Services, Madison, WI; NPS = National Park Service; USFWS = U.S. Fish and Wildlife Service; USGS = U.S. Geological Survey

Glen Canyon Environmental Studies Review Process - Continued

REPORT	INTERNAL REVIEWERS	EXTERNAL REVIEWERS
II - 3	Frank Baucom, USFWS	Steve Carothers, Environmental Consultant Chuck McAda, USFWS Gerold Cole, Environmental Consultant James La Bounty, BOR Thomas Burke, BOR
III - 1	Bob Baumgartner, HBRS Mike O'Donnell, BOR Curt Brown, BOR Martha Hahn-O'Neill, NPS	John Loomis, Univ. of Cal., Davis
III - 2	Mike O'Donnell, BOR Curt Brown, BOR Martha Hahn-O'Neill, NPS	Bo Shelby, Oregon State Uni John Loomis, Univ. of Cal., Davis
III - 3	Mike O'Donnell, BOR	Tom Parker, Recreation Consultant
III - 4	Mike O'Donnell, BOR Curt Brown, BOR Martha Hahn-O'Neill	
IV - 1	Steve Hodapp, NPS	Bob Strand, BOR, E&R Jim Blanton, BOR, E&R Bob Barton, BOR Dan Kimball, NPS
IV - 2	Bob MacNish, USGS Julie Graf, USGS Jack Schmidt, USGS	Jim Robb, USGS, Woods Hole Dan Kimball, NPS
IV - 3	Steve Hodapp, NPS	Rhea Williams, USGS David Ruben, USGS Dan Kimball, NPS
IV - 4	Jerold Lazenby, BOR Ernie Pemberton, BOR Steve Hodapp, NPS	Errol Jensen, BOR Chris Bogl, BOR Martin Roche, BOR Rick Gold, BOR Dan Kimball, NPS
IV - 5	Ernie Pemberton, BOR Jerold Lazenby, BOR Tim Randle, BOR	Fred Raichlen, California Inst. of Technology

Glen Canyon Environmental Studies Review Process - Continued

REPORT	INTERNAL REVIEWERS	EXTERNAL REVIEWERS
IV - 6	Steve Hodapp, NPS Dick Marks, NPS	Jerry Witucki, NPS
IV - 7		Bob Strand, BOR, E&R Jim Blanton, BOR, E&R Bob Barton, BOR Dan Kimball, NPS
IV - 8	Steve Hodapp, NPS Julie Graf, USGS	Jerry Witucki, NPS Dan Kimball, NPS
IV - 9	Sue Kieffer, USGS	Steve Reneau, Univ. of California, Berkeley Tom Pierson, USGS Dan Kimball, NPS
IV - 10		Bob Strand, BOR, E&R Jim Blanton, BOR, E&R Bob Barton, BOR Dan Kimball, NPS Marshall Flug, NPS
IV - 11		Bob Strand, BOR, E&R Jim Blanton, BOR, E&R Bob Barton, BOR Dan Kimball, NPS Marshall Flug, NPS
V - 1	Tom Gamble, BOR Steve Hodapp, NPS Wayne Cook, BOR	Jeff McCoy, Western Area Power Administration
V - 2	Steve Hodapp, NPS Wayne Cook, BOR	Patricia Port, NPS William Swan, USDI Solicitor Dave Stilley, Lawyer

APPENDIX C

GLEN CANYON ENVIRONMENTAL STUDIES RESEARCH INVESTIGATORS

National Park Service

L. Susan Anderson
Lawrence Belli
Nancy Brian
Bryan T. Brown
Durl Burkham
Martha G. Hahn-O'Neill
R. Roy Johnson
Lauren M. Lucas
Marie McGee
George A. Ruffner
Lawrence E. Stevens
Gwendolyn L. Waring

Bureau of Reclamation

Curtis A. Brown
Ron Ferrari
Ernest L. Pemberton
Michael G. Pucherelli
Timothy Randle
David L. Wegner

Arizona Game and Fish Department

Dennis M. Kubly
Henry R. Maddux
William R. Persons
Cecil R. Schwalbe
Richard H. Staedicke
James C. deVos, Jr.
Peter L. Warren
Rebecca L. Wright

Northern Arizona University

Dean W. Blinn
Gloria G. Hardwick
William C. Leibfried
W. Linn Montgomery
Chris Pinney
Howell D. Usher

U.S. Geological Survey

Julia B. Graf
Susan Werner Kieffer
Jack C. Schmidt
Robert Webb
Richard P. Wilson

Others

Michael D. Yard, Humphrey Summit Associates

Loren Haury, Scripps Institution of Oceanography

A. Heaton Underhill, Michael H. Hoffman, and Ronald E. Borkan, Cooperative National Park Resources Studies Unit, University of Arizona

Richard C. Bishop, Kevin J. Boyle, Michael P. Welsh, and Robert M. Baumgartner, Heberlein-Baumgartner Research Services

APPENDIX D

GLEN CANYON ENVIRONMENTAL STUDIES REPORTS

Index to author affiliation abbreviations: AGF = Arizona Game and Fish; BOR = Bureau of Reclamation; CPSU = Cooperative Park Study Unit, University of Arizona; DPO = Durango Projects Office; E&R = Engineering and Research Center, Denver; GCNRA = Glen Canyon National Recreation Area; HBRS = Heberlein-Baumgartner Research Service, Wisconsin; NAU = Northern Arizona University; NPS = National Park Service; and USGS = U.S. Geological Survey.

SEDIMENT TRANSPORT AND HYDROLOGY

1. Trends in Selected Hydraulic Variables for the Colorado River at Lees Ferry and near Grand Canyon for the Period 1922-1984. (Consultant to NPS)

2. Unsteady Flow Modeling of the Releases from Glen Canyon Dam at Selected Locations in Grand Canyon. (BOR)

3. Sonar Patterns of the Colorado River Bed in the Grand Canyon. (USGS)

4. Sediment Data Collection and Analysis for Five Stations on the Colorado River from Lees Ferry to Diamond Creek. (Consultant to BOR)

5. Sediment Transport and River Simulation (STARS) Model Development. (BOR, E&R)

6. Results and Analysis of STARS Modeling Efforts of the Colorado River in Grand Canyon. (Consultant to BOR and BOR, E&R)

7. Recent Aggradation and Degradation of Alluvial Sand Deposits, Colorado River, Grand Canyon National Park, Arizona. (USGS)

8. Topographic Surveys of Selected Sandy Beaches Along the Colorado River in the Grand Canyon National Park. (BOR, DPO)

9. The Rapids and Waves of the Grand Canyon, Arizona. (USGS)

10. Debris Flows from Colorado River Tributaries in the Grand Canyon National Park. (USGS)

AQUATIC BIOLOGY

1. Evaluation of Varied Flow Regimes on Aquatic Resources of Glen and Grand Canyons. (AGF and NAU) This report covers:

- Mainstream Aquatic Study
- Aquatic Reproduction Study
- Lees Ferry Fishery
- Macroinvertebrate Study
- Aquatic Habitat Study
- Tributary Aquatic Study
- Fish Movement Study
- Algal Study
- Plankton Study
- Water Quality Study

2. Instream Flow Microhabitat Analysis and Trends in the Glen Canyon Dam Tailwater. (BOR)

3. Colorado River Water Temperature Modeling Below Glen Canyon Dam. (BOR, E&R)

TERRESTRIAL BIOLOGY

1. Evaluation of Riparian Vegetation Trends in the Grand Canyon Using Multitemporal Remote Sensing Techniques. (BOR, E&R)

2. Aerial Photographic Comparison of 1983 High Flow Impacts to Vegetation at Eight Colorado River Beaches. (NPS)

3. Effects of Post-Dam Flooding on Riparian Substrates, Vegetation and Invertebrate Populations in the Colorado River Corridor in Grand Canyon, Arizona. (NPS)

4. Effects of the Post-Glen Canyon Dam Flow Regime on the Old High Water Line Plant Community Along the Colorado River in Grand Canyon. (NPS)

5. The Effects of Recent Flooding on Riparian Plant Establishment in Grand Canyon. (NPS)

6. Herpetofauna Along the Colorado River in Grand Canyon National Park: Possible Effects of Fluctuating River Flows. (AGF)

7. Fluctuating Flows from Glen Canyon Dam and Their Effect on Breeding Birds of the Colorado River and Population Densities Along the Colorado River in Grand Canyon. (NPS and CPSU)

RECREATION

1. Glen Canyon Dam Releases and Downstream Recreation: An Analysis of User Preference and Economic Values. (HBRS) This study will include attribute and contingent valuation studies.

2. Simulating the Effect of Dam Releases on Grand Canyon River Trips. (CPSU)

3. Reported and Observed Boating Accidents as a Function of River Flows from Lees Ferry to Diamond Creek, Grand Canyon National Park. (NPS, BOR, and CPSU)

4. Recreation Analysis of the Relationship Between Flow Levels and the Rate of Accidents in the Glen Canyon National Recreation Area (GCNRA).

GLEN CANYON DAM OPERATION

1. Colorado River Storage Project Constraints and Operation of Glen Canyon Dam. (BOR)

2. Colorado River Law. (BOR)

GCES INTEGRATED REPORT

1. Final Draft, Glen Canyon Environmental Studies, July 1987.

APPENDIX E

BIOGRAPHICAL SKETCHES OF COMMITTEE MEMBERS

G. RICHARD MARZOLF (Chairman) received his Ph.D. from the University of Michigan in zoology. Dr. Marzolf has held various positions at Kansas State University including assistant professor of zoology, to associate professor of biology, and associate director of the division of biology. He is currently professor of biology. He was also visiting professor of zoology at the universities of Wisconsin, Oklahoma, and Oregon. He is a member of the International Association of Theoretical and Applied Limnology, American Society of Limnology and Oceanography, and Ecological Society of America. His areas of research are reservoir limnology, and riparian/stream linkages. Dr. Marzolf is a member of the NRC's Water Science and Technology Board.

VICTOR R. BAKER received his Ph.D. in geology in 1971 from the University of Colorado. He is professor of geosciences, professor of planetary sciences, and professor in the Lunar and Planetary Laboratory at the University of Arizona. Dr. Baker has worked as a hydrologist/geophysicist for the U.S. Geological Survey; as the city geologist of Boulder, Colorado; and as a research scientist for the Bureau of Economic Geology at the University of Texas. He has authored approximately 100 research papers, plus numerous reports, abstracts, and encyclopedia articles. His books include The Channels of Mars, Flood Geomorphology, Catastropic Flooding, Surficial Geology, and The Channeled Scabland. He has served on numerous technical and advisory committees, including NRC committees and NASA programs. Specific projects of interest have included paleohydrologic studies in Texas, Utah, Arizona, and northern Australia; flood geomorphology; channels, valleys, and geomorphic features on Mars; river morphology in South America; and karst hydrology in New York.

DAVID DAWDY received his M.S. in statistics from Stanford University. His professional experience is with the U.S. Geological Survey from 1951 to 1976 as research hydraulic engineer; adjunct professor of civil engineering from 1969 to 1972 at Colorado State University, Ft. Collins; assistant district chief for programming, California District, Water Resources Division from 1972 to 1975. He has served on numerous advisory groups including NRC committees. From 1976 to 1980 he was chief hydrologist with Dames and Moore in Washington, D.C., and is currently a private consultant in surface water hydrology.

CHARLES R. GOLDMAN received his Ph.D. in limnology (fisheries) from the University of Michigan in 1958. He was employed as a research assistant in aquatic biology at the State Natural History Survey in Illinois; teaching fellow in fisheries at the University of Michigan from 1955 to 1957; biologist on fisheries research at U.S. Fish and Wildlife Service, Alaska, 1957 to 1958; from instructor to professor of zoology, 1958 to 1971, and director, Institute of Ecology, 1963 to 1966. He is now professor and director of the Tahoe Research Group, and professor, Division of Environmental Studies, at the University of California at Davis. He is a member and past president of the American Society of Limnology and Oceanography and U.S. representative to the

International Association of Theoretical and Applied Limnology. His textbook Limnology with A. Horne was published in 1983. Another book, Environmental Effects of Water Development for the National Water Commission was approved in 1973. His research interests, largely supported by NSF grants, are aquatic biology-limnology, biological productivity, eutrophication and nutrient-limiting factors in lakes, tropical reservoirs, and environmental impacts of hydroelectric projects.

WILLIAM GRAF received his Ph.D. in August 1974 from the University of Wisconsin at Madison with a major in physical geography and a minor in water resources management. He specialized in fluvial geomorphology, hydrology, conservation policy and public land management, and aerial photographic interpretation. He was director, Center for Southwest Studies at Arizona State University, from 1981 to 1983. He has served as consulting geomorphologist for the U.S. Army Corps of Engineers in a research and advisory role concerning the environmental impact assessment of flood control works, Salt and Gila Rivers in Arizona; and for Camp, Dresser, and McKee, Inc. by writing a report on geomorphology and geology of the western Salt River Valley, Arizona. His research activities have included fluvial geomorphology and the effects of human activities on streams; public land management, especially wilderness preservation, and rapids in canyon rivers, dynamics and recreation management, Arizona, Utah, and Colorado. Dr. Graf has published many articles and book chapters on the impact of suburbanization on fluvial geomorphology; resources, the environment and the American experience; and the effect of dam closure on downstream rapids.

EVE GRUNTFEST received her Ph.D. in geography from the University of Colorado, Boulder, in 1982. Her research focuses on human response to natural and technological hazards and recreation planning.

In 1985 she developed a Flood Hazard Mitigation Plan for Manitou Springs, Colorado, sponsored by the Federal Emergency Management Agency. In 1986, with funds from the National Science Foundation, the National Oceanic and Atmospheric Administration, and the U.S. Army Corps of Engineers, Dr. Gruntfest organized the Symposium "What We Have Learned Since the Big Thompson Flood." Since 1980 she has been assistant professor in the Department of Geography at the University of Colorado, Colorado Springs.

W. MICHAEL HANEMANN received his Ph.D. in public finance and decision theory from Harvard University in 1978. Since 1984 he has been associate professor in the Department of Agricultural and Resource Economics at the University of California at Berkeley. He has been a lecturer at the Department of Economics at Northeastern University, Boston; consultant, National Bureau of Economic Research, Inc., for the National Commission on Water Quality; economic consultant, Urban Systems Research and Engineering Inc.; and staff economist at Urban Systems and Engineer, Inc. Dr. Hanemann has also served as a consultant to the U.S. Environmental Protection Agency; U.S. Department of Energy; and the California Department of Water Resources. He has been author and co-author of many publications, such as a Theoretical and Empirical Study of the Recreation Benefits from Improving Water Quality in the Boston Area; The Economics of Water Development and Use in California Water Planning and Policy: Selected Issues; and "Welfare Evaluations in Contingent Valuation Experiments with Discrete Responses" in the American Journal of Agricultural Economics among others.

DONALD R.F. HARLEMAN received his doctorate in civil engineering from MIT. He has held various positions at MIT since 1945, from research assistant to his present position as Ford Professor of Engineering. His major research interests are in fluid transport and mixing processes as affect the effluents discharged into lakes, reservoirs, estuaries, or the oceans; mathemat and physical models for water quality control; coastal engineering and tidal hydraulics; stratified flow due to temperature and salinity; waste heat disposal associated with electrical energy generation by fossil or motor fuels; and solar energy collection and storage by means of salt gradient solar ponds. He has been a member of the NAE since 1974.

EVELYN HOWELL received her Ph.D. in botany from the University of Wisconsin-Madison in 1975. Her professional experience has been as teaching assistant, Department of Botany, University of Wisconsin, 1969 to 1971; research assistant, International Biological Program, 1971; fellow, Department of Botany, University of Wisconsin, 1972 to 1973; and research assistant, Critical Resources Information Program, 1974. She is currently associate professor, Department of Landscape Architecture, at the University of Wisconsin. Dr. Howell has served on many university committees for the Institute for Environmental Studies, the University Arboretum Center for Restoration Ecology, and the Department of Landscape Architecture. She has published many articles and co-authored many book chapters on such subjects as: introduction of selected prairie forbs into an established tall grass prairie restoration; the role of ecology in landscape architecture; field study of native plant communities; and concepts of resource definitions, uses, and measurements, among others.

TREVOR C. HUGHES received his Ph.D. in civil engineering from Utah State University. His professional experience includes teaching since 1972 at Utah State University in the Civil and Environmental Engineering Department; research experience as NDEA fellow at Utah State; associate professor of Civil and Environmental Engineering, Utah Water Research Lab; and research scientist at International Institute of Applied Systems Analysis, Austria. Since 1971 he has conducted research projects on the management of salinity in the Colorado Basin; drought management analysis and policy design; regional planning of rural water supply systems; economic analysis of alternative water conservation concepts; river system operational models--Sevier River; and application and development of water demand functions for domestic water systems at recreation developments.

JOHN V. KRUTILLA received his Ph.D. from Harvard University. His professional experience includes director, Natural Environments: Wildlands, Wildlife and Scenic Resources Program at RFF, 1968 to 1974; principal economist, TVA, 1954 to 1955; and research associate, Resources for the Future, 1955 to 1960. He has been senior fellow at Resources for the Future since 1975. He has served as a consultant to the NAS, the U.S. Government, and the United Nations.

WILLIAM M. LEWIS, JR., received his Ph.D. in zoology with a minor in mathematics from Indiana University in 1973. He was a research associate and subsequently adjunct assistant professor of zoology at the University of Georgia between 1973 and 1974. In 1974, he moved to the University of Colorado at Boulder as assistant professor of biology. At the University of Colorado he held the rank of assistant professor from 1974 to 1978, associate professor from 1978 to 1982, and professor after 1982. He is presently director of the University of Colorado Center for Limnology. Dr. Lewis was a Guggenheim fellow in 1980 to 1981 and has previously served on NRC committees. His interests include aquatic food chains, trophic status of lakes, chemistry of surface water, mass transport by large rivers, and interactions between floodplains and rivers.

NANCY Y. MOORE received her Ph.D. in water resources systems with a minor in operations research and econometrics from the University of California at Los Angeles. Her thesis was entitled "Optimal Solution to the Timing, Sequencing and Sizing of Multiple Reservoir Surface Water Supply Facilities When Demand Depends on Price." Her professional experience includes research assistant, Department of Engineering Systems, UCLA, 1971 to 1973; civil engineer, Investigations Section B, Water Resources Branch, U.S. Army Corps of Engineers; postgraduate research engineer, Department of Engineering Systems, UCLA, 1974 to 1975; lecturer, School of Engineering and Applied Science, UCLA, 1978 to 1983; and associate engineer, The Rand Corporation, 1974 to 1976. She is a registered civil engineer in the State of California and is currently Director of Development for RAND. Dr. Moore's interests are the economic, legal, and institutional aspects of water resources.

DUNCAN T. PATTEN received his Ph.D. in botany from Duke University. His professional experience includes being assistant professor of Botany at Virginia Polytechnic Institute from 1962 to 1965; assistant professor to associate professor, 1965 to 1973; assistant academic vice president from 1972 to 1976; and his current position as professor of Botany at Arizona State University since 1973 and director, Center for Environmental Studies, since 1980. He served on the Commission on Natural Resources of the NRC from 1975 to 1976 and is on the Board on Environmental Studies and Toxicology of the NRC. His research interests include ecology of montane and subalpine zones of Yellowstone National Park and northern Rocky Mountains; autoecology of desert succulents; heat and water flux within desert ecosystems; riparian processes; and man's impacts on semiarid ecosystems.

HEINZ STEFAN received his doctorate in hydraulic engineering from the University of Toulouse, France. His professional experience includes his present position as professor of water resources engineering and hydromechanics at the University of Minnesota since 1977; associate director, St. Anthony Falls Hydraulic Lab, University of Minnesota 1974 to present; and assistant to associate professor at the University of Minnesota from 1967 to 1972. He has taught courses in fluid mechanics, water resources engineering, hydrology, analysis, and modeling aquatic environments and ground water flow. His research interests are in the analysis of effluent plumes, heat budgets of lakes, dispersion of mass and heat in surface and ground water flow, density currents, modeling of lake temperature regimes, and stratification and stream and lake productivity analysis and modeling.

A. DAN TARLOCK received his LL.B. from Stanford University. His professional experience includes private practice, San Francisco, 1966; professor in residence at a law firm in Nebraska, summers of 1977 to 1979; and consultant. He has been a professor of law at Chicago Kent College of Law since 1981. He has authored and co-authored many publications and articles concerning water resources management and environmental law and policy. Mr. Tarlock served as a member of an NRC Committee on Pest Management and co-authored one of the basic casebooks in water law.

NAS
NAE
IOM

National Academy Press

The National Academy Press was created by the National Academy of Sciences to publish the reports issued by the Academy and by the National Academy of Engineering, the Institute of Medicine, and the National Research Council, all operating under the charter granted to the National Academy of Sciences by the Congress of the United States.