THE GRAND CANYON MONITORING AND RESEARCH CENTER
FISCAL YEAR 2000-2004
MONITORING AND RESEARCH STRATEGIC PLAN

by

GRAND CANYON MONITORING AND RESEARCH CENTER

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EXECUTIVE SUMMARY

INTRODUCTION

This Strategic Plan is designed to implement the adaptive management and ecosystem science approaches called for in the 1992 Grand Canyon Protection Act (GCPA), Glen Canyon Dam Environmental Impact Statement (GCDEIS, 1995) and the Record of Decision (ROD, 1996). The monitoring, research and information technology activities outlined for physical, biological, cultural, socioeconomic, and recreational resources will be implemented over a five-year period. Within each of these years, an annual monitoring and research plan will be developed which describes critical elements of the Strategic Plan to be accomplished in that year.

The Strategic Plan and subsequent annual plans will be developed cooperatively with the Adaptive Management Work Group (AMWG). All activities proposed will relate to determined or potential resource impacts primarily in the Colorado River ecosystem[1] between Glen Canyon Dam and Lake Mead resulting from "The effects of the Secretary's actions."[2]

Independent reviews of past research in the Colorado River ecosystem suggest several actions to ensure sound future monitoring and science programs. These include:

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[1]The "Colorado River ecosystem" is defined as the Colorado River mainstem corridor and interacting resources in associated riparian and terrace zones, located primarily from the forebay of Glen Canyon Dam to the western boundary of Grand Canyon National Park, a distance of approximately 300 river miles. The scope of GCMRC activities also includes limited investigations into some tributaries (e.g., the Little Colorado and Paria Rivers). "Colorado River ecosystem" will be used throughout this document as the standard definition of the monitoring and study area for GCMRC.

[2]As specified in the 1992 Grand Canyon Protection Act, the Glen Canyon Dam Environmental Impact Statement (1995), and the Record of Decision (1996). The "Secretary's actions" include dam operations or alternative dam operating criteria as well as other authorized actions.

1. Implementation of an adaptive management process to facilitate close interaction of science and management in applying new management criterion and evaluating the impacts of those criterion.
2. Development of a conceptual model of the Colorado River ecosystem to define critical attributes within resource categories, critical attribute linkages across resource categories, and interdependencies of resource attributes.
3. An assessment of predam baseline resource conditions in the Colorado River ecosystem riverine resource changes associated with construction of the Glen Canyon Dam, and subsequent changes associated with "the effects of the Secretary's actions."
4. Identifying causal relations between environmental stressors, their ecological effects and the appropriate selection and validation of these indicators of stress.

MISSION AND SCOPE OF GCMRC AND THE STRATEGIC PLAN

The GCPA and GCDEIS direct the Secretary of Interior, "To establish and implement long-term monitoring programs and activities that will ensure that Glen Canyon Dam is operated in a manner consistent with that of Section 1802" of the GCPA.

The mission of the Grand Canyon Monitoring and Research Center (GCMRC) is to develop and implement long-term monitoring and related research activities to determine "The effect of the Secretary's actions" on the natural, recreational, and cultural resources of Grand Canyon National Park and Glen Canyon National Recreation Area, as well as other information needs specified by the AMWG.

Long-term monitoring will occur on resources of concern to determine changes in resource attributes. Research will be used to interpret and explain trends observed from monitoring, to determine cause and effect relationships and research associations, and to better define interrelationships among physical, biological and social processes.

In addition to monitoring and research activities, the GCMRC will develop information technologies to assure information archiving and transfer to managers and stakeholders and science organizations. Specific protocols will be developed to ensure sensitive information such as location of endangered species and cultural resource sites are maintained in confidence.

More specifically, the geographic and institutional scope of the long-term plan is limited to the natural, cultural and recreational resources within Grand Canyon National Park and Glen Canyon National Recreation Area affected by actions taken by the Secretary under the GCPA and GCDEIS, including modifications to plans and operating criteria for Glen Canyon Dam. The physical scope of the program is the Colorado River ecosystem defined as the Colorado River mainstem corridor and interacting resources in associated riparian and terrace zones, located primarily from the forebay of Glen Canyon Dam to the western boundary of Grand Canyon National Park, a distance of approximately 300 river miles. The scope of GCMRC activities also includes limited investigations into some tributaries (e.g., the Little Colorado and Paria Rivers).

STAKEHOLDER INFORMATION NEEDS AND CRITICAL RESOURCE ATTRIBUTES

The Strategic Plan responds to the management objectives and prioritized information needs approved by the AMWG for the Colorado River ecosystem. Objectives and information needs are specified in nine different resource areas including hydropower, water, sediment, fish and aquatic, biology riparian vegetation, threatened and endangered species, terrestrial wildlife, cultural, and recreational resources.

Within each of the above resource areas specific management objectives and prioritized information needs have been developed by the Technical Work Group (TWG) and adopted by the AMWG, and contained in Appendix A[3]. Management objectives and information needs are the basis for development of both monitoring and research programs, and these are referenced in the Strategic Plan when discussing monitoring and research programs.

[3]Appendix A contains management objectives and prioritized information needs.

ENSURING QUALITY INDEPENDENT SCIENCE

The GCMRC is established to provide high quality independent science assessments to the Secretary and to the AMWG. To accomplish these goals, specific protocols regarding science-planning, competition, peer-review, administration and publication have been established.

An independent Science Advisory Board (SAB) will be established to provide expert science advice to the GCMRC. The SAB will be established as one of the Independent Review Panels (IRP) outlined in the GCDEIS. The SAB will provide independent scientific review and technical advice to ensure that Glen Canyon Dam Adaptive Management Program scientific and technical activities are efficient, unbiased, objective, and scientifically sound. The selection of this interdisciplinary group of advisors will be based on their standing and accomplishments in the science community.

The GCMRC will maintain objective programs by independently developing needed monitoring and research projects that will be awarded through competitive scientific procedures.

Quality science programming and unbiased and objective research findings will be ensured through independent external scientific peer review. All proposals, data, reports, etc., will be reviewed by independent, external scientists as well as the GCMRC science team.

PROPOSED MONITORING AND SCIENCE PROGRAMS

Monitoring and science programs proposed in the Strategic Plan include the following:

1. Conceptual modeling and synthesis of existing knowledge.
2. Physical resource program.
3. Cultural resource program.
4. Biological resource program.
5. Socioeconomic resource program.
6. Information technology program.
7. Contingency planning.

Each of these areas represent components of the Strategic Plan where important information will be developed to respond to management objectives and information needs specified by stakeholders.

Conceptual Modeling

The development of a conceptual model of the Colorado River ecosystem is a key element of the adaptive management approach being utilized and is critical to understanding this riverine ecosystem and associated impacts from differing dam operations.

The Physical Resources Program

The physical resources monitoring and research program provides information on dynamic hydrologic and geomorphic processes that directly and indirectly link operations of Glen Canyon Dam with downstream ecosystem resources. Streamflow, sediment and their associated interactive processes are the three primary physical resource topics of concern. Although water quality is identified by Glen Canyon AMP stakeholders as a physical resource parameter, management objectives and information needs associated with water quality in the Colorado River ecosystem are exclusively used in relation to the biological program area, such as studies of primary productivity, fish recruitment, etc. As a result, GCMRC activities associated with water quality monitoring and research will be described under the biological program area sections.

Streamflow and its direct association with transport and deposition of fine and coarse sediments are clearly linked to dam operations. The dynamic relation between variable dam releases and downstream sediment storage and export in the mainstem influences:
1) recreational-resource activities such as camping (system-wide quantity and quality of campable beaches), river boating (downstream navigation of rapids in Grand Canyon National Park, and upstream navigation by anglers through shallow reaches in Glen Canyon National Recreation Area); 2) cultural resources, such as archeological sites that are contained and preserved within fine-grained, pre-dam river terraces in key reaches of the ecosystem that also provide habitat for culturally important plants and animals; and 3) biological resources of the aquatic and terrestrial environments, including plants, invertebrates and vertebrates that rely on sediment-related features such as return-current channels [backwaters], fine-grained terrestrial substrates, or are limited by inputs and storage of fines [light attenuation and burial of coarse substrates], such as primary production.

Monitoring and research efforts will concentrate on four aspects of water and sediment, as follows:

1) **Mainstem streamflow** - and related dynamic fluvial processes that are driven by dam releases and combined with tributary inputs within the context of the geomorphic framework of the river and its tributary processes.

2) **System-wide sediment budget –** local and system-wide sediment inputs versus storage and export to Lake Mead for both fine and coarse sediments, including linked influences on mainstem turbidity and long-term trends in evolution of the geomorphic framework of the mainstem ecosystem.

3) **Interactions between hillslope and fluvial processes –** debris flow and mainstem streamflow relations at and between fan-eddy complexes that relate to navigation through rapids, and long and short-term changes in shoreline habitats and channel substrates that structure the aquatic and terrestrial ecosystems, as well as alterations to channel storage of sediment.

4) **Modeling of fine and coarse sediment flux –** real time and decade-averaged estimation of sediment inputs from all tributaries, in combination with estimated grain-size evolution and downstream transport within the mainstem, as a means of tracking the total sediment budget of the ecosystem.

The Biological Resources Program

Monitoring and research activity for biological resources is intended to develop information about the structure and function of the Colorado River ecosystem, as well as the impacts of differing dam operations on the ecosystem and associated flora and fauna. The effort will provide the knowledge base required to implement ecosystem management strategies within an adaptive management framework. It is key that relationships between the biotic and abiotic components of the Colorado River ecosystem be addressed to predict impacts on critical biological resources.

Monitoring activities will address management objectives and information needs within two programmatic activities: an aquatic and a terrestrial monitoring program. Specific research projects will be implemented to address specific questions related to the aquatic food base, native and non-native fish species, wildlife and other riparian invertebrates and vertebrates.

It is generally recognized that water quality changes from Lake Powell through Grand Canyon primarily affect biological components of the aquatic ecosystem. It is proposed that this integrated water quality program be moved under the direction of the

Biological Resources program as part of this five-year strategic plan. As appropriate the biological resources monitoring and research program will consider and address information needs of the Biological Opinion.

The Cultural Resources Program

The cultural resources program will accommodate both ongoing activities of the Programmatic Agreement (PA), and new programs proposed to address needs of the AMWG.

Activities necessary to the PA will be incorporated into the cultural resources program at the request of the agency and Native American tribal members of the AMWG. Monitoring and research information needs and activities from the PA are expected to be a major component of the GCMRC's cultural resource program.

The Strategic Plan incorporates a more comprehensive perspective of cultural resources than those outlined in the PA. This perspective is derived from objectives and information needs specified by agencies, Native American tribes and other stakeholders, relating to cultural resources and their association with other resources in the Colorado River corridor.

The cultural resources program for the GCMRC is comprised of three primary components: a core program of monitoring and research activities as directed by stakeholders in the AMP, a tribal projects component, and a cooperative programming component. Further, the cultural resources program manager is responsible for coordination with other program managers to incorporate Native American concerns within these programs.

The objectives and information needs specified by the stakeholders have been incorporated into the following general monitoring and research activities proposed in the Strategic Plan.

1. Develop data and monitoring systems to assess impacts.
2. Develop data to assess risk of damage and loss of cultural resources from varying flow regimes.
3. Develop tribal monitoring programs for evaluation of impacts to cultural resources.

4. Develop a predictive model of geomorphic processes that are related to archaeological site erosion.
5. Develop mitigation strategies related to documented site impacts and monitoring assessments.
6. Characterize resource values through scientific study.

The Socio-Economic Resources Program

There are many socio-economic resources associated with the Colorado River corridor including recreation, electric power and water. The objectives of recreation monitoring and research will be to determine whether recreation is enhanced and safety improved when comparing current or proposed dam operations to historical dam operations, and whether wilderness changes in recreational patterns resulting from the dam operations have any effect on the Canyon's downstream recreation resources.

In the Lees Ferry reach, monitoring methods will be established to characterize changes in sport fish recreation (trout) relative to the Secretary's actions regarding dam operations.

Continued monitoring and research is needed to assess changes in recreational and camping beach areas associated with "the effects of the Secretary's actions."

Hydropower supply is an integral part of the economy of the region. Changes in power operations result from changes in annual dam operations which affects power supply and its costs. Power generation monitoring will also be used for estimating water discharge rates and volumes. A Cost Benefit Analysis (CBA) model is proposed to evaluate all associated market and non-market costs and benefits, including intrinsic or existence values of key resources.

The Information Technology Program

Extensive data and information currently exists in the GCMRC relating to resource levels, quality, and relationship to other resources. Potentially equal amounts of data and information exists within museums, universities, state and Federal agencies, etc. However, much of this information has not been evaluated to assess the interrelationship of resource attributes and differing flow regimes.

Several areas of focus will be implemented through the information technology program, including the following:

1. Development of protocols for data collection, processing and use.
2. Development of extensive databases across all resources and a database management system.
3. Development of a robust geographic information system to accommodate multiple layers associated with all resources of interest to stakeholders.
4. Development of databases associated with remotely sensed data not yet incorporated in the GCES/GCMRC database system.
5. Stakeholder direct access to selected data and information in the database management system and GIS.
6. Development of outreach programs to transport data and information to stakeholders and train stakeholders in utilization of data and models incorporated in the information technology program.
7. Remote Sensing Initiative

Contingency Planning

The TWG and AMWG have adopted hydrologic criteria and resource criteria for triggering a BHBF. When implemented, these criteria provide little lead time for research planning. In addition, hydrologic conditions can lead to unplanned release events which will also require GCMRC to implement monitoring and research activities with little to no lead time. The potential for these events to occur result in the need for contingency planning. Annually, GCMRC will develop contingency plans for implementation of:

(1) baseline assessments before and/or after unplanned events; (2) research assessments of "spills" or other short-duration high flow unplanned events; and (3) a monitoring and research program for planned events between January-July of a given year.

SCHEDULE AND BUDGET

The strategic plan outlined in this document addresses monitoring and research activities for a five year period: fiscal years 2000-2004. Each year, in April, a new Annual Plan will be drafted and used to structure and guide implementation of specific elements of the Strategic Plan. The Annual Plan will be reviewed by the Technical Working Group (TWG) and the AMWG and approved by the Secretary of Interior.

Budget for GCMRC activities under this five-year Strategic Plan is anticipated at approximately $8 million dollars per year for FY 2000, 2001, and 2002 with reductions intended for FY 2003 and 2004. The budget and program plan is developed by GCMRC in response to the management objectives and information needs specified by the AMWG. The AMWG thoroughly reviews the annual science plan and budget and recommends it to the Secretary for adoption.

The Grand Canyon Monitoring and Research center
Monitoring and Research Strategic Plan

CHAPTER 1
HISTORY OF MONITORING AND RESEARCH IN THE GRAND CANYON

The U.S. Department of the Interior (USDOI) Grand Canyon Monitoring and Research Center (GCMRC), was established by the Assistant Secretary for Water and Science in 1995. This Strategic Plan is designed to implement, within the GCMRC, the concepts of adaptive management and ecosystem science called for in the Grand Canyon Protection Act (GCPA) and the Glen Canyon Dam Environmental Impact Statement (GCDEIS, 1995). The Strategic Plan is designed to be a guidance document, from which annual monitoring and research plans will be drafted over the period 2000-2004. The Strategic Plan presents brief historical documentation of past science, as well as more in depth discussion of planned future monitoring and research programs. An appropriate starting point is discussion of historical science in the Grand Canyon.

SCIENCE IN THE GRAND CANYON

The first formal scientific investigations in the Grand Canyon and associated riverine area were conducted by John Wesley Powell (Powell 1869). Powell's scientific investigations included technical assessments of physical and cultural resources associated with the Grand Canyon Region, including the first ethnographic study of indigenous peoples. Powell's profound accomplishments resulted, in part, in the founding of the U.S. Geological Survey. Since Powell's initial investigation, significant scientific studies have been conducted in the Grand Canyon by many differing individuals, groups, and institutions.

In the first half of this century, economic interests paralleled scientific interest in the canyon. The Colorado River represented a significant opportunity to harness extensive hydroelectric power and provide water storage for growing agriculture and urban development in the Southwest. These interests culminated in the completion of Glen Canyon Dam in 1963, a facility that impounded over 25 million acre feet of water in Lake Powell.

Glen Canyon Dam was heralded as an economic and recreational resource for peoples of the Southwest. It was also criticized as a man-made instrument that destroyed valued Colorado River resources, both upstream and downstream of the Dam. Concerns over potential damage to downstream resources have been persistent since 1963, and relate to both the existence of the dam and operating criteria used for power generation.

Widespread interest in the potential operating impacts of Glen Canyon Dam on river resources resulted in the establishment of the Glen Canyon Environmental Studies (GCES) Program by the Bureau of Reclamation (BOR) in 1982 (NRC 1987). That program operated until October 1996, and accumulated extensive research information on biophysical, cultural, and socio-economic resources. There has also been significant study of canyon resources by organizations and individuals not directly affiliated with the GCES Program. These projects were ongoing before establishment of the GCES program, and they have continued through the duration of that program. Unlike these projects, GCES had unified themes in several resource areas.

The GCES Program general mission was to investigate relationships between Glen Canyon Dam operations and changes in Colorado River resources throughout Grand Canyon. Although some effects of flow regulation were relatively obvious in 1982, many other cause-and-effect relationships and ecosystem links between Glen Canyon Dam operations and the downstream river environment were poorly understood. (Howard and Dolan 1981, Turner and Karpiscak, 1980; Laursen et al. 1976, Dolan et al. 1974).

The GCES Program was conducted in two phases: Phase I from 1982-1988 and Phase II from 1990-1996. Phase I studies involved Federal and state agency related research, with some studies and summary efforts extending to 1988. The program included descriptive studies of aquatic and terrestrial biology, avifauna, sediment-transport processes, hydrology, and recreational use. The results of Phase I research were presented as a series of single discipline technical reports and publications (DOI 1988a, 1988b). These studies confirmed that dam operations affected downstream resources. However, 1983 through 1986 were high inflow years and the resulting reservoir spills limited scientific understanding of effects from low fluctuating flows resulting from typical hydropower operations, the primary focus of the original research.

Following their review, the National Research Council (NRC) commented that despite extensive research during Phase I, the GCES single-discipline reports lacked integration (NRC 1987). No conceptual ecosystem model had been developed to guide hypothesis testing, and the resulting understanding of the system was therefore less complete than it could have been had the studies been integrated from the start. For example, information on hydrology and organic material in the water column had not been brought together with information on humpback chub diet, to examine food availability over time and space. To provide deeper insight into the implications of initial research, documentation was prepared to summarize the results and conclusions of Phase I research (DOI 1988b).

The NRC concluded that the GCES Program had demonstrated that impacts on Grand Canyon resources were related to Glen Canyon Dam operations could be reduced (NRC 1987). In 1988, the DOI concluded that additional technical information was needed before dam operations could be modified in order to minimize impacts on downstream resources. A Phase II program was then launched encompassing a broader base of resources, to respond to external criticism.

Phase II planning studies began in 1988. At the recommendation of the NRC, a senior scientist was appointed to provide direction and oversight for the overall GCES science plan (Patten 1991).

Shortly after Phase II studies began, the DOI mandated an Environmental Impact Statement on the operation of Glen Canyon Dam. The goals and schedule of Phase II studies were then modified and accelerated to support the Environmental Impact Statement process. This (BOR 1995) redirection of Phase II studies eliminated aspects of integration that had originally been planned, in favor of rapid evaluation of areas of special concern for the environmental impact studies (Graf 1990, Webb et al. 1991, Melis and Webb 1993, Melis et al. 1994, McGuinn-Robbins 1995, Melis et al. 1995, Schmidt and Rubin 1995, Stevens et al. 1995, Stevens and Wegner 1995, Webb and Melis 1995, Webb 1996, Webb et al. 1996).

At present, relationships between the geomorphic framework of the Colorado River, including its hydrology, geology and sediment, and its aquatic and riverine habitats and related resources, are only partially understood despite considerable research efforts aimed at understanding the individual components of the river system.

Phase II studies included research on sediment transport (e.g., Schmidt and Graf 1990, Andrews 1991, Cluer 1991, Cluer and Carpenter 1993, Kaplinski et al. 1993, Schmidt 1993, Schmidt and Rubin 1995, Wiele et al. 1996), physical and hydrological synthesis (Andrews 1991), Dawdy 1991), organic drift (e.g., Angradi and Kubly 1994, Ayers and McKinney), benthic ecology (Blinn et al. 1992, 1993, 1994, Shannon et al. 1994, Stevens et al.1995, Angradi and Kubly 1993, Ayers and McKinney 1995, 1996, Pinney 1991), photosynthetically available radiation (Yard et al. 1993), water quality studies (e.g., Ayers and McKinney 1996, Verneiu and Huetfle 1996, Bennett et al. 1994), biological synthesis (e.g., Blinn and Cole 1991, Minkley 1991), life history characteristics of humpback chub (e.g., Kubly 1990, Valdez et al. 1991, 1992, Valdez and Ryel 1995; Gorman 1994; Gorman and Meretsky 1996;), fish habitat (Gorman 1992, Mattes 1993, Converse 1996), other native fish (Weiss 1993), avifauna (e.g., Brown et al. 1989, Brown and Leibfried 1990, Brown et al. 1992), vegetation (Stevens et al. 1991, Stevens and Ayers 1991, recreation (Kearsley and Warren 1993, Kearsley et al. 1995), archeology (Herford et al. 1993, Fairley et al. 1994).

The extensive data base and understanding developed as a result of GCES Phase I and Phase II activities and the GCDEIS (BOR 1995) provides a rich foundation of knowledge upon which the GCMRC program will build. The GCMRC is privileged to have that information as a starting point.

CHAPTER 2

GCMRC PROGRAM JUSTIFICATION AND MISSION

The rich history of research and information developed primarily by the Bureau of Reclamation GCES Program, the GCDEIS (BOR 1995) and National Park Service, has provided information of the impacts of dam operations on selected resources. Interested parties and agencies who are charged to protect and manage these resources have realized that effective protection and management will only be attained through an improved understanding of the interacting components of the system, via ecosystem assessments using information derived from monitoring and research efforts. Further, these efforts will be greatly enhanced, if they are accomplished within a well structured adaptive management program (BOR 1995).

Stakeholder concern over a need to understand impacts to canyon resources from an ecosystem perspective has resulted in the Adaptive Management Program (AMP) called for in the Grand Canyon Protection Act of 1992 (GCPA) (PL-102-575), and the Glen Canyon Dam Environmental Impact Statement (GCDEIS) (BOR 1995). The Act and GCDEIS direct the Secretary of the Interior to **"establish and implement long-term monitoring programs and activities that will ensure that Glen Canyon Dam is operated in a manner consistent with that of Section 1802**" of the GCPA. "**Long-term monitoring of Glen Canyon Dam shall include any necessary research and studies to determine the effects of the Secretary's actions under Section 1804 of the law on the natural, recreational, and cultural resources of Grand Canyon National Park and Glen Canyon National Recreation Area**." The monitoring information is necessary to **"protect, mitigate adverse impacts to, and improve the values for which Grand Canyon National Park and Glen Canyon National Recreation Area were established, including but not limited to natural and cultural resources and visitor use**."

The Secretary's actions shall be implemented "**in a manner fully consistent with and subject to the Colorado River Compact, the Upper Colorado River Basin Compact,**

the Water Treaty of 1944 with Mexico, the decree of the Supreme Court in Arizona v. California and the provisions of the Colorado River Storage Project Act of 1956 and the Colorado River Basin Project Act of 1968 that govern allocation, appropriation, development, and exploration of the waters of the Colorado River Basin." Actions of the Secretary will also be consistent with all other Federal and state laws relating to resources, federal, tribal state, and local interests.

GRAND CANYON MONITORING AND RESEARCH CENTER MISSION

The EIS for future operation of the Glen Canyon Dam specifies the establishment of the (AMP) for assessment of Glen Canyon Dam operating criteria as defined in the Record of Decision (BOR 1995), (DOI 1996). The AMP includes development of an Adaptive Management Work Group (AMWG), Technical Work Group (TWG), the Grand Canyon Monitoring and Research Center (GCMRC), and Independent Review Panels to guide and conduct assessments.

The AMWG includes representatives from Federal and state resource management agencies, Native American tribes, and a diverse set of other private and public stakeholders. The AMWG is appointed by the Secretary of the Interior as a Federal advisory committee to work cooperatively with the GCMRC in implementing the AMP (BOR 1995). In adaptive management, the decision and management process should constantly evolve (Lee 1993) with continuous input of new information from the GCMRC.

The mission of the GCMRC is to develop and implement long-term monitoring and related research and other scientific activities to determine "The effects of the Secretary's actions"[4] on the natural, recreational, and cultural resources of Grand Canyon National Park and Glen Canyon National Recreation Area, as well as other information needs specified by the AMWG, utilizing an ecosystem science paradigm. The GCMRC is mandated to inform the AMWG of resource protection, management and use implications of differing operations criteria evaluated.

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[4]As specified in the 1992 GCPA and reflected in the Record of Decision of the Glen Canyon Dam EIS (USDOI 1996).

CHAPTER 3

SCIENCE PROGRAMMING WITHIN ADAPTIVE MANAGEMENT

INTRODUCTION

Figure 3.1 contains a schematic from the GCDEIS of the Adaptive Management Program (AMP) and its critical entities, including the Monitoring and Research Center, now designated as the GCMRC. Following are the defined roles for other specified entities in the AMP.

Secretary of the Interior/Assistant Secretary for Water and Science/Designee: To serve as the Secretary's principal contact for the AMP and as the focal point for issues and decisions associated with the program. Responsibility would include ensuring that the DOI complies with its obligations under the GCPA and GCDEIS. The designee would review, modify, accept or remand the recommendations from the AMWG in making decisions about any changes in dam operation and other management actions.

Adaptive Management Work Group (AMWG): To provide the framework for AMP policy, goals, direction and priorities. Develop recommendations for modifying operating criteria (and plans) and other resource management actions. Facilitate coordination and input from interested parties. Review and forward the annual report to the Secretary and his designee on current and projected year operations. Review and forward annual budget proposals. Ensure coordination of operating criteria changes in the Annual Operating Plan for Colorado River Reservoirs and other ongoing activities.

The Adaptive Management Program and processes for determining future operations of Glen Canyon Dam

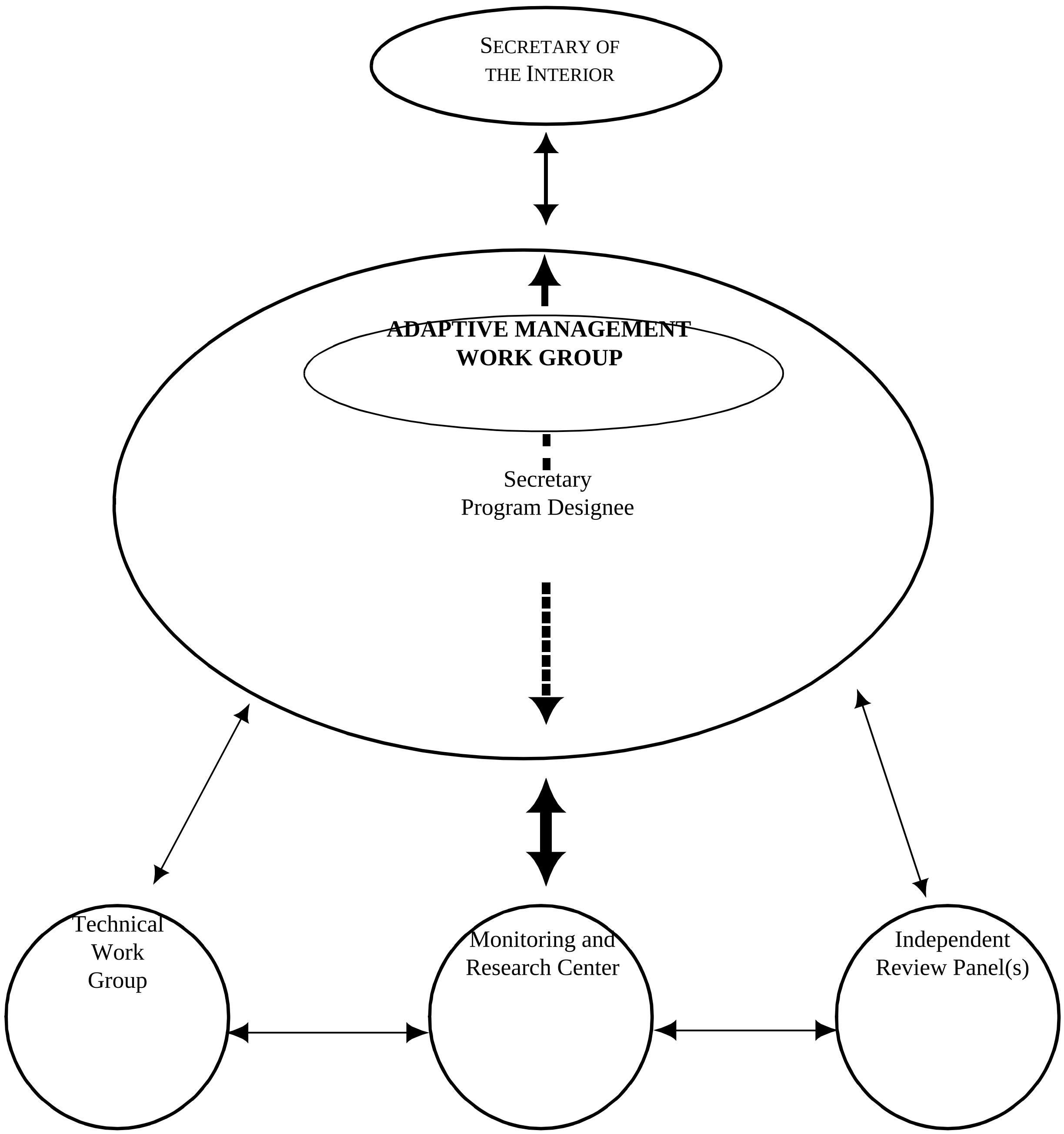


Figure 3.1. Adaptive Management Program Entities.

Technical Work Group (TWG): To articulate to the GCMRC the science and information needs expressed in the objectives defined by the AMWG, and to assist in recommending science priorities.

Independent Science Review Panel(s): Independent science advisory boards and review panels will provide independent science assessments of proposed research plans and programs, technical reports and publications and other program accomplishments.

Grand Canyon Monitoring and Research Center: The mission of the GCMRC is to develop and implement long-term monitoring and related research and other scientific activities to determine "The effects of the Secretary's actions" on the natural, recreational, and cultural resources of Grand Canyon National Park and Glen Canyon National Recreation Area, as well as other information needs specified by the AMWG, utilizing an ecosystem science paradigm.

ADAPTIVE MANAGEMENT

Adaptive management begins with a set of management objectives and involves a feedback loop between the management action and the effect of that action on the system (Figure 3.2 [USFS & BLM, 1994]). It is an iterative process, based on a scientific paradigm that treats management actions as experiments subject to modification, rather than as fixed and final rulings, and uses them to develop an enhanced scientific understanding about whether or not and how the ecosystem responds to specific management actions.

The process begins with the definition of a series of management objectives defined by stakeholders and managers of the system. Once management objectives have been articulated and agreed to, management actions based on current "state-of-the-science" assessments can be taken to achieve these objectives.

An important interim step in this process is to allow for a dialogue between managers, stakeholders, and scientists who are knowledgeable about the system in question. Such a dialogue provides an opportunity for scientists to "reality-test" management objectives. That is, if managers wish to attempt to manage a system for a given outcome that is not feasible, it is important that they understand that at the outset. Experience has demonstrated that such a "scientific reality-testing"

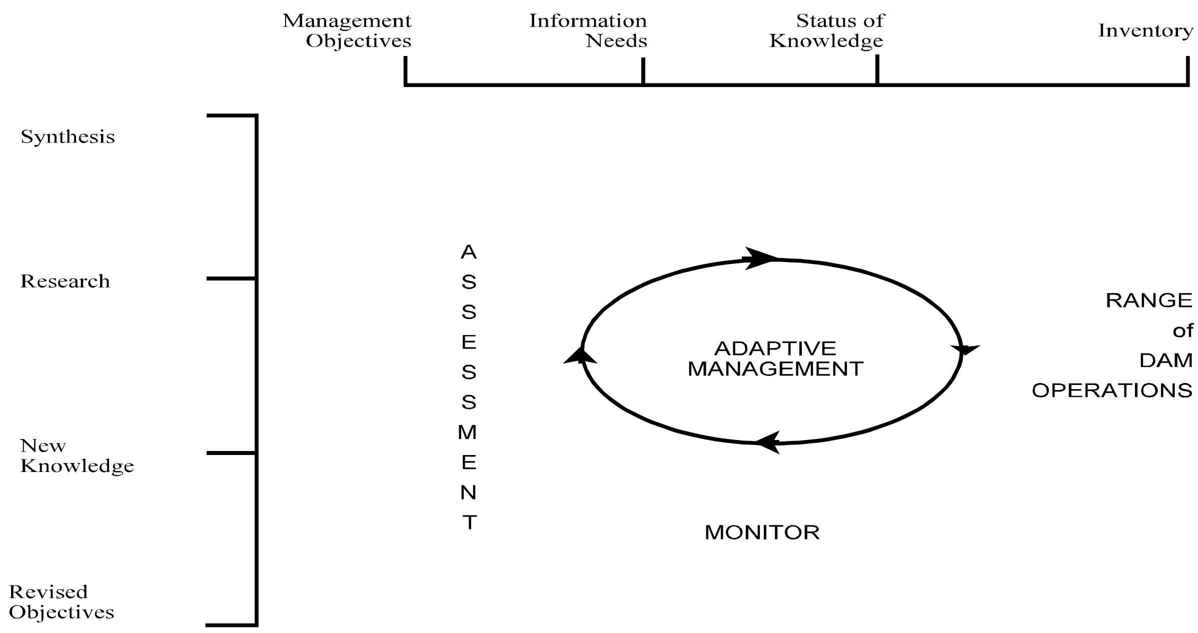


Figure 3.2. The Grand Canyon Monitoring and Research Center's approach to Adaptive Management (modified from USFS and BLM, 1994).

of management objectives leads to a better outcomes in the long-run. Bridging the culture between scientists, managers, and stakeholders takes commitment and effort.

According to Lee (1993), "An adaptive policy is one that is designed from the outset to test clearly formulated hypotheses about the behavior of an ecosystem being changed by human use. In most cases, these hypotheses are predictions about how one or more important species will respond to management actions." An adaptive design permits learning from a policy action, so that future decisions can proceed from a better knowledge base.

Understanding derived from inventory, monitoring, and research efforts are used to predict how the resources of interest will both interact and respond to alternative management actions. The system is monitored to see if it responds to the management actions as predicted. Learning takes place as a result of the monitoring, and the management actions are adjusted in response to new knowledge or insights regarding ecosystem functioning. In most instances, a research program coupled with the monitoring program, is required to discern the nature of the cause and effect relationships indicated by the monitoring program.

Lee (1993) points out that, "Reliable knowledge comes from two procedures: controls and replication. Replication is essential because if knowledge is reliable it can be shown to work more than once; real relationships between cause and effect will show up consistently."

What is unique about an adaptive management approach to decision making is not simply the existence of a feedback loop between the management action and outcome, but rather the use of an explicit monitoring and experimental design that has appropriate controls and statistical power required to test hypotheses: that is to determine if the management action did in fact have the desired (predicted) effect.

ADAPTIVE MANAGEMENT AND ECOSYSTEM MANAGEMENT

Several steps are required to undertake successful ecosystem management within an adaptive management framework. Ecosystem management requires the ability to see the ecosystem as a whole in some fashion. Baseline ecological information must be gathered and synthesized. Models that integrate the interactions among ecosystem components (e.g., population trends, water quantity and quality and other habitat variables) must be developed.

Research must be undertaken to examine cause and effect relationships as a basis for predicting the ecological consequences of alternative management actions and to discern the relative importance of various factors that may impact ecosystem function and provide predictive linkages between species, communities, and the physical setting. Models of these relationships must be developed and tested at appropriate spatial and temporal scales. Models are important tools for organizing data and knowledge and describing the relationships that are believed to represent the important factors affecting the behavior of the system. Models can be used to explore comparison across time or space among biological parameters of interest. These models must be validated and refined in response to the data generated from the monitoring of key ecosystem parameters. Models can also be used to simulate the behavior of the system as a means of testing assumptions about the factors believed to affect the dynamics of the system, to evaluate monitoring data, and to refine hypotheses for testing through experimentation.

THE ROLE OF SCIENCE

The GCMRC was established to conduct independent scientifically rigorous investigations in response to prioritized management objectives and information needs determined by the AMWG. Management and science information will be transmitted constantly (Lee 1993) between the GCMRC and AMWG via the adaptive management process. Science is a powerful mechanism to learn about natural processes for prioritizing outcomes of management actions associated with uncertainty and risk, and for recognizing significant outcomes from unexpected responses. Science will be used to provide critical information and technology to managers and stakeholders in the AMWG, so they can better define management, protection, and use practices appropriate to both dam operations and management of physical, biotic, cultural, and human resources in the canyon.

GCMRC PROGRAMS

All GCMRC monitoring and research programs will adopt ecosystem science approaches, which will require integrated resource scientific assessments across space and time. These techniques represent progressive methods for advancing both science and management capabilities, while supporting enhanced protection, management, and use of natural resources.

Long-term monitoring and research activities are used for a variety of purposes including, but not limited to, assessing: 1) natural ecosystem conditions, 2) trends of attributes, 3) definition and refinement of decision criteria, 4) effectiveness of developed decision rules, 5) project impacts, 6) model efficacy, and 7) compliance with standards on resource conditions (MacDonald et al. 1991). Many of these purposes are attributable to the evaluation of the impacts of Glen Canyon Dam operations.

Long-term monitoring

Long-term monitoring is defined here as the repetition of measurements of selected environmental attribute(s) over an extended period of time to determine status or trend in the environmental attribute(s) being monitored. These measurements are made over a period of time and they are different from an inventory. Inventories are a measurement, or a number of measurements, made at a specific point in time. They are often used to establish baseline conditions to which all other measurements are compared, and they are generally the first step in conducting a monitoring effort. The distinguishing attribute of a monitoring effort is the measurement of possible change over time.

Long-term monitoring is conducted to detect and project both expected and unexpected changes in this ecosystem, across time scales as related to the ROD-designated preferred alternative. It will also be utilized to establish current baseline conditions for resources and determine the effects of differing operations criteria on current and pre-dam resource baselines. This portion of the program is expected to be relatively stable, dependent upon consistent methodologies, and modified only after in-depth evaluations. Specific protocols will be developed and reviewed at different intervals for scientific relevance. Maintenance of long-term databases and archives is an essential element of the monitoring program.

Monitoring programs will be developed through cooperative efforts by the TWG and GCMRC and review by the AMWG. Annual monitoring activities will be developed through competitive selection processes that include an open call for proposals and open competition.

All monitoring implemented will include independent peer review of proposals, and GCMRC consultation with the AMWG. Criteria for selection of differing proposals will include support of management information needs, scientific capability and merit, and cost effectiveness. Projects and programs will be administered as contracts, cooperative agreements or interagency agreements.

All monitoring data sets will be accessible to outside investigators and interested parties through developed information and technology services, except for selected sensitive data restricted by law, such as endangered species and cultural resource locations or proprietary information such as utility rate structures. All maps, databases, archiving, and retrieval procedures will conform to Federal standards.

Research

Research as defined here is the measurement of environmental attribute(s) to test a specific hypothesis or provide descriptive assessments. Research will be used to interpret and explain trends observed from monitoring, to determine cause and effect relationships and resource associations, and to better define interrelationships among physical, biological, and social processes. Research will play an important role in development of integrated methods of monitoring, prediction of key physical and biological processes, definition of resource interactions, and development of ecosystem models. Research programs will be developed through cooperative assessments by the TWG and the GCMRC with review by the AMWG. Research will be founded in the ecosystem science paradigm. However, other appropriate methods may be used to evaluate traditional and cultural values.

The proposed long-term monitoring and research program for the river corridor in Glen and Grand Canyon is not equivalent to a long-term science plan for the entire river corridor ecosystem. It is critical to distinguish this program, whose intent is the monitoring and research of impacts of operations of Glen Canyon Dam on the Colorado River ecosystem. This mission meets the objectives of EIS, the 1992 GCPA and resource management agencies and interested stakeholders.

GCMRC's mission is constrained by design. For this reason upstream monitoring in Lake Powell, and in tributaries, (i.e. Little Colorado River), is constrained to those probable impacts on downstream resources associated with dam operations. All parties involved realize these to be constraints that inhibit understanding of the entire system. Nevertheless, the ultimate purpose of this program is to monitor resource changes in the Colorado River ecosystem that are explicitly related to dam operations.

Information Technologies

Information technologies, including information archiving and transfer is a third critical part of GCMRC programming. The program will be directed primarily toward managers and stakeholders, including representatives of the Bureau of Reclamation (BOR), National Park Service (NPS), Fish and Wildlife Service (FWS), Native American tribes, associated state resource agencies, and a broad cross section of other non-government and non-management entities. The GCMRC views this part of the science program as critical to realizing the full benefit and power of the AMP.

Information archiving will be based on collection of information from monitoring and research projects under prescribed protocols, including, but not limited to, electronic, written, photographic and video format. New GCMRC information will be added to information previously developed under the GCES Program with metadata collected for each research and monitoring element. Selected information will be archived and available only to specific parties. For example, restricted data access protocols are being developed regarding proprietary information such as locations of cultural resources and endangered species.

Information transfer programs will utilize a broad array of methods to bring monitoring and science information to users. This will include computer access, Internet connections, computer tapes and disks, audio and video tapes, reports, publications, symposia, workshops, briefings, etc.

REQUEST FOR PROPOSALS (RFPS) AND PEER REVIEW

As recommended by the NRC (1996), GCMRC utilizes a competitive proposal solicitation process open to government employees, public-section contractors, and universities through an open Request for Proposals (RFPs). Monitoring and research projects are selected on the basis of their scientific merit, submission timeliness on previous work (as evaluated through an independent, objective and unbiased peer review process), relevance to management objectives and information needs, demonstrated capabilities of proposers, and cost effectiveness. Following the selection of proposals, appropriate procurement mechanisms (i.e., grants, contracts, cooperative agreements) are utilized for supporting selected projects.

GCMRC's commitment to ensuring the high quality of the scientific information produced by its programs highlights the importance of peer review at all levels of GCMRC scientific activities. GCMRC is committed to the use of scientific peer review for all GCMRC proposals, programs, publications, and other products; to clearly convey the unambiguous standard of scientific objectivity and credibility followed by GCMRC.

GCMRC's guidelines for scientific peer review ensure that GCMRC matches the level of peer review to the nature of the proposal, program, publication or other product being reviewed, and describes the selection of qualified scientific peers, independence of the review process, and the inclusion of external (i.e., outside GCMRC) reviewers in the scientific peer review process.

In general, following approval by the AMWG of the strategic plan, an annual monitoring and research program will be completed and approved each year in April. After approval of the annual monitoring and research plan, RFPs will be issued. All proposals will undergo an independent and objective scientific peer review. Awards will be made on the basis of the results of peer review, along with the program manager's evaluation of project relevance, and technical contracting requirements.

GCMRC's peer review guidelines are consistent with the "U.S. Department of the Interior Guidelines for Scientific Peer Review of Research" issued by the Secretary of Interior. These include:

- Objectivity and independence of reviews.
- Reviews conducted by true scientific peers, as judged by demonstrable scientific achievements.
- Independence of peer reviewers.
- Provision of constructive feedback to the investigator.
- Anonymity for peer reviewers, unless waived.

- Periodic evaluation of the effectiveness of the GCMRC peer review process.

GCMRC'S SCIENCE ADVISORY BOARD (SAB)

To ensure that the long-term monitoring and research activities initiated by GCMRC are unbiased and objective, scientifically sound, and focused on the most important issues, an independent Scientific Advisory Board (SAB) will be established to advise GCMRC on the coordination and planning of its monitoring and research programs, and to review the results of GCMRC's monitoring and research programs. The SAB is synonymous with the Independent Science Review Panel (ISRP) specified in the GCDEIS (BOR 1995). The SAB will be an advisory and not a decision-making body, but both the GCMRC and the AMWG should be prepared to explain why it has accepted or rejected advice provided by the SAB.

The SAB will be an interdisciplinary board, composed of scientists who are qualified, based on their record of scientific achievement, in a range of disciplines related to the work of GCMRC. Scientists will be selected for their expertise and not as representatives of a particular agency, organization, or other stakeholder group.

Members will be selected for a three-year term, renewable for one consecutive three-year term. The initial members of the SAB will be selected for staggered one, two, and three year terms, to ensure that their is continuity in membership on the SAB and that all of the members do not turn over at one time.

The SAB will be expected to meet at least twice each year and to provide ongoing consultations to any of the GCMRC's program managers. All meetings of the SAB and any reports produced by the SAB will be open and available to the public.

Consistent with government regulations, where appropriate, SAB members will be reimbursed for their time spent reviewing and commenting on GCMRC materials, activities, and programs. SAB members will be prohibited from competing for GCMRC long-term monitoring and research awards while they serve on the SAB and for two-years following completion of their term of service.

ADMINISTRATION

Administration of GCMRC programs will be accomplished by a staff of 10-12 permanent full-time science and technical specialists and 8-10 term-appointed specialists. The Chief, three Program Managers representing physical, biological, and cultural and socio-economic resource disciplines along with an Information/Technology Program Director, will comprise the primary program management positions in the Center. The Cultural Resource Program Manager will direct all Native American program coordination across resources, and socio-economic monitoring and science programs.

The GCMRC Chief's primary responsibility will be to provide adaptive management and ecosystem science leadership for program planning and design, implementation, and interpretation. The Chief also provides external liaison to the office of the Secretary, other agencies, Native American tribes, non-governmental organizations and the public. Program Managers will exercise primary responsibility, with the Chief, for science interpretation in their resource areas.

The program managers will be supported by research analysts and a senior research/field scientist. In addition, GCMRC will retain in-house surveying capability, needed to ensure consistency and continuity with respect to the accuracy of the physical location of sites and resources to be monitored. Finally, GCMRC will also provide logistical planning and support to scientists proposing work in response to program solicitations. As appropriate the above duties and responsibilities will be carried out by permanent full-time or term employees.

CHAPTER 4
STRATEGIC RESEARCH PLANNING UNDER REVISED PARADIGM AND INSTITUTIONAL CONSTRAINTS

The Grand Canyon is a unique, complex and dynamic environment. It is also a highly regulated system, in terms of river flows and use. Its uniqueness demands careful stewardship. In the face of evolving scientific understanding about the Grand Canyon's riverine ecosystem, it is not yet possible to identify only a few attributes that characterize the entire system. In light of this uncertainty, it would be irresponsible to restrict science within the river corridor ecosystem to a very small number of attributes and assume that all other attributes are related to those measured.

This proposed program is designed to evaluate resource changes and impacts associated with differing dam operating criteria, and it must accomplish assessments utilizing an ecosystem science paradigm, and in a cooperative adaptive management program with all concerned stakeholders. The program attempts to strike a balance between the extremes of: 1) very restricted monitoring which recognizes the impacts of scientific study on the essence of what the Grand Canyon means to most humans, and 2) full measurement of all ecosystem attributes predicated on a belief that an unmeasured parameter might be critical at a later time.

CRITICAL ATTRIBUTES

The monitoring and research programs emphasize measurement of attributes deemed critical for evaluating resource effects of alternative operations of Glen Canyon Dam. The prediction and significance of potential attribute response to dam operations is discussed in four general program areas, i.e., physical, biological, socio-economic, and cultural. Under the long-term monitoring program, responses of these critical attributes will be used in adaptive management decisions. Critical attributes developed in the Glen Canyon Dam EIS process, and utilized in this Strategic Plan follow:

1. Quantity and quality of water from Lake Powell and in the Canyon.
   a. annual stream flows in mainstem and key tributaries
   b. discharge rates and lake volume and spill frequency
   c. chemical, physical and biological characteristics of water in Lake Powell and the Colorado River from Glen Canyon Dam to Lake Mead.
2. Sediment supply and transport.
   a. stored riverbed sand
   b. mainstem and eddy complex interactions
   c. elevated sandbar erosion
   d. dynamics of debris fans and rapids
   e. tributary stream dynamics and sediment flux; backwaters
   f. nutrient dynamics
3. Fish.
   a. aquatic food base
   b. reproduction, recruitment and growth of native fishes
   c. reproduction, recruitment and growth of non-native warm water and cool water fishes including trout
   d. habitat condition and availability
   e. competition parasitism and predator-prey interactions
4. Vegetation.
   a. area and species composition of riparian plants
   b. area and species composition of emergent marsh plants
5. Wildlife and wildlife habitat.
   a. area and species composition of riparian habitat for associated vertebrates and invertebrates
   b. aquatic food base for terrestrial vertebrates
6. Endangered and other special status species, their habitat and food base.
   a. humpback chub
   b. razorback sucker

c. bald eagle
d. peregrine falcon
e. southwestern willow flycatcher
f. belted kingfisher
g. Kanab ambersnail
h. other federal and state species of concern

7. Cultural resources.
   a. archaeological sites directly, indirectly, or potentially affected such as those on high water terraces
   b. Native American traditional cultural properties directly, indirectly, or potentially affected
8. Recreation.
   a. fishing trips and angler safety
   b. day rafting trips attributes and access
   c. white-water rafting trip attributes, camping beaches, safety, and wilderness values
   d. navigability
   e. net economic value and regional economics
9. Hydropower production to network and customers at lowest costs.
   a. changes in power operations
   b. power marketing benefits lost or gained
10. Non-use valuation.
   a. values placed on Glen and Grand Canyon riverine system by the public

This program also adopts a conservative approach of measuring attributes that reasonably might be affected by dam operations, and for which no surrogate attributes exist. <u>However, this program does not propose monitoring or research of those attributes clearly unrelated to "... the effect of the Secretary's actions," or those which are adequately represented by other parameters</u>. It also emphasizes use of data collected in the Grand

Canyon that are not field intensive. Wherever possible, monitoring will be conducted using non-invasive means.

The program is designed to respond to short- and long-term management objectives and information needs of resource management agencies and stakeholders. Acceptance of changing conditions of each of the above attributes as it responds to dam operations is contingent upon these management objectives. A change in an attribute, determined through the long-term monitoring program, may represent a deviation from an acceptable condition (determined by management agencies and interests) that would trigger consideration of changes in dam operations.

THE GEOGRAPHIC SCOPE OF MONITORING AND RESEARCH PROGRAMS

The area to be monitored is defined as the Colorado River mainstem corridor and interacting resources in associated riparian and terrace zones, located primarily from the forebay of Glen Canyon Dam to the western boundary of Grand Canyon National Park, a distance of approximately 300 river miles. The scope of GCMRC activities also includes limited investigations into some tributaries (e.g., the Little Colorado and Paria Rivers (Figure 4.1). This area is about 270-280 river miles long, as the headwaters of Lake Mead vary with reservoir elevation. Because the Lake Mead shoreline ecosystem is greatly affected by the reservoir operations and the existence of Hoover Dam, the Grand Canyon monitoring and research program ends at approximately Separation Canyon (RM 280), the generally accepted head of Lake Mead. The program in following the GCPA includes the riverine corridor in the Grand Canyon National Park ending at river mile 293. However, the effects of fluctuations in Lake Mead and the influence of changes in the Colorado River below Separation Rapids resulting from dam operations might be considered as extensions of the geographical scope of the long-term monitoring program. The program also includes the monitoring of selected attributes in LP that may be affected by dam operations and also have the potential to affect downstream resources.

The lateral extent of the monitoring effort is defined by the extent of processes and conditions influenced by dam discharges and river flows associated with operating criteria in the ROD. The relevant lateral study zone area is the maximum regulated discharge and the inundated

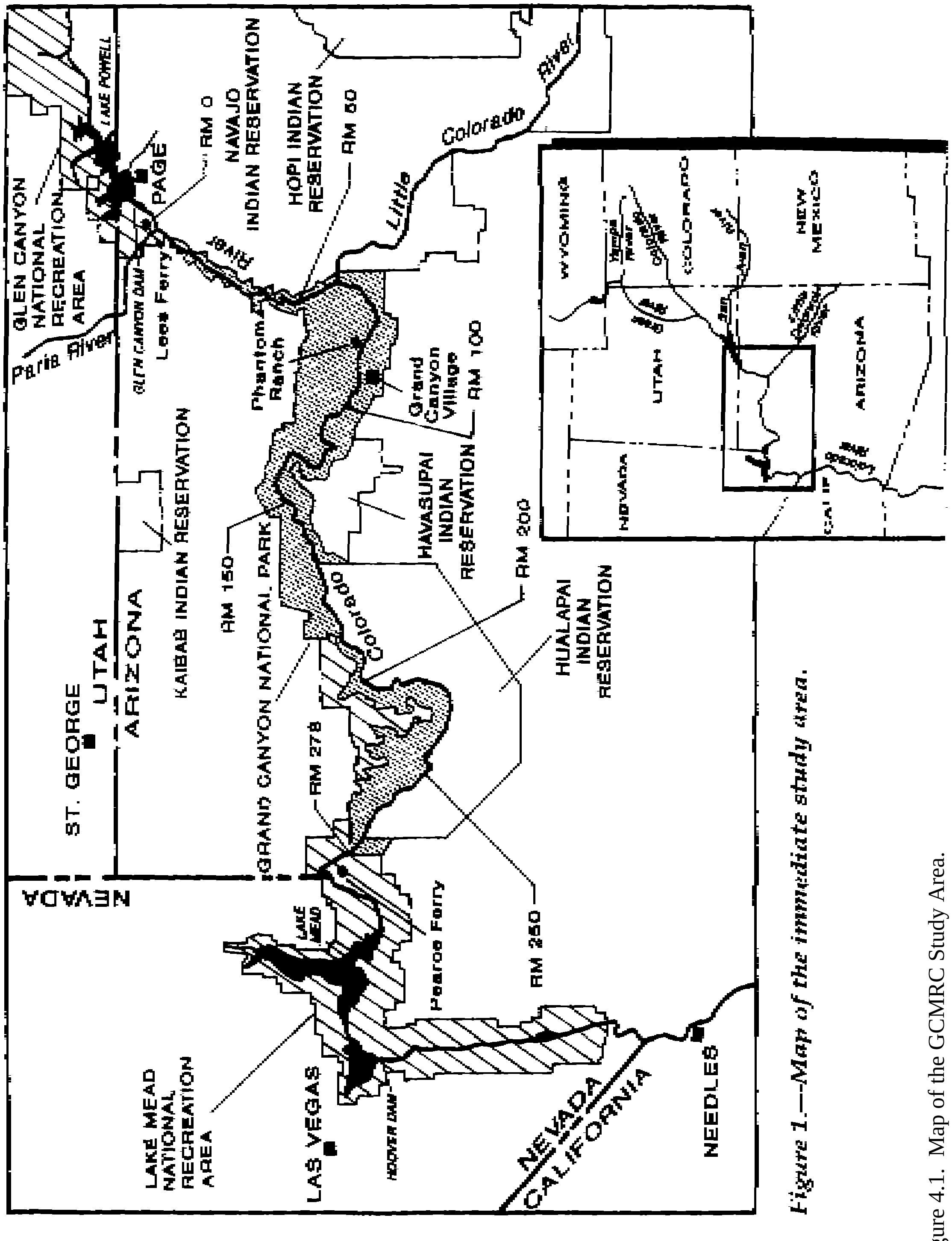
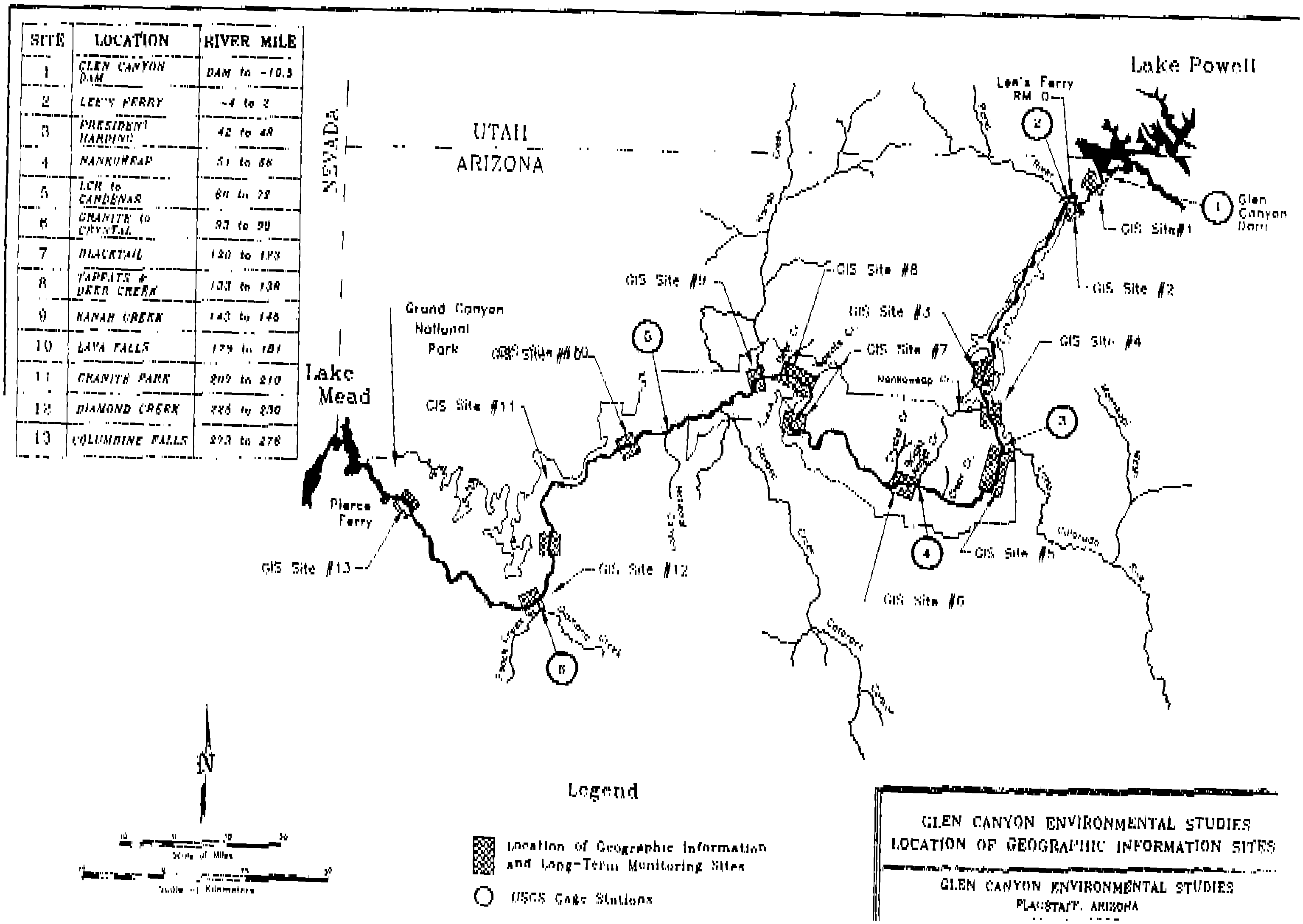


Figure 1.—Map of the immediate study area.

Figure 4.1. Map of the GCMRC Study Area.

area for mean annual pre-dam peak flow of 90,000 cfs. However, the old high-water zone vegetation community begins at about this elevation and extends to higher levels. Arroyo head cutting caused by current low flow operations may extend above this level. Thus, it is prudent in some areas of the Canyon to include elevations above the stage associated with a discharge of 100,000 cfs.

Thirteen reaches, varying in length between 2 and 12 miles were established by GCES as Geographic Information System (GIS)-reaches (Figure 4.2), and detailed topographic data at a scale of 1:2400 are available for these reaches. These sites were selected because they represent reaches of the Colorado River in which there were ongoing studies or potentially important ecological conditions. Although the scientific basis for their selection did include considerations of the long-term representativeness, at some point data on all reaches will eventually be put into the GIS. As a consequence, additional sites may be selected as programs proceed, to adequately represent geomorphically distinctive reaches.



SITE	LOCATION	RIVER MILE
1	GLEN CANYON DAM	DAM to -10.5
2	LEE'S FERRY	-4 to 2
3	PRESIDENT HARDING	42 to 48
4	NANKOWEAP	51 to 58
5	LCR to CARDENAS	60 to 72
6	GRANITE to CRYSTAL	93 to 99
7	BLACKTAIL	120 to 123
8	TAPEATS & DEER CREEK	133 to 138
9	KANAB CREEK	143 to 148
10	LAVA FALLS	179 to 181
11	GRANITE PARK	209 to 210
12	DIAMOND CREEK	226 to 230
13	COLUMBINE FALLS	273 to 276

Figure 4.2. Map of the GIS-reaches established by GCES (March, 1992).

CHAPTER 5

DEFINING STAKEHOLDER OBJECTIVES AND INFORMATION NEEDS

MANAGEMENT OBJECTIVES AND INFORMATION NEEDS

Introduction

In the Spring of 1996 management objectives were initially developed by a working group of stakeholders organized by the Upper Colorado Regional Office of the BOR. Many stakeholders that participated in this group are now also in the Adaptive Management Work Group (AMWG) and the Technical Work Group (TWG) providing continuity for the Adaptive Management Program (AMP). Since the BOR was responsible for the GCDEIS and drafting the Charter for the AMWG, it was appropriate that they facilitated the workshops to formulate management objectives. The purpose of the management objectives is to define measurable standards of desired conditions which will serve as targets expected to be achieved by the AMP.

Information needs were also formulated during 1996 with participants in the program. Several workshops were held to define the information needs that were associated with the various management objectives. These information needs were reviewed by the stakeholders and scientists to assess existing information and applicability to the management objectives.

In early 1997, discussions were held with the Transition Work Group and later the TWG and AMWG about revisiting and possibly revising the management objectives and information needs. In the July 1997 meeting of the Adaptive Management Work Group, the AMWG requested the Technical Work Group proceed with evaluation and revision of Management Objectives and Information Needs. The revision represents a concerted effort by the stakeholders to identify objectives as desired resource conditions sought by various stakeholders. The revised information needs clarify required monitoring and research activities to assist stakeholders in determining the condition of these resources, and how conditions are affected by management actions.

Revision Process

Starting in January 1998, a volunteer ad hoc group from the TWG met to address the Management Objectives and Information Needs as well as out year budget planning. Approximately 10 to 25 members of the TWG met several times to discuss these matters. (Table 5.1.)

Meetings were held to discuss general procedures for the revision process and the objectives and information needs by resource area. Five workshop sessions were held between January 28, 1998 and April 9, 1998, to discuss these issues. Table 5.1 provides information on the meeting schedule. The purpose of the meetings was to review and revise management objectives and information needs, to establish relative priorities by study type, resource class, and research/monitoring question. The group was also tasked with reporting to the TWG during the process and to present recommendations on the revised information to the AMWG for adoption. The revised management objectives and information needs are the foundation to formulate annual plans and they will be reviewed and revised annually.

Prioritization of Information Needs

The expanding information needs has created an increasing demand upon GCMRC to accomplish all desired projects in a timely manner. To allow the GCMRC to continue to address expanding needs, time related priorities were established for all information needs. The prioritized information needs are listed in Appendix B. The established priorities will permit the GCMRC to stage the various information needs currently specified by stakeholders over years FY2000 to 2004. High priority information needs will be initiated in years FY2000 and FY2001 whereas other monitoring and research needs may be delayed for initiation until FY2002 or beyond. It is anticipated that some monitoring and/or research activities on all information needs currently proposed by stakeholders can be initiated in the next 5 years. Because the information needs are so extensive, and because many relate to annual or intermittent monitoring requirements, it is anticipated that less than a third of the information needs specified will actually be completed in the 5-year planning period. For example, much monitoring is expected to continue into an extended 10-year program.

Fourteen stakeholders prioritized information needs on April 23, 1998. The prioritization process was based on the time for initiation of the studies; no implication was

Table 5.1 Management Objectives/Information Needs Ad Hoc Group

Purpose/Goals: Review/revise MO's & IN's, establish relative priorities by study type, resource class, research/monitoring question. Report to TWG until finished. Present to AMWG for adoption. Use as foundation to formulate annual plans. Review & revise annually.

1998 Meetings	Objectives/Activities
Jan 20	Ad Hoc Group formed at TWG Meeting
Jan 28 Rev. 1/28	Review & revise 7/2/96 MO's Biological Hydropower Lake Powell Cultural Physical Recreation
Feb 17-18 Rev. 2/17	Review Vegetation & Fish/Aquatic MO's at TWG Meeting (revised). LP MO's discussed.
Feb 24-25 Rev. 3/4, 3/16	Complete review of MO's. Establish IN's. 1. Step down general categories to specific resources & establish IN's 2. FWS/USBR requested to indicate legal mandates and those which have flexibility 3. Discussed whether daily dam operations affect LP
Mar 24-25 Rev. 3/24, 3/27	Complete IN's for prioritization. Review LP MO's & changes from GCNRA. Finalize.
Apr 9 Rev. 4/16	Review Biological Resources section, GCNRA changes & eliminate dups. Establish IN's.
Apr 23-24 Rev. 5/1, 5/28	Prioritization of Information Needs
May 17	Prioritization process reviewed at TWG
June 9	Review changes to MO's/IN's from river guides & proposal to bring forward to AMWG

Appendix A provides the current version of the revised objectives and information needs. The TWG reviews were completed and the information was presented in July 1998 to the AMWG and approved.

made regarding the value of a specific stakeholder information need. The stakeholders value all objectives and information needs and no ranking was made regarding the differential absolute values of the various information needs. The prioritization relates only to the scheduling of relative information needs. Some of the information needs must be accomplished immediately whereas others could be delayed.

The procedure to prioritize information needs had the following guidelines: 1) GCMRC staff provided technical clarification; 2) Ranking referred to scheduling for start of research or monitoring on a specific information need, no ranking would occur on objectives; and 3) Votes by each stakeholder could only be cast for 55 (approximately one third) of the information needs using two different methods. This was a constraint placed to make sure that greater focus was placed on picking the most critical time dependent information needs.

All information needs were ranked by two methods. Method O was developed across all information needs regardless of category, i.e., biology or cultural resources. For example, a stakeholder could cast all 55 votes for biological information needs. O's were placed beside information needs for these 55 votes. Method X was developed to emphasize information needs within resource areas. Each stakeholder was asked to vote for at least 30 percent of information needs in each resource area. X's were placed for each of the 55 votes.

In Appendix B, information needs are listed in a declining number of votes placed by the fourteen stakeholders who did the ranking evaluation. Those information needs ranking highest, between 8 and 14, were the information needs that this group of stakeholders felt needed to have monitoring and research activity started immediately, that is, within FY2000 and FY2001. Those information needs having a ranking of 0 to 4 are information needs that this 14 member stakeholder group generally felt could be delayed to FY2002 or beyond and still provide value to the Adaptive Management Process.

The rankings in Appendix B do not mean that those information needs ranked between 8 and 14 are more important (except for scheduling) than other information needs ranked lower. Neither do information needs ranked 0, 1 and 2 have less value to stakeholders. They simply have different scheduling priorities for initiation in FY2000 and FY2001.

The prioritization developed by the stakeholders did accomplish, for the GCMRC, the objective of defining information needs that could be delayed in the research and monitoring process. The prioritization was approved by the AMWG in July 1998 and the GCMRC will use this information in programming monitoring and research from FY2000-2004.

The results of the prioritization of information needs by the stakeholders indicate a concern to focus in areas of biology, especially endangered species. Also listed are cultural resources, the water quality program at Lake Powell and aquatic productivity. When this group of information needs is contrasted against information needs on hydropower, water flows, sediment, trout, wildlife viewing, recreation, etc., there are different scheduling priorities.

CHAPTER 6

MONITORING AND SCIENCE PROGRAMS

Presented below are the six primary areas of the Strategic Plan:

1. Conceptual Modeling & Synthesis of Existing Knowledge
2. Physical Resource Program
3. Cultural Resource Program
4. Biological Resource Program
5. Socio-Economic Resource Program
6. Information Technology Program

Conceptual Systems Model

An Adaptive Environmental Assessment Model (i.e., a conceptual systems model) of the Colorado River ecosystem is being developed. This conceptual systems model focuses on the specific management objectives and information needs articulated by the AMWG, managers and other stakeholders. Development and validation of the conceptual model, will provide critical input into the selection of parameters to be monitored based on the known or suspected cause and effect relationships that are identified through the development and implementation of the conceptual systems model. Critical to the development of a sound long-term monitoring and research program is the development of a conceptual systems model of the system being studied.

Good conceptual system models are elegant representations of the ecosystem being studied. That is they are simplifications which contain only the level of complexity needed to describe the behavior being modeled. As such, they are often incomplete representations of the ecosystem under study and their strength–the ability to organize complicated relationships into an understandable framework of study–are also their weaknesses. That is, predictions resulting from models will often, be incomplete and therefore require validation through monitoring, experimentation and testing. Models and their associated data bases have been important tools for use by scientists and managers dealing with complex natural systems (Meadows et al., 1982; Fight et al., 1986). In addition, the process of building a simulation model of an ecosystem provides an opportunity to test assumptions and to develop a shared view among scientists and managers of what is being managed and what the management objectives are.

The development of a conceptual system model of the Colorado River ecosystem is important because it provides a general framework for understanding how the system works, requires organization of many scattered pieces of information, and imposes a rigorous framework on one's thinking. Computer models are precise and consistent require assumptions and relationships to be written out explicitly so they can be criticized and understood by everyone, can contain many variables and keep track of them simultaneously, can be changed and tested quickly, and can provide a platform for thought and simulated experiments (Meadows et al. 1982, Fight et al. 1986).

The conceptual systems model and long-term monitoring program are designed in recognition of the spatial and temporal characteristics of the Colorado River ecosystem in Glen and Grand Canyons. Given the range of spatial and temporal scales at which Colorado River resources function, this may mean that monitoring activities may actually occur only within representative areas of the larger area. The selection of such representative areas will depend upon the process or parameter to be monitored, and the sensitivity or fragility of the resource or habitat.

Similarly, the conceptual system model and associated long -term monitoring programs need to be designed to provide information, over the long-run, on the responses of the Colorado River ecosystem to the long-term operations of Glen Canyon Dam. This will probably require the long-term monitoring program to continue through the life of the dam. The intensity of the monitoring program might change over time, depending on results of periodic reviews of the program. However, the type, frequency and location of measurements still should follow from the goals of the monitoring program as they relate to specified stakeholder objectives and the current knowledge base. (Davis et al., 1994).

(Figure 6.1) has proposed a step down approach for the development of a long-term monitoring and research program that incorporates a conceptual system model.

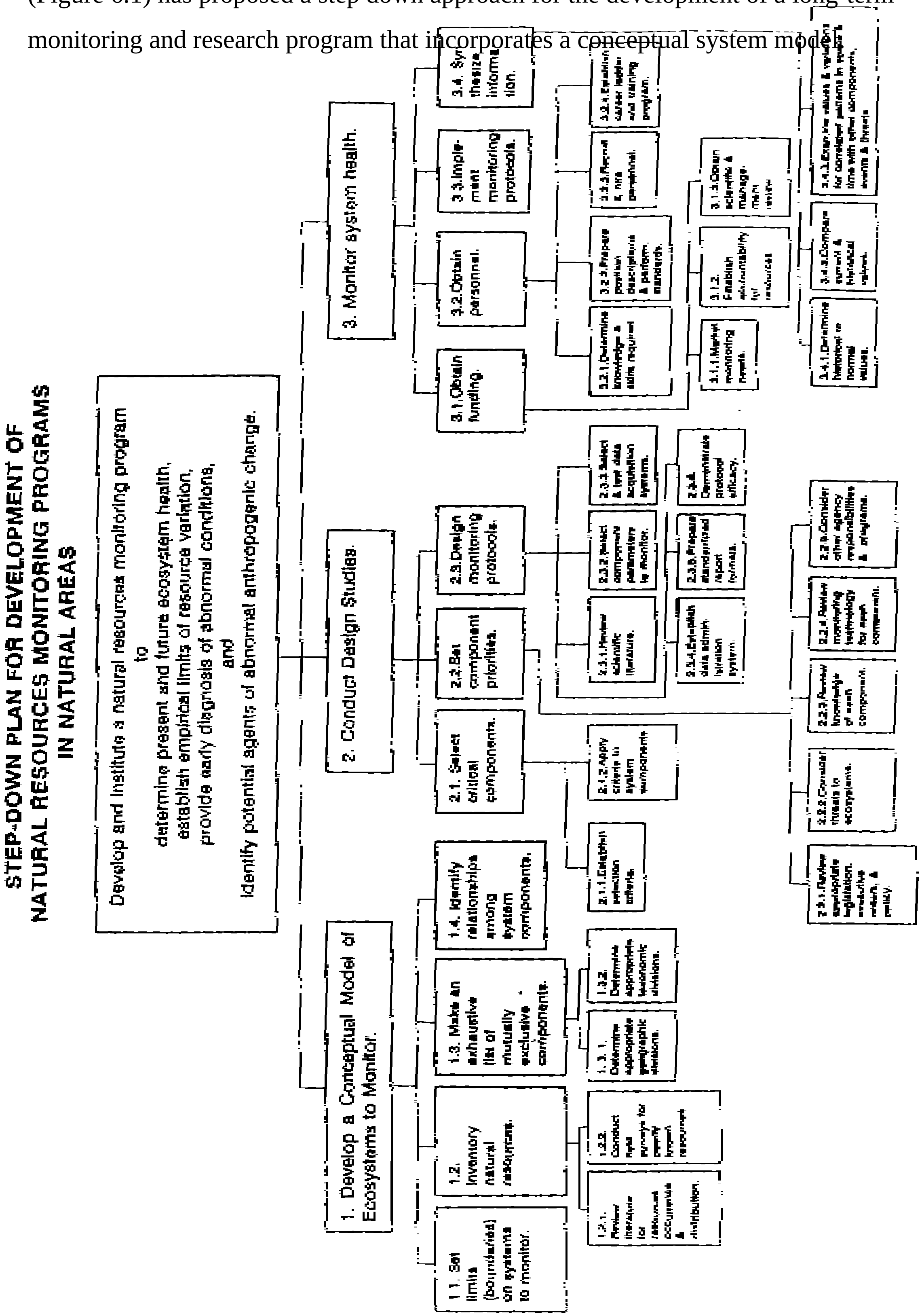


Figure 6.1. Step Down Approach to the Development of a Long-term Monitoring and Research Program (Davis, 1994).

To reiterate, long-term monitoring should be designed to provide regular feedback for adaptive management which permits mid-course adjustment of Glen Canyon dam operations to ensure achievement of the goals of the Record of Decision (1996) and the management objectives articulated by the stakeholders.

Synthesis of Knowledge

One of the interesting quandaries in natural resource science endeavors, especially those that attempt to evaluate impacts of management action over time, is the difficulty of defining what would have occurred to resources in a system had there been no management action. The task is made more difficult when the western riverine ecosystem under study has been significantly altered from its original character.

Many ecosystems are extremely dynamic, and are subject across time and space to natural perturbations that in and of themselves can evoke more significant impact and change to resources in the system than human directed activities over the same period. Nonetheless, when attempting to measure anthropogenic impacts on a natural system through time, such as a large desert river, there is a need to contrast these measured changes to changes in similar riverine systems where there are no man imposed activities. Contrasting these two systems will often permit the scientists to more directly evaluate the natural resource impacts of human induced activities such as a dam and its operation. The more natural system then becomes the control. Contrasting resource changes in these two systems embodies the basic underlying assumption that determined resource departures are in fact due to human induced activities. The assumption is, of course, weakened by the fact that natural perturbations in the control system over time could be significantly different than the managed system, and in fact could overshadow changes due to human induced activities in the managed system.

The scientific challenges faced in evaluating impacts of Glen Canyon Dan operating criteria on downstream riverine resources is much more complex than the above example, if we are considering comparative analyses to other, more natural, western rivers, (i.e., not regulated by a dam). Contrasting resource change due purportedly to dam operations on the Colorado River mainstem against resource changes in a southwestern riverine ecosystem in a more natural state, is obviously confounded by changes due to the dam itself. That is, placement of the dam structure may have so altered riverine ecosystems that any resource changes due to modified dam operations are impossible to determine. This is due in major part to radical changes in hydrology, sediment loads, and temperature regimes in the river, all due to the existence of the dam.

The above observation does not mean that attempting to establish some evidence of original baseline conditions in the Colorado River by observing conditions in somewhat similar rivers without dams is not warranted. Determining pre-dam baseline conditions for the Colorado River mainstem resources and a similar, more natural riverine ecosystem, and contrasting changes in these systems over time is important to this science investigation. For example, even though scientists agree that current population variation in humpback chubs is at least partially caused by existence of the dam and/or dam operations, that does not mean that removal of the dam would in fact restore these populations. Populations in other, more natural, riverine settings in the western United States also vary and some appear to be in decline. That is, other resource attributes such as interaction with non-native fish, change in climatic variables or water chemistry resulting from agricultural uses upstream may be contributing factors.

There has been insufficient synthesis of knowledge on both the Colorado riverine ecosystem and other western riverine ecosystems to appropriately establish baseline conditions on the natural range of variation in attributes to which we can compare and contrast resource changes over time due to human activities. Although there is high probability that one could not compare any observed changes statistically, such synthesis could be fruitful to the science effort at hand. In fact, descriptive assessments of these type of synthesis may offer considerable insight into changes wrought by dam placement and operating scenarios.

The third objective of the synthesis is to define the most prominent effectors of resources of concern to stakeholders. Definition of these effectors and their probable impact on the resources of concern is required in the context of dam operations under operating criteria specified in the ROD. Understanding effectors from a perspective of the entire ecosystem is critical. Should an effector be found to be prominent, and changes in that effector are potentially positive to a particular resource of concern, it is necessary to know if that change would affect and impact other resources in a negative manner. A critical need from this analysis is to define effectors that are the primary contributor to changes in the resources of concern or to linkages among resources. It is important to determine if these effectors have varied significantly over time, and if the variance in these effectors today are far outside the ranges observed over time, in both pre-dam and post-dam periods.

The primary intent of the synthesis program is to form a basis for guiding more effective monitoring, and prescribing appropriate research questions to specify more explicit relationships among attributes that are effectors both within and among resources. This knowledge is important to making critical adjustments in the following physical, cultural and biological resource science programs in years three through five.

A SCIENTIFIC PHILOSOPHY OF MONITORING AND RESEARCH IN THE COLORADO RIVER ECOSYSTEM AFFECTED BY GLEN CANYON DAM

The Role of Science in Adaptive Management

Adaptive ecosystem management requires that management actions be conceived, designed and implemented as carefully assessed scientific experiments (Walters and Holloing 1990). Such an approach involves: (1) the clear definition of management goals, objectives (including controls) and key resources by stakeholders; (2) the application of unbiased scientific methods for management action planning, design, implementation, analysis, and reporting; (3) consideration of appropriate spatial and temporal scales of monitoring, and guaranteed continuity of needed data sets through protocol comparison between projects and data archival; (4) using appropriate scientific methods to answer applied research questions; (5) development of contingency plans and being prepared for unanticipated ecological changes; (6) timely reporting of peer-reviewed results in a fashion designed to benefit managers; and (7) feedback from scientists and managers on continued application of results to improved management.

Monitoring and Applied Research as Scientific Activities

Adaptive management (AM) requires defensible, unbiased scientific reporting of changes in prescribed ecological resources or processes (i.e., monitoring), as well as associated applied research into resource and process interactions and refinement of interpretation. Monitoring and research on large ecosystems for AM is an applied scientific inquiry, which incorporates the use of scientific methods (i.e., hypothesis definition and testing through statistical time series analysis and against scientific controls) to determine the change in variables specified by stakeholders. Thus, AM monitoring and research involves analysis of resource or process change through time or in relation to pre-identified condition, as well as analysis of interactions between components and interactions. As such, AM monitoring and research must be based on: (1) a clear definition of hypotheses behind stakeholder information needs, (2) an overview of resource interactions (a conceptual model),

(3) prioritization of information needs; (4) identification of the variables to be measured and the protocols to be used (including the sampling schedule); (5) identification of the uncertainties and data gaps related to the research and monitoring questions; (6) timely, peer-reviewed reporting of results; (7) study design that assists managers in interpreting results to effect feedback into the AM process, and (8) unbiased, external analysis of program efficiency and effectiveness.

The participants in the Ecological Resource Monitoring Change and Trend Detection Workshop (Olsen et al. 1997, as reported in Dixon et al. 1998) concluded that multiple approaches are needed for the ecological monitoring of large, complex ecosystems. Although several monitoring methods and statistical approaches may be appropriate, the participants identified four overall elements that should be considered in program development:

1. The monitoring program must recognize the "different role of intensive (sentinel) sites, networks of sites, surveys, and complete coverage" in assessing resource trends.
2. The term "trend" must be clearly defined.
3. Stressor-oriented monitoring should be coupled with effects-oriented monitoring.
4. Trend assessment should focus on change and uncertainty.

Although the emphasis of this workshop was on monitoring, it is clear that research activities are often required to improve or better understand monitoring results. In the following section, an overview of various components of monitoring and research are discussed.

Components of Adaptive Management Research and Monitoring

Scientific Research: Applied research for adaptive management is designed to answer specific questions or develop specific models to improve understanding of relationships between key variables and the context in which monitoring is conducted. Specific models and solutions may be sought to improve monitoring technology or methodology. Protocol assessment and calibration are research activities which also aid in improving monitoring and interpretation of results.

Research and Monitoring Prioritization: Research prioritization requires consideration of the order in which questions must be answered to address stakeholder information needs. Research prioritization requires completion of an initial conceptual ecosystem model, and construction of a concatenated series of monitoring activities and research questions to address information and relationship gaps. The prioritization and implementation of research should be expected to modify the structure of the monitoring program.

Spatial and Temporal Scales in Monitoring: Monitoring of large ecosystems requires consideration of spatial and temporal scales that are ecologically relevant. The spatial scale for monitoring is best based on the spatial scale of change of the resource in question. In the Colorado River ecosystem, several spatial scales have been recognized (Schmidt and Graf 1990; Stevens et al. 1995, 1997): (1) microsite (<10m), local (<0.5 km), geomorphic reaches (10-100 km), river-wide (500 km), and basin-synoptic (from the top of Lake Powell to Hoover Dam, 1000 km). Temporal scales relevant to the Colorado River ecosystem involve consideration of life histories and release schedules, and include: hourly, quarter-day, day, week-day vs week-end, monthly, seasonal, annual, interannual, and pre-dam versus post-dam time periods.

Selection of Indicator Components or Processes: Monitoring of the entire ecosystem and all its resources is impossible, therefore selection of indicator components and processes is required. However, the debate as to which components or variables to measure is rarely resolved. Endangered, endemic, non-native and indicator resources should be considered as the first choices for monitoring. Indicators may include rare-but-otherwise-unprotected components and processes, and/or common, widely distributed components or processes that are considered sensitive to the stressors of interest. No single indicator (e.g., a single endangered species) can represent the entire ecosystem, and attention should be paid to representing various trophic levels among the selected indicators.

Monitoring Protocols: Protocols developed for monitoring should be as consistent as possible through time. Following a "cook-book" formula is desirable, as this approach leaves as little doubt about the methodology as possible. Any major shift in project or protocol should be accompanied by a detailed protocol calibration, to assure that future data are compatible with past data. Although this approach advocates carefully following specific protocols, monitoring technicians should also be sufficiently good field scientists who regularly record their observations on the ecosystem, noting changes and irregularities as they are encountered.

Controls: The use of controls in science is far more complex than most laypersons recognize, and is of utmost importance to evaluating trends. For example, a commonly posed question about regulated rivers is: "To what extent are the changes observed over time related to climate or to dam operations?" Without appropriate control sites, resolution of that question is nearly impossible. The comparison of regulated river conditions with those in control reaches or using models initially can be expected to involve research efforts.

The use of controls for monitoring and research in regulated rivers have been described by Ward and Stanford (1982, and modified here), and involve comparison of the regulated river with: (1) pre-impoundment conditions (largely unavailable for the aquatic domain in the Colorado River ecosystem); (2) nearby upstream unregulated reaches (i.e., Cataract Canyon); (3) nearby analogous unregulated rivers outside of the basin in question; (4) comparison with unregulated tributaries (a strategy most useful for distinguishing between dam impacts and the effects of climate-driven change; (5) time-series data across distance in the regulated segment (a scientifically weak strategy because resources in the modified river system may be very different from the desired resource conditions); and (6) basin-wide fluvial and riparian models that contrast regulated and unregulated reaches, and encompass the size of regulated river under study.

Implementation of a Monitoring Program: The conduct of monitoring should be thrifty, efficient and effective, minimize staff changes and, as stated above, all new projects should be calibrated to previous data collection efforts.

Monitoring and research of the effects of Glen Canyon Dam on the Colorado River ecosystem are difficult because of the remoteness of study areas, and because of administrative restrictions. In addition, field logistical costs are enormous, and the high demand for river access may create conflicts between monitoring trips and recreational visitors. Therefore, to the extent possible, future monitoring in Grand Canyon should rely on remotely sensed data, minimizing ground-truthing and technician time in the field. Technicians, especially those that are brought on new, should be trained intensively prior to being responsible for collecting and processing data, and should be trained in visitor contact, as well as wilderness protocols. Technicians should be carefully overseen by the Principal Investigators.

The above logistical difficulties indicate that the most appropriate approach for on-the-ground activities will be to use a small series of river trips per year, during which most activities can be conducted. When possible, monitoring should take place out of the high-use periods so as not to cause conflicts with visitors.

Data Management: Monitoring and research data should be subjected to rigorous quality control standards, and then archived in such a fashion as to be secure over a period relevant to the project (centuries in the case of Glen Canyon Dam). The data and hard copy products should also be readily available for regular analysis and updating.

Reporting: Monitoring results should be made available to the adaptive managers as soon as possible, but no later than six months after each sampling period; however, scientists should be entitled to reserve access to collected data for at least one year after the close of the most relevant reporting period before it is released to the adaptive managers and the public, to allow sufficient time for publication in peer-reviewed scientific journals.

A comprehensive reporting of change and trends among all resources being monitored is planned through GCMRC's preparation of the annual State of the Colorado River Ecosystem Report, which will be electronically accessible to managers and the public.

THE PHYSICAL RESOURCES PROGRAM

The physical resources of the Colorado River ecosystem, consisting most importantly of streamflow and sediment, respond directly to dam operations and link those operations with other dynamic ecosystem resources, such as cultural, recreational and biological processes and attributes. Relations between mainstem streamflow and fine-sediment transport have been established through decades of streamflow and sediment monitoring at key locations below the dam, such as the mainstem stream gages at Lees Ferry and near Phantom Ranch, operated by the U.S. Geological Survey's Water Resources Division. Detailed geomorphic and environmental studies since 1983 have also established relations between dam operations and the navigability of rapids formed by debris flows, as well as the geomorphology of fine-grained sediment deposits within and between recirculating fan-eddy complexes. Further, long-term records of fine-sediment inputs from the Paria and Little Colorado Rivers make it possible to predict inputs with numerical modeling methods, and in fact, such modeling efforts have already been initiated.

Many aspects of the river's geomorphic framework, including its debris-fan/eddy complexes and sand bars, are known to support aquatic and terrestrial habitats important to ecosystem viability. The sediment and streamflow resources of the ecosystem support many habitat types, including backwaters used by fish, cobble and gravel bars colonized by benthic organisms and used for spawning by fish, shoreline types used preferentially by juvenile native fish, substrates used by plants, and terrestrial sand bars used for camping by recreationists. Over the past three decades, scientists have demonstrated that dam operations are vitally linked to every attribute of the ecosystem through the physical resources and related processes. In addition, pre-dam river terraces containing cultural resources are known to be impacted by dam releases directly at some sites, and are thought to be indirectly linked to all preservation settings within fine-grained terraces.

Recently, a large-scale experimental test of the Beach/Habitat-Building Flow, (DOI, 1995) showed that both fine and coarse-grained sediments within the mainstem ecosystem adjust rapidly to changes in dam operations. By maintaining dam releases within the range of operations specified by the Record of Decision (ROD; DOI, 1996), sediment storage in the mainstem can also be enhanced between episodes of higher managed releases. Through a prescription of sediment conservation dam operations (Low Modified Fluctuating Flows, DOI, 1995), combined with periodic Habitat Maintenance and Beach/Habitat-Building Flows (HMF and BHBF, respectively; DOI, 1995), it is hoped that the sediment resources that are the foundation of the Colorado River ecosystem can be managed in a sustainable manner. Hence, the objective of the physical resources program is to monitor key aspects of sediment transport and flow below Glen Canyon Dam so as to provide managers and other decision makers timely information on how effectively the Record of Decision operations are achieving: restoration of critical hydrologic and geomorphic processes and process interactions, long-term conservation of sediment in the mainstem, and ecosystem sustainability overall.

Information Needs

Two main areas of stakeholder objectives are addressed in the physical resources program - streamflow and sediment. Specific objectives and associated information needs of interest to stakeholders are listed in Appendix A. Although water quality is included by stakeholders under the management objectives for the physical resources program, these information needs are used exclusively to address biological issues, and hence will be discussed in the sections describing the biological resources program.

A broad array of information needs are specified by Glen Canyon AMP stakeholders (Appendix A). The following synopsis of information needs developed by stakeholders characterizes the breadth of management concerns for streamflow and sediment resources, as well the recognition that geomorphic processes that are natural components of all river ecosystems must also play a vital role in preservation of the Colorado River ecosystem.

While each of the following topics can be addressed independently and reported on to the stakeholders, nearly all are ultimately related to dam releases and the system-wide sediment budget of the Colorado River ecosystem. While dam operations can be managed to the exclusion of basin-scale climate forcing of short time periods, climate forcing of the hydrology of Lake Powell and sediment inputs below Glen Canyon Dam ultimately dictate the balance between streamflow and the sediment budget below the dam. It is hoped that long-term management strategies for dam operations can achieve sustainability of downstream sediment resources and viability of ecosystem processes overall.

Within the Colorado mainstem study area, from Glen Canyon Dam to the western most boundary of Grand Canyon National Park, there are four aspects of streamflow, sediment and river geomorphology where monitoring and research efforts are critical: Mainstem streamflow; System-wide sediment budget; Interactions between hillslope and fluvial
processes; Modeling of fine and coarse sediment flux.

Hence, the primary strategic objectives of the physical resources program in the current planning and implementation phase are:

1) **Sediment Budget** - to define and construct a robust methodology for monitoring the system-wide sediment budget in a manner that is useful to managers and decision makers in evaluating the effectiveness of the Record of Decision with respect to sediment conservation.
2) **Historical Synthesis** - to facilitate a comprehensive synthesis of all historical pre- and post-dam information on the hydrology, sediment transport and geomorphology of the Colorado River, and thus provide some perspective on how the system functioned with respect to sediment transport, storage and tributary versus mainstem interactions before regulation.
3) **River Channel Base Map** - in order to better achieve the above objectives, there is a need for construction of a system-wide topographic base map of the river corridor, including channel bathymetry, is planned between FY2000 and 2002. The national mapping standards established for GIS site maps under the Glen Canyon Environmental Studies (GCES) will be maintained – 1-meter contour intervals.

Local and system-scale channel geometry derived from the topographic base map will better facilitate monitoring of flow and sediment through field-based measurements combined with model-based approaches. Once developed and tested, such modeling capabilities will enhance the ability to monitor and eventually predict changes in the sediment budget, especially storage changes in the mainstem, and will support the design and development of a data base for all resources that can be accessed and used with a geographical information system. Construction of a base map also allows for physical and other monitored resource attributes to be spatially referenced to one another in a systematic manner conducive to integrated interpretation of ecosystem processes and responses. At present, topographic maps of the shorelines between the 5,000 and approximate 300,000 cfs stage elevations exist for a small percent of the river system where GIS sites [reaches] were previously established by the GCES. Channel geometry below the 5,000 cfs stage elevation exists for less than about 3 percent of the entire river. Without high resolution channel geometry, at least in critical reaches, mutli-dimensional hydrodynamic flow and sediment modeling, for instance to predict aggradation of backwaters or camping area sandbar responses, is impossible. Further discussion on the methods for obtaining the topographic base map are described in the Information Technologies Program surveying and remote sensing sections.

In addition to the three major goals mentioned above, physical program activities will also focus on the following resource concerns:

Streamflow

- Monitor mainstem and tributary streamflow as it occurs throughout the ecosystem from the points of discharge at Glen Canyon Dam, and where major inputs occur that affect stage throughout the ecosystem and to the western most boundary of Grand Canyon National Park.

Sediment

- Monitor fine-grained sediment deposits through the ecosystem that are of critical concern, such as active sandbar in the New High Water Zone, return-current channels within fan/eddy complexes [backwaters], and pre-dam river terraces that contain cultural resources.
- Define character and structure of sandbars and backwaters throughout system after the 1996 experimental BHBF flow.

- Define historical and current (character and structure) levels of river stored sediment in system and associated flow regimes through a reach-based geomorphic mapping approach through synthesis efforts.
- Identify physical relationships between geomorphic settings and processes and cultural resources.
- Determine baseline conditions for resource attributes of interest.

Glen Canyon Dam Discharges and the 1996 ROD

Dam operations directly influence downstream flows that control many Colorado River ecosystem processes and components, including: sediment-transport and storage dynamics, water quality, recreation, navigation, cultural site preservation, aquatic and terrestrial habitat development, primary production, habitat use, fish recruitment, and fish population dynamics. The objectives for monitoring Glen Canyon Dam releases and flows are to determine how closely dam operations adhere to the releases prescribed under the ROD (DOI, 1996). These flows which also include discharges or spills above dam hydropower operations, are to be monitored at: 1) the dam, based on highly accurate continuous flow velocity measurements (Accusonic Systems, Inc.) within the penstock tubes. Flows to be monitored include, average hourly flow volume and ramping rates (changes in discharge over the hour). From the above

data, synthesis information on maximum and minimum daily discharges and daily fluctuations, and frequency and volume of spills, can be determined and placed in a perspective of average conditions and variance. Under the current AMP agreements, Western Area Power Administration (Salt Lake City, UT), in cooperation with the Bureau of Reclamation (BuRec) reports violations of the ROD as they occur to stakeholders on a daily basis. Dam release and U.S. Geological Survey streamflow data acquired by the GCMRC shall be made available to interested parties through the GCMRC Information Technologies Program (see later sections).

Water and Sediment Transport

The transport of water and sediment through the Canyon are closely related through empirically derived rating curves and other monitoring information on bed storage and grain-size evolution. Discharge volumes and hourly ramping rates associated with dam operations combine with reach-averaged geomorphic channel characteristics and periodic tributary inputs to influence the amount of sediment transported and stored in the ecosystem through time. Fine alluvial sediment is a primary substrate for many riverine biological processes, cultural resources, as well as camping beaches. Coarse sediment deposited at discreet locations along the river channel [mainly at tributary mouths] structures the pool/riffle framework of the river and provides for enhanced primary production [on cobble bars and coarsened debris fans], and sand storage locally [within eddies and upper pools]. The major objectives for monitoring streamflow and sediment transport are to determine whether the flux of water and sediment through the various reaches through time results in long-term trends of net storage or depletion of fine sediment input from tributaries. Likewise, to determine whether coarse sediments are accumulating with the channel, and if so whether aggradation of these sediments is detrimental or beneficial to sediment conservation, and what impact there may be on biological, cultural or recreational resources . Measurement objectives are: 1) continuously measure dam releases as well as the flux of water through the ecosystem; 2) measure and estimate flux of all sediment, including coarsest boulders, between Glen Canyon Dam and the downstream boundary of the management area; and 3) estimate storage through time as the differences in flux between the dam and the downstream extent of the management area by isolating tributary inputs and various geomorphic reaches. An important component of the sediment and flow routing efforts needed to estimate an accurate sediment budget also requires a full understanding of the role of grain-size evolution on the channel bed once sediments enter the mainstem from tributary sources. Sorting of sediment is known to occur over both short and long time periods under dam operations as well as during the pre-dam era.

River managers have expressed concern about impacts of dam operations on upstream reaches of the Grand Canyon, and these reaches have been shown to have the greatest potential for sediment storage deficit. It is therefore important that sediment and streamflow gaging stations on the mainstem Colorado River at Lees Ferry, above the Little Colorado River, and Grand Canyon upstream from Bright Angel Creek be maintained as sediment measurement stations as well as discharge stations. It is also critical to measure outflow from the system and maintain existing gaging stations. Data suggest that the most effective rating curve for estimating system-wide export of fine sediment is the Grand Canyon station near Phantom Ranch.

The ongoing streamflow and sediment monitoring and modeling effort is primarily a research effort and represents a long-term alternative to continued widespread gauging presence in the Grand Canyon. Such modeling should also create the capability for calculation of flux differences in many of the short reaches of the Grand Canyon which have limited study. Other flow and sediment modeling efforts would be considered part of long-term research, such as deposits in and erosion of side channel debris, changes in existing rapids, formation and degradation of beaches, and arroyo down-cutting in upper terraces.

A synthesis of all existing water and sediment fluxes for differing reaches of the Canyon under differing dam operations is currently underway as a joint project by researchers from Utah State University and the U.S. Geological Survey. The objective of this current synthesis is to compare long-term historical records of flow and sediment transport at Lees Ferry and the Grand Canyon gages to determine patterns of seasonal storage and export that occurred in both the pre- and post dam eras.

Calculation of the fully comprehensive sediment budgets for both fine and coarse sediment also requires measurement and estimation of water and sediment inflow from both gaged and ungaged tributaries. Stations on the Paria River at Lees Ferry and Little Colorado River near Cameron will be continued. Efforts to produce predictive models that estimate sediment volumes and grain-size distributions from these tributaries are nearly complete.

Mainstem and Tributary Interactions

Interaction of mainstem and tributary streamflow and sediment is influenced by dam operations primarily at their confluence with the mainstem. In addition to the influence on flows at the confluence, tributaries are an input of both inorganic and organic materials to the mainstem. As such, the objective for long-term monitoring and research on tributary characteristics is to evaluate possible causes of mainstem changes, that is, operational causes versus tributary influences. Tributaries of the Colorado River area may provide refugia for native fish, trout and other non-native fishes, as well as riparian ecosystems. For this reason, they are included in the long-term monitoring and research program. They are considered controls for evaluating changes in selected attributes in the mainstem (e.g., aquatic biota), and as a source of attribute inputs.

Sediment dynamics in the system represent critical resource attributes to many other resources. Sediment in the ecosystem is either in transport or in storage above or below the river surface. Sediment transport flux is monitored periodically at gage sites below the dam. Stored sediment in upper pools and eddies throughout the channel represent source volumes for entrainment and redeposition during managed high-flow operations.

The prescribed dam operations in the ROD consider sediment accumulation in the river system, in the channel or eddies, and in elevated deposits (e.g., beaches). Therefore, the objective of monitoring changes in stored sediment is to evaluate the sediment budget predictions of the EIS relative to the selected alternative in the ROD. To determine the influence of dam operations on the integrity of both fine and coarse sediment deposits, the objective of the monitoring program is to determine changes in sediment storage in different geomorphic settings and unique reaches of the ecosystem, along shorelines within and between fan/eddy complexes and on the channel bottom. Accomplishing this objective will require measurement of temporal change in the status of submerged bars and eddy and channel-margin shoreline sediment deposits, as well as cobble bars and debris fans on a system-wide basis.

Selected sandbar and campsite beaches will continue to be measured periodically to identify the relationships between sediments resources and recreational beaches. Established survey techniques would be employed by trained surveyors, and remote sensing technologies will be employed to the greatest degree feasible to increase information and decrease environmental impacts. Measurement of short-term changes on cobble and sandbars, although of interest in determining sediment dynamics, is a focus of the long-term monitoring program with respect to high-flow events that are implemented as management actions, or occur owing to hydrological conditions that force spills.

Measurement of sediment bar changes throughout the ecosystem will be made to the greatest extent possible using remotely sensed data and methods, and will be assessed over interannual to decade time scales for trend using change detection techniques. Such measurements permit wider ranging measurements using less invasive measurement strategies. Short-term repeat photography is highly recommended as part of the long-term sediment monitoring program except perhaps at sensitive archaeological sites to determine change. These data may be especially valuable is stereo photogrammetric techniques are able to provide quantitative results on changes in geomorphic surfaces and related features.

Mainstem Transport and Conditions

Mainstem sediment transport (export) to the Lake Mead Delta represent a significant physical resource impacts caused by dam operations; one that needs to be minimized if sediment conservation within the ecosystem is to be achieved. Assessment of impacts due only to dam operations may be difficult, however, due to confounding associated with operation of Hoover Dam. Assuming a consistent pattern of operations at Hoover Dam and somewhat stable water levels, variable operations of Glen Canyon Dam would produce differing long-term changes in physical, biotic, and cultural resources in the upper Lake Mead region. Inflows to reservoirs are often the most dynamic region of a reservoir's physical and biotic resources (BOR, 1995).

Defining resource impacts from dam operations in this region is, however, extremely difficult due to the influence of downstream dam operations on Lake Mead reservoir level. Nonetheless, operating criteria changes such as the unplanned flows of 1983-1986 and the beach habitat building flow of 1996 function as a significant energy pulse, creating impacts to marsh zones, spawning beds, sediment deposits, standing biomass levels, riparian vegetation, etc. An area of monitoring research proposed for this interactive zone is to determine with remote sensing, short and long-term changes in sediment deposits, backwater and marsh habitats, riparian vegetation and primary productivity.

THE BIOLOGICAL RESOURCES PROGRAM

"An Ecosystem degradation is not inevitable; it is simply cheaper and easier for some in the short term. Ecosystem health is also not inconsistent with economic imperatives and political realities. In fact, a healthy environment is the basis for a healthy economy." Likens, G.E., 1992.

INTRODUCTION

Deciding what to measure, how, when, and where, as well as how to analyze and interpret the resulting data are some of the most critical issues to be addressed in the development of a long-term monitoring program for biological resources. To be successful, the long-term monitoring program must ensure that data collection, analysis, and interpretation will address specific management needs and objectives.

The Grand Canyon Monitoring and Research Center (GCMRC) has followed a process which is designed to ensure that the information produced will address the needs of managers and decision-makers. In addition, the iterative nature of the process used to develop management objectives and information needs will help ensure that the scientists and managers are in agreement over the most critical questions to be addressed.

The design of an effective long-term monitoring program is not a trivial task. Many case studies indicate that long-term monitoring programs are often confused with data collection activities that are part of research efforts. These programs are also affected by the difficulty in selecting appropriate parameters to measure and the appropriate approach to use in measurement. "For example, monitoring to measure degradation in fish communities could focus on the number of species in the community, community trophic structure, population estimates, the incidence of abnormalities, or many other parameters" (NRC 1990).

As pointed out by the NRC (1990) monitoring programs must be designed to discern change over time while accounting for variability and uncertainty in the system, and still produce data sets that can be analyzed to determine cause and effect relationships. In addition, monitoring needs to be dynamic so that monitoring needs can be prioritized and modified in response to what is learned from the ongoing monitoring and research activities, especially regarding the effectiveness of prescribed management actions, and in light of real-world scientific, logistical, and financial constraints (NRC, 1990).

Finally, the NRC (1995) has identified the development of a conceptual model as an essential step in the selection of environmental parameters to be modeled.

Program Elements

Three programmatic elements are required to develop an understanding of biological resources needed to effectively support the selection of appropriate management actions for achieving specified management objectives. These are: 1) inventory of the biological resource components of the Colorado River ecosystem within Glen and Grand Canyons and the development of a conceptual model with the linkages between the biotic and abiotic components of the ecosystem, 2) monitoring of ecosystem behavior, both short and long-term to determine if the models of the ecosystem are predictive, both in response to natural perturbations and alternative dam operations, and 3) research to explore cause and effect relationships, test alternative hypotheses, and develop an improved understanding of the ecosystem. These elements must be implemented iteratively with much feedback, (Figure 6.2, GCMRC Approach to Ecosystem and Adaptive Management).

Program Goals

The Biological Resources Program is intended to develop information about the structure and function of the Colorado River ecosystem within Glen and Grand Canyons, as well as the impacts of a range of alternative dam operations on the ecosystem, in order to provide the knowledge base required to implement ecosystem management strategies within an adaptive management framework. The development of a fundamental information base on the structure (components) and function (processes) of the Colorado River ecosystem in Glen and Grand Canyons is a prerequisite to prediction of ecosystem responses from alternative dam operations. Information on structure and function should include knowledge of the basic components of the ecosystem and an understanding of impacted and un-impacted ecological components and processes, both biotic and abiotic.

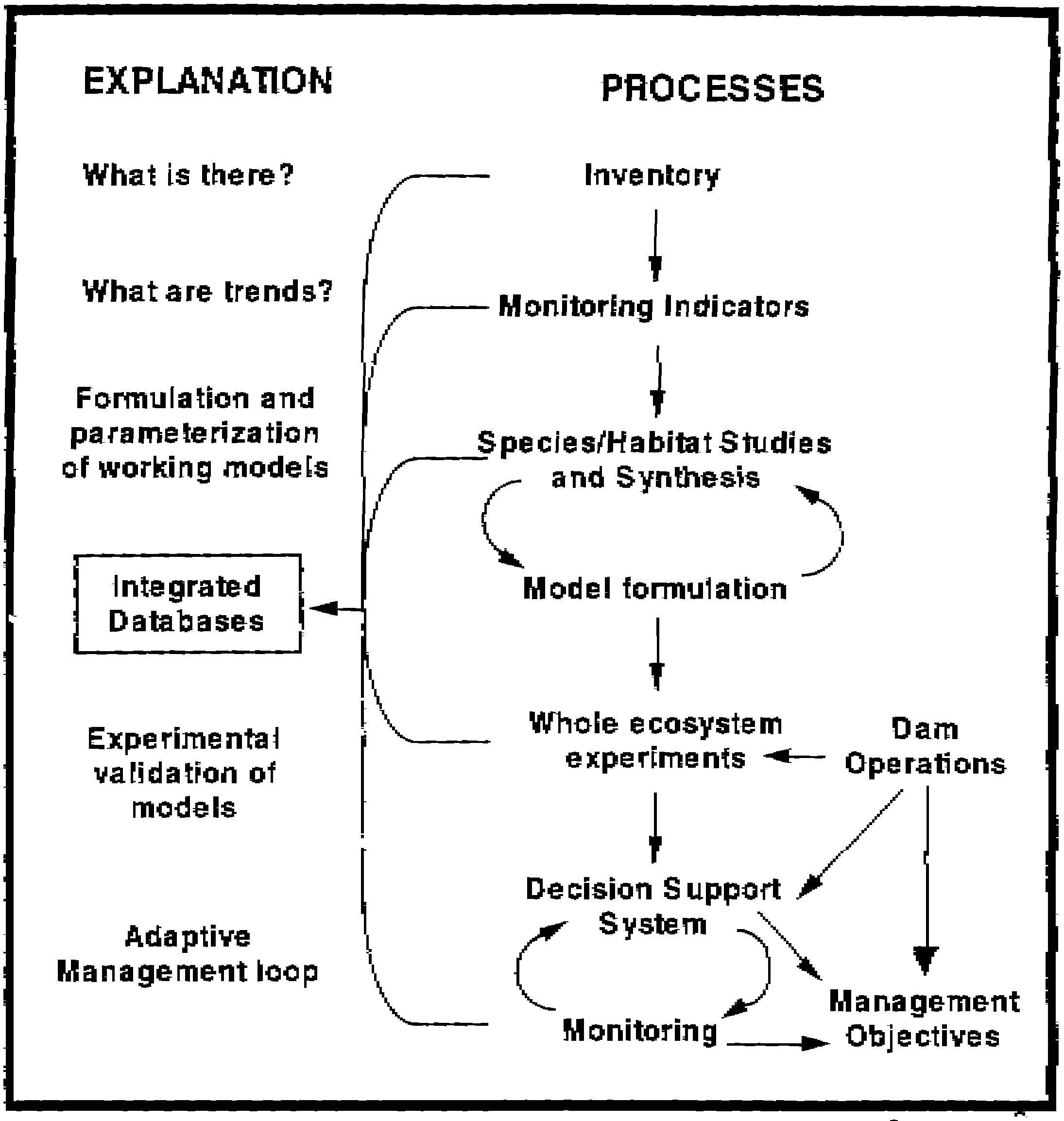


Figure 6.2. GCMRC Approach to Ecosystem and Adaptive Management (Adapted from CENR, 1995).

The adaptive management process is an integrative and iterative process involving feedback loops between management goals and objectives associated with the resources and resources response to environmental inputs. For the Colorado River ecosystem the inputs are often manmade (e.g., water release patterns from the dam, stocking rates of rainbow trout, human impacts from fishing, whitewater rafting, camping and hiking). Determining the multivariate effects on resources and evaluating which variable plays the largest role in downstream resource change or quality requires monitoring of multiple resources.

Alternative dam operations may impact the Colorado River ecosystem in Glen and Grand Canyons in ways and on scales (temporal and geographic) not generally experienced under natural perturbations. Knowledge regarding the impacts of natural and anthropogenic factors on biodiversity and ecosystem dynamics, and the adaptation of communities and organisms to those factors, is needed in order to propose management alternatives for achieving specified management objectives.

The goals of the biological monitoring and research program in the Colorado River ecosystem are multi-faceted and linked to management objectives, the goals include:

1. Ecosystem Quality - Maintain or enhance aquatic and terrestrial habitat and improve ecosystem functions to support sustainable populations of diverse plant and animal species.
2. Feasibility - Monitoring programs must be developed in such a manner that they are logistically and monetarily feasible.
3. Durability - Monitoring should be designed to answer questions regarding the effects of releases on downstream resources and designed in a manner that data collection is repeatable regardless of who collects the data.
4. Useable - Monitoring data should be collected in a manner that related research questions can utilize the data rather than replicating efforts.
5. Trend Monitoring - Habitat and species/population trend monitoring with the ability to cut across scales of monitoring to provide Predictive Trend Monitoring.

6. Reduced Impact Due to Monitoring - Monitoring should be less intrusive, if possible, so that the monitoring activities themselves do not affect the quality of the resources.

BIOLOGICAL RESOURCE COMPONENTS

Aquatic Ecosystem

Fish are an important part of the Colorado River ecosystem because of their trophic role, *evolutionary significance,* important recreational value, inherent value for biodiversity, and because some are listed as threatened or endangered under the Endangered Species Act. The Colorado Rivers native and endangered fishes have been affected by environmental changes resulting from the construction of Glen Canyon Dam and subsequent power plant operations, and the introduction of non-native fishes, plants, and invertebrates.

For native fish populations to remain viable, successful recruitment must occur. In general for fish, the timing of reproduction must coincide with local food production cycles, and larvae must be transported to a favorable nursery habitat. Management of river flows can affect larval transport to nursery grounds, and thereby influence their survival and ultimate recruitment. Food production and nursery habitat quality are tied to physical factors such as temperature, suspended loads and nutrient supply, both of which are partially dependent on the timing and quantity of water releases upstream. Slower growth rates increase the duration of high risk life stages, potentially increasing mortality and reducing recruitment. The goals of the long-term monitoring and research program for fish resources will be to develop an understanding of the links among dam operations and the resulting flow regimes on spawning, larval transport, trophic dynamics, and recruitment.

The Humpback Chub (Gila cypha) is endemic to the Colorado River basin in Colorado, Utah, and Arizona. Inundation of canyon habitats by mainstem dams, cold tailwater releases, altered flow regimes and introduction of non-native fishes have reduced its range and numbers. The population of humpback chub in Grand Canyon is probably the largest and most reproductively viable population known. Valdez and Ryel (1995), identified nine distinct aggregations of humpback chub located in the Grand Canyon. Yet, the only aggregation that is known to be self-sustaining is the population concentrated in the Little

Colorado River (LCR) and adjacent to it in the mainstem Colorado River. Humpback chub are also found in low numbers in one location above of the LCR reach, Fence Fault Springs (RM30), and seven locations downstream of the LCR reach, including upper Bright Angel Creek inflow (RM 87.7); Shinumo Creek inflow (RM 108.8); Middle Granite Gorge (RM 127); Havasu Creek inflow (RM 156.9); and Pumpkin Springs (RM 212.9). These other aggregations tend to be associated with springs or tributary inflows and are not known to be self-sustaining.

Survival of cohorts (year classes) and recruitment into the adult population is vital to the existence of humpback chub in Grand Canyon. Since this species appears to be long-lived (20 years or more) and adaptable to changing habitat conditions as adults, recruitment to adult age (3 to 4 years) probably greatly enhances fitness.

Young humpback chub are commonly found in backwaters and have been assumed to use them as nursery habitats if these habitats are warm, turbid, and sheltered from mainstream inundation or desiccation. Backwaters under fluctuating flows can be short-lived, as they are inundated or desiccated on a daily basis. The short and long-term existence of these habitats is vital to the life history of many fish species. Also, shorelines with complex structure (i.e., talus slopes, debris fans and vegetation) are frequently occupied by native fish and may offer shelter from predators, provide immediate sources of food, and protect the fish from rigors of mainstem flow. Young fish can be easily displaced when flows exceed habitat requirements (e.g., velocity becomes too great from rising flows or shoreline rocks become exposed with descending flows).

Other native fish species, such as the flannelmouth suckers and bluehead suckers may have been reduced in number and distribution in Grand Canyon since the construction of Glen Canyon Dam. These fish appear to spawn primarily in tributaries (LCR, Shinumo Creek, Kanab Creek, Bright Angel Creek, Havasu Creek) between March and May. Adults spend up to two months in tributaries during spawning, but relatively little is known of the larvae and young following emergence. Flannelmouth and bluehead suckers are found throughout the Grand Canyon, with large spawning aggregations at major tributaries.

The razorback sucker is very rare in Grand Canyon. It is thought that only a few old and senescent adults remain in such low numbers that the species can be considered extirpated from the region. However, the possibility exists for razorback suckers to occupy the lower reaches of the Colorado River just upstream of the Lake Mead inflow (Separation Canyon to Pearce Ferry) and this area has been suggested as a potential recovery habitat for this species.

Little is known about the biology of speckled dace in Colorado River ecosystem in Glen and Grand Canyons. The species is ubiquitous throughout the western US, but little has been synthesized on its status, genetic diversity and population trends in Grand Canyon. Speckled dace are most common in riffles and rocky shorelines, but are also found in tributaries, silt-substrate backwaters and shorelines.

Non-native fishes, in Grand Canyon are thought to pose a threat to the native species with competition for resources, predation, and parasites and diseases. The various non-native species have different direct and indirect effects on multiple aquatic resources.

Rainbow Trout, were first introduced into tributaries of the Colorado River ecosystem in Grand Canyon during the 1920s. Seasonally warm water temperatures and high sediment loads probably precluded their sustained use of the mainstem prior to closure of Glen Canyon Dam. Stocking of trout below Glen Canyon Dam began in 1964 and has continued to date. Natural reproduction commonly occurs but may be insufficient to sustain desired trout numbers for recreational angling. The 25 km reach below Glen Canyon Dam is managed as a blue-ribbon fishery with emphasis on production of trophy-sized trout. Although trout occur throughout the Colorado River and several tributaries in Grand Canyon, recreational fishing below Lees Ferry is quite limited compared to the upstream reach.

Alternative dam operations and the resulting flow regime can directly and indirectly effect trout found in the dam tailwater. Direct effects include stranding of all life stages in isolated pools, dewatering of spawning and rearing habitats, and displacement of individuals from preferred habitats. Indirect effects involve ecosystem processes and lower trophic levels that provide the food base for the fish. Stranding and dewatering are sources of mortality for adults, juveniles, and larval fish, while displacement may cause increased energy expenditure, reduced food intake, and disruption of reproductive activities.

Aquatic primary and secondary productivity is the primary trophic link and energetic conduit throughout the Colorado River ecosystem. This aquatic food base is composed primarily of green algae (Cladophora glomerata), diatoms and detritus, and other macrophytes, chironomids, Gammarus, gastropods, oligochaetes, simuliids, lumbricids and other macroinvertebrates. Many wildlife species, especially fish, depend on this aquatic food base for their survival. Yet, benthic composition and production and its overall availability are temporally and spatially unequal with a notable decreasing trend downstream. Fluctuations in the amount and types of aquatic food available can trigger changes in the population dynamics of native and non-native fish species.

Fluctuations in the aquatic food base are associated with certain environmental stressors that include water temperature, turbidity, and flow fluctuations, to name a few. Understanding the relationships between dam operations and productivity of the aquatic food base is an important step towards understanding the effects of dam operations on higher trophic levels, especially the population dynamics and interactions of native and non-native fish species in the Colorado River ecosystem.

Terrestrial Ecosystem

Riparian vegetation prior to the construction of Glen Canyon Dam, was subject to periodic flooding. The destabilizing actions of historic flows resulted in a community that was often re-establishing itself rather than expanding. Since the establishment of Glen Canyon Dam, the hydrograph has become dampened and resulted in more stable riparian communities both with respect to those components associated with the old high water line (120,000 cfs), and those composing the new high water zone (5,000 cfs to 31,000 cfs). Additionally, reduced seasonal fluctuations associated with dam operations has established and expanded marsh communities that were rare prior to the dam.

The riparian communities along the Colorado River ecosystem are important for bank stabilization, aquatic and terrestrial faunal habitat, are botanical resources for tribal groups, and offer aesthetic and recreational value. Three distinct riparian or marsh communities are represented along the mainstem of the Colorado River: the upper riparian zone; the lower riparian zone; and the near shore wetland communities.

Terrestrial invertebrates along the Colorado River in Grand Canyon provide essential food resources for riparian insectivores (insects, amphibians, reptiles, birds and mammals), thereby linking vegetation, productivity and habitat conditions with secondary consumer population dynamics. Glen Canyon Dam significantly increased the stability of riparian habitats, permitting an increase in terrestrial invertebrate populations. The biotic inventory of invertebrates is incomplete, and it is likely that numerous endemic taxa remain to be discovered and described.

Terrestrial/riparian vertebrate populations in the Colorado River ecosystem are significant secondary consumers. Trophic interactions between habitat conditions and availability, and invertebrates and primary consumers affect the sustainability of higher level consumers. The river corridor supports high densities of terrestrial/riparian vertebrates. The populations of many of these animals are changing. More than a dozen native vertebrate taxa have been lost, or their status is unknown (e.g., river otter), while several native and non-native species populations have increased (e.g., waterfowl, beaver).

Terrestrial vertebrates have a significant influence on ecosystem structure and energy flow, and are recognized as a priority resource by the NPS. Fortunately the conspicuous nature of many of the vertebrates, make monitoring them relatively easy. Avifauna are especially conspicuous and are trophically significant secondary consumers. The Grand Canyon is an important flyway and stopover location for migratory waterfowl, raptors and passerine birds; however monitoring of these occasional and migratory species has been inconsistent. Monitoring avifauna provides information regarding habitat suitability, food resource production (invertebrates), and predator populations.

PURPOSE: LONG-TERM MONITORING AND RESEARCH PROGRAM

Implementation of long-term monitoring within the Colorado River ecosystem is problematically complex due to the large geographic area that is covered and the multiple species that are being monitored, each with differing biologic requirements for their sustainability. Monitoring all species is prohibitive, both logistically and monetarily. One affective monitoring approach to utilize is to monitor stressors in the system (e.g., temperature, water volume, salinity) and indicators (e.g., species diversity, productivity) that represent critical components of the ecosystem.

Monitoring ecological parameters likely to cause an effect on organisms considered stressors is a method that permits the development of probabilities for a range of indicator responses. Establishing a baseline for these variables or parameters permits the development of an understanding of the "condition" of the resource of concern.

Scientific Basis for Long-term Monitoring and Research

The current and future monitoring and research program is intricately connected to the adaptive management approach and the information needs, as specified by the stakeholders. A monitoring program measures the health and trends of an environment, while applied research addresses questions about observed trends that may appear to be detrimental to the ecosystem's health. While monitoring ecological parameters are necessary, a long-term investment in research is a necessity if an further understanding is to be realized on how components of the ecosystem react and interact to changing environmental variables. A properly designed monitoring program provides managers an ability to monitor the pulse of an ecosystem by providing a means to detect resource decline in advance of reaching known critical thresholds. Monitoring is to observe and detect subtle shifts (or gross depending on the prioritization and sensitivity of the resource) occurring outside the normal range of variability, analyze and interpret data and adaptively respond to resource changes.

Boundaries of Long-term Monitoring Program

Successful monitoring and research programs generally require boundaries or limitations to be defined. These limitations may be political, geographical, temporal, or monetary, to name a few. The monitoring program for the Colorado River ecosystem has several constraints including:

- institutional (Glen Canyon Dam Operating Criteria);
- legal (Endangered Species Act, Law of the River, EIS);
- aesthetics
- economic concerns (Recreational issues);

- environmental values (wilderness designation, natural reproduced fish, non-motor season);
- physical constraints (Glen Canyon Dam Physical Structure);
- natural variation of ecosystem.

Admittedly these boundaries can be complex when determining if monitoring programs are inclusive of them. A conceptual model can institute and integrate these boundaries more easily than the human mind. It is at this point that the benefit of using a conceptual model to assist in monitoring plan development becomes apparent.

CONCEPTUAL MODEL

Using conceptual models as the primary framework for systematically organizing, developing and evaluating complex ecological processes can be a very powerful tool in determining resource response predictions to ecological parameters (stressors), and developing testable research hypotheses. For this reason, selection of adequate parameters and resource components as indicators are essential to the development of an effective long-term monitoring program.

Conceptual Model Development

A conceptual model uses existing ecological data and empirically derived relationships in conjunction with existing ecological tenants to develop a scheme of how biological and physical elements interact in a system. Though modeling approaches are numerous, mechanistic models predictively simulate biological processes and outcomes as well as provide ecological explanations.

The Grand Canyon Monitoring and Research Center has initiated the development of a conceptual model for such a purpose, and will use it to assist in the identification of stressors and biological indicators of the system (Korman et al., 1998). Assembling and consolidating information therefore is critical to the continued development and refinement of this conceptual model by linking abiotic and biotic components of the system, as well as identifying key parameters to monitor for long-term monitoring and related research activities.

Conceptual Model Purpose

The purpose of the model is to guide monitoring and research planning, clearly define critical attributes and linkages within and between biological resources, promote improved understanding of ecological stressors that drive changes in the systems, make qualitative assessments of resource change resulting from alternative dam operations, and provide information to stakeholders and managers regarding the potential impacts of alternative dam operations on Lake Powell and the Colorado River ecosystem and associated resources. As an instrument it is extremely helpful in identifying stressors in an ecosystem.

Yet, the reliability of predictive models can only be confirmed through a validation process. Real-time resource predictions lend themselves to being validated through comparative tests of observed (field data) and predicted indicator responses. This type of validation process provides confidence limits on the accuracy of a modeled prediction, and is an essential process for determining the functional generalities and levels of sensitivity associated with all resource predictions. Lack of correspondence with observed responses requires establishing more linkages to relevant ecosystem parameters and continual revisions to the model construction. As a management tool, the above process assists in establishing confidence limits on untestable simulations, identifying data gaps, generating conceptual questions on functional processes and developing testable research hypotheses. For this reason, the conceptual models operation requires a support commitment for assessing existing information, maintaining, improving (programming and upgrading) and responding to management needs.

Ecological Parameters Related to the Biological Monitoring Program

Problems arise due to our limited knowledge of the natural variability of a resource, its response and resilience, as well as understanding the causal nature of environmental disturbance. There are certain variables that are inherent in all systems that can be considered stressors. Many physical and water quality characteristics act as stressors in biological systems, and in this system, the collection of physical parameters are (is) considered essential to our understanding the role the dam and (the) operations has on the ecosystem.

Certain abiotic changes in the environment are thought by most researchers to be responsible for the present status and condition of numerous aquatic and terrestrial resources, which include: native and non-native fish populations, primary and secondary benthic components, and other terrestrial/riparian communities. These physical changes, resulting primarily from the fundament and operations of Glen Canyon Dam, include reduced sediment transport, altered flow regimes, reduced water temperatures and increased water clarity. In addition, the altered flow regimes have lead to a change in channel morphology, including the degradation of backwaters thought to be important nursery habitat.

The causal relationship between ecological stress and certain biological responses to these stressors have been established. Some of these causal relationships have been derived from a combination of research effort previously and presently being conducted in the Colorado ecosystem. Other causal relationships have originated from work from other applicable systems.

Selection of Indicators

The most critical stage in establishing an effective monitoring program is in the selection of resource indicators. Its success or failure will ultimately be based on the success or failure to correctly select the right indicator. For this reason, identification of biological components (Indicators) responsive to environmental stressors in the Colorado River ecosystem is important. Since direct and secondary effects of stressors are of biological significance to the Colorado ecosystem, having structured communities and regulated the spatial distribution, relative abundance, reproductive strategies and success of certain resources. Based on resource objectives, conceptual models should be capable of identifying structural and compositional elements of the ecosystem that are effected by stress. This process leads to the selection of ecological indicators required for measurement.

The best indicators to select are those components with related stressors that have been previously established or suspected of having cause and effect relationships. Additionally, some of these biological components are considered keystone species and function biologically as an indicator of ecological health, where other species are spatially or temporally limited and considered more of a focal species (sensitive) of interest in the Colorado ecosystem.

The rapidity to detect resource responses are based on the selection of these types of indicators and the degree of desired sampling scale (spatial and temporal). The conceptual model will reflect processes that are functionally operating at specific scales, as well as the constraints imposed for those operating outside those scales. Therefore, the selection of appropriate indicators should be based on resource prioritization, known (negative and positive) interdependencies, predicted responses, critical thresholds and known stressors. Yet, not all resources require monitoring due to their known interdependencies to other resources and their similar response curves to abiotic and biotic stressors.

Identification of Inherent Inter- and Intra-resource Conflicts

Certain management actions directed toward effecting a specific or series of resource response(s), regardless whether it has a benefit or negative effect to a resource(s) can alternately have a conflicting and secondary counter effect to other physical, cultural or biological resources. Some of these secondary interactions are desirable and some are not. Additionally, certain biological resources can also function directly as a biological stressor toward other desirable resources. For this reason, understanding the natural variation (population dynamics) that exists for a given resource, coupled with good scientific knowledge of the direct and indirect interactions are a critical component in a functional and effective monitoring program. For this reason, identification of possible inter- and intra-resource conflicts are important. Yet, sometimes the identification of these conflicts are not possible, and the long-term effects are unforseen and can ultimately be counter to the desired management objective.

Listed below, are some of the known physical, biological and human induced stressors that have counter conflicts with multiple biological resources in the Colorado ecosystem. They are:

Physical Abiotic Stressors

- Sediment loads effects on primary production (abrasion, light and substrate availability)

- Temperature effects on reproduction (reproductive development, growth rates, survival, movement, emigration, fish composition, and benthic invertebrates and algal communities)
- Flow discharges on habitat availability and use, and reproductive, development and recruitment of endangered species.

Biological Stressors

- Inter and intra-predation loads on developing young-of-year
- Effects of non-native flora and fauna on the native component (expansion of riparian vegetation and avifauna assemblage, invasion and exclusion effects)

Anthropogenic Stressors

- Recreational effects on resources (tributary access, riparian vegetation, resource composition)
- Management policies (catch and release, harvesting and stocking) effects on trout population

Prior knowledge of known and possible resource conflicts are important in using a conceptual model. This information provides the basis for testing predictions and developing research hypotheses on how critical resources might respond to management actions and environmental stressors. Additionally, iterative ecological simulations can be used for the purposes of identifying and evaluating the effects of resource interactions and their responses. This can be an effective means for prioritizing resources and identifying possible response sensitivities and critical thresholds.

LONG-TERM MONITORING APPROACH

Management goal for the Colorado River ecosystem are to manage the resources in an ecosystem approach. With this overall goal in mind, monitoring and research efforts will increasingly focus on developing and exploring interdisciplinary approaches to monitor environmental stressors and selected resource indicators of both aquatic and terrestrial resources as they relate to natural variation and dam operations.

Essential Data Requirements for Monitoring

Components of monitoring should include a suite of abiotic and biotic parameters. As stated previously, these ecological parameters should measure in a manner (location and time) that provides meaningful data. A minimal component approach, essential for monitoring biological resources in the Colorado River ecosystem must include both terrestrial and aquatic parameters. The primary component in aquatic environments is water, yet this can be parameterized into many different units of measurement, such as water quality (i.e., temperature, dissolved oxygen, pH, conductivity, nutrients), discharge (volumetric rate), fluctuations (rate of change), and other suspended abiotic constituents or load (suspended sediment, nutrients). Additionally, some of these parameters can be further reduced or parameterized depending on the desired resolution. The effects of these parameters on specific resources may very depending on the frequency, magnitude and duration.

The extent to which sediment plays a role in biologic systems, for example riparian vegetation, are limited by the amount of available shoreline and time since a deposition event. In other words, sediment can be an event driven parameter that influences most biological resources in the Colorado ecosystem. Event driven parameters versus other ecological parameters that have continual effects on resources need to be deciphered and prioritized for a fiscally constrained monitoring program. Physical resources such as rocks and sediment also form the basis for biological habitats, particularly for aquatic resources. However, currently it is the volume of water that affects aquatic habitats and their availability more than the sand that makes the habitat. As with terrestrial habitats, sediment often has event driven effects rather than continually effecting biotic resources.

A minimal component approach also must be attentive to the scale at which measurements are made. Monitoring objectives to some extent determines the level of scale at which parameters are measured. For example, if a monitoring program asks if native fish are present, then monitoring may consist of setting hoop nets at one locality once a year to determine the presence or absence of native fish. The scale in this case is not numeric, but qualitative and provides monitoring information about native fish. Alternately, specific monitoring questions may require a refinement of the scale at which data are collected and reported. Accomplishing monitoring objectives shall involve an interdisciplinarian approach with other programs. This requires integrating with other concurrent monitoring efforts and utilizing data across multiple disciplines.

Reflective of management needs, the intent of monitoring can change over time and the scale of monitoring may change accordingly. Regardless of the degree of intensity a resource is monitored, a minimal component of monitoring should be that the collected data is compatible and comparable to previous data collection efforts. Without compatibility, the notion of adaptive management and long-term monitoring is merely bandwagon jargon pulling a cart of no substance.

Structured Approach

The approach for long-term monitoring varies with each scientific discipline due to the nature of the resources and the indicators being measured. For example, riparian vegetation may need to be monitored on a yearly or bi-yearly time frame if the question being addressed is how perennial plant densities representing riparian community zone change over time. Conversely, resources that react quickly such as algae or aquatic macrophytes may require a more intensive, or more frequent sampling effort.

The choice of how much to monitor and when are critical if monitoring is to be useful for management decisions. Factors driving how much, and when to monitor include the information needed, the nature of the resources and the amount of money in the pocketbook. Included with monitoring ecological parameters (stressors and indicators) are research questions that may be paralleling monitoring efforts and how monitoring these data may assist in research efforts.

Try as hard as one can, the future is predictable only in that things will change. And so, even the best monitoring program that selects the currently considered "essential data" will undoubtedly miss collecting critical data needed in the future. At best one can examine the time and resources available and propose to measure ecological parameters that are known to be integral to biotic systems. Included in this consideration should be the immediate long-term research needs and parameters that these studies will likely utilize. By considering basic biological processes and immediate research questions, a monitoring program can provide data across multiple disciplines and promote integrative research.

Long-term Research Program. An adaptive approach to managing resources at an ecosystem scale is not effective without understanding the functional distinction that exists between monitoring and research. Observational information derived solely from a monitoring program is inadequate for determining causal relationships. Therefore, neither monitoring nor research can independently address or provide the types of information necessary to understand long-term implications of management actions on natural, physical and cultural resources without the strong functional interaction of both. It is imperative that research studies are conducted concurrently with monitoring in a complimentary fashion, focused toward determining the causal nature and source of ecosystem stress. For this reason, the monitoring and research program are conceptually separated, each reflecting the fundamental differences that exist between monitoring and research.

As with all things, science is not static. Ideas concerning species and community interaction change as well as the methodologies used. The present state of knowledge is often insufficient for addressing unforeseen questions and concerns of the future. Managed ecosystems are dynamic as certain resources adjust in response to management activities. Therefore, this requires a commitment to develop greater scientific understanding through research to address questions and concerns and provide the solutions to short-term management needs, as well as continued improvements to a long-term monitoring program. Research can only be effective if there is a consistent and robust baseline long-term data that serves as a reliable foundation. The source of these data are a result of long-term monitoring. Gross and fine adjustments to the ecosystem through time will require constant revisions to our conceptual understanding of a functional ecosystem. Often times this will require re-addressing perspectives and resource prioritization. Scientific creativity is essential to tease part misconceptions of thought (i.e. paradigm shifts) and continue to develop, improve and re-evaluate the existing monitoring program. Therefore, prioritizing the required research will provide the necessary timeline and conceptual framework for conducting research to address both short and long-term goals and management objectives defined by the Stakeholders.

Prioritization of Research Elements. The question of what areas of research should be most heavily invested arises if research is to be conducted within a monitoring program. Presumably, the monitoring program is tailored in such a fashion that baseline parameters, reflective of the ecosystem are collected and the options for monitoring are to collect or not. Options associated with research can vary from either a triage approach to one that thinly funds all resources of concern. The direction a research program takes can be decided by considering the present state of knowledge of the resources; upcoming legal constraints that need to be addressed; the immediate and long-term management questions that need to be addressed; and the amount of funding available for research. The cases involving legal constraints or immediate and long-term management questions may tip the scales towards a triage approach to funding research questions rather than equal funding for all resources. Limited funding further tips the scale toward funding research that will have immediate value and can be completed in a short amount of time.

Determining the selection process involves identifying the research need as it is linked to management objectives, determining the priority of the research need, estimating the time it will take to conduct the research and determining the amount of funding available for the research project. The Grand Canyon Monitoring and Research Center solicits proposals for research by advertising requests for proposals. The structure of the solicitation includes identifying the information needs, a brief background history of the resource to be studied and a reason for the information need. The GCMRC also entertains unsolicited proposals in which researchers submit their ideas for possible funding. A problem associated with unsolicited proposals is that they are competing for research funding that has already been prioritized. In other words, while a research proposal that is unsolicited may address an information need of the stakeholders, the need may be of low priority and may be years away from funding. Recommended proposals that have gone through the competitive peer-review process are funded by GCMRC.

Monitoring Objectives

As discussed previously, the monitoring approach of GCMRC is to monitor parameters that address management objectives and needs of the adaptive management stakeholders. Management objectives reflect the long-term goals the stakeholders have for these resources. Management needs represent information that stakeholders need to know to assess if management strategies are moving toward the goals. In some cases the needs are specific quantifiable data, while other needs represent information gaps that require research to answer.

There are 16 management objectives associated with the Biological Resources Program. Twelve of these objectives are either directly associated with endangered species, or are associated with the habitat or food base for these species. With these management objectives are information needs that number over 100. Thirty-eight of these represent information needs that can be answered via monitoring programs, with the remaining are needs that can only be answered through research. How does a monitoring program develop a structure that meets the information needs of the stakeholders?

The process of developing a structured monitoring program that addresses management needs must consider the management objectives and the structure of the ecosystem that is being monitored. Monitoring that is capable of making correlations between trophic level responses to resource availability and quality are more informative than data that are collected separately in space and time. In both aquatic and terrestrial environments, there can be advantages to collecting data simultaneously for resources that are linked (e.g., fish abundance and phytoplankton composition/abundance). Changes detected in fish health at one instance may be associated with changes in available diet (phytoplankton) that was measured during a previously monitored period. The linked monitoring effort provides a clue to changes in the ecosystem. The reason for changes would need to be addressed via the avenue of research. This scenario reiterates that complimentary research activities needed to co-occur along with monitoring.

A structured sampling approach is to be instituted as part of the GCMRC Long-term Monitoring program to assure data continuity and collection consistency with previous research and monitoring efforts conducted in the Colorado River. For this reason, GCMRC has instituted a data collection plan that identifies specific sampling protocols and constraints. The intended purpose of the sampling protocols are not to discourage the further exploration of alternate sampling methods, but rather to guarantee the continuation of known sampling methodologies until ample information are obtained prior to the discontinuance of the methodologies referred to below.

Data Collection Plan

Six resource areas are currently funded by GCMRC for monitoring and research. The resources are the aquatic food base, the Lees Ferry Trout Fishery, native fish, Kanab ambersnail, riparian vegetation and avifauna. The programs address information needs concerning the status of each of these resources; they are: age class, recruitment, population size, habitat availability, changes in habitat, percent biomass, and diversity. These projects are funded separately and run independently with encouragement for the investigators to integrate data. The intention for the five-year monitoring plan is to combine projects and develop aquatic and terrestrial monitoring programs.

The integrity of the data underlies sound resource management. Data that are taken in a consistent fashion, following specific protocols and at prescribed times are mechanisms that can be developed to insure data integrity. Additionally, data collected in a manner that is consistent with previous data collection efforts or methods that are least compatible with historic data ensures that continuity of monitoring data sets are maintained. Data collection for the purpose of monitoring downstream resources of the Colorado River ecosystem should be at a minimum compatible with previous data collection efforts. In addition, data must be in a format that is compatible with current computer technologies and accessible to multiple platforms if it is to be useful to researchers outside of the monitoring center.

All gear types, sampling methods and measuring protocols for data collection are to be collected to previous established standards (AGF 1992, McKinney et al. 1998, Valdez and Ryel 1995, Hoffnagle et al. 1997, Gorman et al. 1992, and Marsh and Douglas 1994). If alternate methods are used these are to be correlated to previous methodologies. The type of data fields (alpha and numeric codes), data entry protocols (QA/QC), and database applications and format structures are to be equivalent and compatible to previous databases in accordance to established metadata standards. Since 1991 data collection efforts that were associated with Glen Canyon Environmental Studies (GCES) were collected with the intention that they be tied into a Geographic Information System (GIS) and as a consequence meet National Mapping Standards for positional accuracy (Wright et al 1995). However, certain types of data collected due to their intended use are not spatially referential nor applicable to a GIS system. The organization and format of these types of tabular data are an important aspect of the Information Technology Program database system.

Status and Trends of the Biological Components

The proposed structured approach to monitoring biological resource components include a step-down process beginning with management objectives, proceeding toward prioritized information needs and correlating these with ecosystem processes and biotic and trophic level interactions. A format to evaluate the effectiveness of the proposed monitoring program includes listing the pertinent management objectives/information needs and specifying the areas of intensity of monitoring required to meet the needs.

<u>Aquatic Resource</u>. Long-term monitoring objectives for the aquatic resource program are to collect data to evaluate the status and trends of fish populations (e.g., native and sport fish), and the aquatic resources that trophically support these fish populations in the Colorado River ecosystem in Glen and Grand Canyons. The long-term monitoring program is designed to monitor how biomass, habitat, and composition of the aquatic food base will respond to known environmental stressors. The collected data will be used to assess the responses of native and non-native fish communities to alternative operations of Glen Canyon Dam. Since different fish resources are valued for separate reasons of interest (i.e., recreation vs biological diversity) they are conceptually separated here as two distinct sub-components for the purposes of organizing and realizing the management objectives. However there are certain resource overlaps that conflict with certain management objectives, yet the types of biological monitoring data needed for both resources are similar and for this reason can be combined. The sampling effort shall be conducted to coincide with critical seasonal activity and, if possible, concurrently monitoring at corresponding sites selected for alternative objectives (e.g., fishery related and aquatic food base monitoring). The Management Objectives and Information Needs (Appendix A) that pertain to Aquatic Resources are identified in the Biological Resource Section.

Terrestrial Monitoring Objectives. Several of these terrestrial species are federally listed as rare and endangered, including bald eagle, peregrine falcon, and southwestern willow flycatcher. The listing of these vertebrate species strongly supports the need to monitor this resource component. The new, riparian habitats, associated with the dam (e.g., tamarisk stands and marshes) are known to be colonized for nesting, while the status of avian use in the upper riparian zone is poorly known. For long-term monitoring purposes, all three communities should be included because each plays a different role in the trophic interactions associated with riparian communities. However the level of monitoring may differ for each of these communities due to their response rates to changes in flows or sediment inputs. The Management Objectives and Information Needs (Appendix A) that pertain to Terrestrial Resources are identified in Biological Resource Section.

WATER QUALITY MONITORING AND RESEARCH FOR LAKE POWELL AND THE COLORADO RIVER IN GRAND CANYON

"DRAFT" TO BE REVISED BASED ON THE INFORMATION PROVIDED BY THE TWG AD-HOC LAKE POWELL GROUP

INTRODUCTION

Goals and Objectives

The goal of this strategic plan is to establish a framework to develop and implement appropriate monitoring and research programs related to dam operations and their effects on various resources in Lake Powell downstream in the Colorado River ecosystem. The plan develops priorities and strategies for accomplishing this goal and determines appropriate responsibilities and assignments. The plan also articulates the relationship between the Grand Canyon Monitoring and Research Center (GCMRC) monitoring program and ongoing monitoring and research efforts by other agencies.

This plan represents an integration of all water quality monitoring and research being performed by the GCMRC from Lake Powell, the forebay upstream of Glen Canyon Dam, the tailwater from the dam to Lees Ferry, and the Colorado River through Grand Canyon. Some of this work has been under the Physical Sciences program, other work has been done under the Biological Resources program, while other work has been separately conducted under the Lake Powell program. This restructuring ensures that the water quality information is collected consistently, using comparable methods and instrumentation, and is integrated into a common data management system for accessibility by all interested researchers and other parties.

Water quality changes that occur in Lake Powell and are released downstream to the immediate tailwater have been documented by the existing Lake Powell program. Other water quality monitoring efforts from the forebay downstream through Grand Canyon have been under the direction of the Physical Sciences program, because these measurements are of a physical and chemical nature. The existing thermal monitoring program in Grand Canyon has been conducted by the Biological Resources program. Regardless of which administrative distinction directs this work, it is generally recognized that water quality changes from Lake Powell through Grand Canyon primarily affect biological components of the aquatic ecosystem. For this reason, **it is proposed that this integrated water quality program be moved under the direction of the Biological Resources Program Manager as part of the five-year strategic plan.**

Background

The Grand Canyon Protection Act, Glen Canyon Environmental Impact Statement, and the resulting Record of Decision (ROD) specify the need to assure protection and enhancement of resources in the Glen Canyon National Recreation Area (GCNRA) and the Grand Canyon National Park as related to operations of Glen Canyon Dam.

The stakeholder groups within the Adaptive Management Program (AMP) include managers and interested parties from various federal, state, tribal, and private organizations. These groups identify the management objectives and information needs of the AMP. The GCMRC formulates monitoring and research programs that address stakeholder objectives and the specified information needs.

In fiscal year 1996, the GCMRC lacked clear definition of its authority for continuing the AMP-funded monitoring and research programs in Lake Powell. The Transition Work Group accepted a proposal by the GCMRC to conduct a six-month assessment of Lake Powell long-term water quality data to determine if dam operations under the ROD exhibited any impact on the physical, chemical, and biological resources of Lake Powell. The Transition Work Group reviewed and approved the GCMRC proposal to conduct the evaluation.

A draft of the Lake Powell impact assessment was completed and externally reviewed by leading limnologists for validation. The findings were presented to the Adaptive Management Work Group (AMWG) at its first meeting on September 9-10, 1997. The report findings and limnologists' review determined that dam operations specified under the ROD did produce impacts to the physical, chemical and biotic resources in Lake Powell and the Colorado River below Glen Canyon Dam.

Based upon the GCMRC's findings of resource impacts to Lake Powell and downstream resulting from operations of Glen Canyon Dam, the AMWG requested the GCMRC to:

1. Continue the current GCMRC monitoring program for the period of October 1997 to October 1998.
2. Conduct additional assessments of existing data relating to Lake Powell and release water quality, including analyses of chemical and biological data that were not performed due to time and monetary constraints.
3. Review with the Technical Work Group, in January 1998, all existing knowledge related to the effects of Glen Canyon Dam operations on the water quality in Lake Powell and downstream releases.
4. Develop, with the Technical Work Group, objectives and information needs for any future Lake Powell water quality monitoring and research programs. This activity would occur in January to March 1998.
5. Develop for the Adaptive Management Work Group and Technical Work Group approval, a proposed monitoring and research plan for any specified future Lake Powell water quality monitoring programs. The draft plan would be produced by June 1, 1998.

The GCMRC has in coordination with the TWG completed all of the above activities as requested by the AMWG. Monitoring and research activities of the GCMRC beyond October 1, 1998 (FY 1999), is based on the approved FY 1999 Monitoring and Research Plan and AMWG review and approval of this long-term Lake Powell Water Quality Monitoring and Research Plan in July 1998. The five-year long-term plan for monitoring and research activities in Lake Powell covers the fiscal year period 2000-2004.

Ongoing Lake Powell Monitoring and Research

In addition to the ongoing GCMRC Lake Powell Water Quality Monitoring Program, several other agencies currently conduct monitoring and research on a broad range of resource issues. Much of the monitoring and research is not directly related to Glen Canyon

Dam operations. These programs are funded independent of the AMP and exceed expenditures for Lake Powell activities that are currently funded by the AMP (Table 1).

MANAGEMENT OBJECTIVES AND INFORMATION NEEDS

Management objectives and information needs were developed to help guide design of the Lake Powell monitoring and research programs for the GCMRC for the period FY2000 to FY2004. In the September 1997 meeting of the Adaptive Management Work Group, the AMWG requested the Technical Work Group (TWG) to proceed with evaluation and revision of management objectives and information needs for the AMP, including those relating to Lake Powell. The revision represents a concerted effort by the stakeholders to articulate their objectives for desired resource conditions and the associated information needs related to specific monitoring and science activities. These activities are necessary to determine the condition of these resources, and how conditions are affected by management actions.

Because the AMWG had not formally approved a long-term monitoring and research plan for Lake Powell, the objectives and information needs for Lake Powell have been specified as separate and distinct from other AMP management objectives and information needs developed for resources below Glen Canyon Dam. Management objectives and information needs for Lake Powell (revised May 1, 1998), were agreed upon by the (TWG) management objectives *ad hoc* group and presented to the TWG for review and use in development of the long-term plan (Appendix A).

In addition to the stated management objectives and information needs developed for Lake Powell (Appendix A) there are numerous downstream management objectives and information needs which require knowledge and information regarding water quality changes from Lake Powell and within the Colorado River below the dam. The integrated nature of this program addresses both the management objectives and information needs for Lake Powell as well as those for downstream resources.

Table 6.1 Current ongoing monitoring and research programs on Lake Powell independent of the AMP.

Research Group	Program Area
National Park Service	Bacterial water quality watershed studies
Bureau of Reclamation	Colorado Basin selenium studies (beginning FY99) Selective withdrawal feasibility Colorado R. water quality (salinity)
Utah Division of Wildlife Resources	Sport fishery monitoring, management, and research
Arizona Game and Fish Department	Sport fishery management and monitoring
USGS/BRD	Native fish research
San Juan Recovery Implementation Program	Endangered fish research
NPS/USGS	Side channel dynamics (proposed for FY99)

FIVE-YEAR MONITORING AND RESEARCH PROGRAM

The Lake Powell management objectives and information needs (Appendix A) can be addressed with a monitoring and research program of $325,000 in fiscal year 2000, if the additional programs noted above are funded from outside sources. The proposed GCMRC out-year programs are planned for similar levels of budget support as FY2000, but actual annual programs and budgets are dependent on GCMRC accomplishments and program reviews by TWG and AMWG.

The following list of monitoring and research projects (Table 2) respond to all TWG-proposed Lake Powell management objectives and information needs identified in Appendix A. Projects are identified as being funded by GCMRC (GCMRC), partially funded by GCMRC (Partial), or funded by outside sources (Outside).

Monitoring and research projects under Management Objective 1: (Water Quality) are addressed first. Projects 1A-1C in Table 2 comprise the current GCMRC water quality monitoring program for Lake Powell (Appendix B) and represent ongoing monitoring through the period of the five-year plan. The remaining items represent research projects which will be scheduled for specific time periods during the period of the five-year plan. Many of the information needs related to the water quality management objective (MO1) are addressed by the current GCMRC water quality monitoring program, which would continue through the five-year plan period, at a funding level of approximately $250,000 per year. Annual work plans would be reviewed by the TWG and/or an external review panel prior to implementation.

Information needs for the aquatic ecosystem management objective (MO2) will be addressed by conceptual modeling, information synthesis, GCMRC cooperative research efforts, and monitoring and research conducted by other supporting agencies.

The GCMRC's primary research activities under MO2 are development of a conceptual model of the Lake Powell ecosystem (Table 2, 2.A.) and integration and synthesis of all historic research and data (Table 2, 2.B.). These two projects account for approximately $75,000 per year for the period 2000-2003. The remaining important projects are currently programmed for only partial support or no support from the GCMRC.

Over the last year, a significant effort has been initiated by GCNRA to bring other funding support to the Lake Powell program. Much of that funding supports other research to better understand the full range of potential impacts of dam operations on Lake Powell resources.

PROGRAM SUPPORT

The GCMRC Lake Powell program is proposed to be funded in FY2000 at $325,000. As noted above, it is assumed funding levels will be maintained through the period of the five-year plan from FY2000 to FY2004, and that other outside funding support will be maintained.

The annual costs to support research vessels, equipment, instrumentation, laboratory analysis, supplies, support staff, etc. and conduct monthly and quarterly water quality monitoring programs to address stated information needs is approximately $220,000 to $250,000 per year. The additional $75,000 to $105,000 annual proposed funds will be allocated to four areas over the next five years: science and data synthesis, conceptual ecosystem modeling, aquatic ecosystem impact assessments, and fish impacts from dam operations. It is anticipated that approximately $75,000 will be needed for years 2000-2003 to conduct information synthesis and conceptual ecosystem modeling.

Over the period of the five-year plan, significant outside funding will be necessary to assist the GCMRC and the GCNRA in understanding the impacts of dam operations on other Lake Powell resources not included in the long-term plan. To accomplish needed comprehensive analysis of impacts of dam operations on all facets of the lake's physical, chemical and biotic resources, the GCNRA will be required to develop programs from outside funding sources that are equal or greater than the GCMRC's program in total annual budget. These efforts will be in addition to the GCMRC scheduled efforts over the period 2000-2004. As noted above, the GCNRA is currently pursuing a comprehensive lake program effort with several cooperating agencies and the GCMRC will actively coordinate with these efforts.

Table 6.2 Proposed five-year monitoring and research program for Lake Powell.

General Monitoring/ Research Area	Specific Monitoring or Research Program	Funding Source	Project Schedule (2000 2001 2002 2003 2004)
1. Water Quality (Addresses MO 1)	A. Evaluate impacts of dam operations on changes in temperature regimes in main channel of Lake Powell.	GCMRC	2000-2004
	B. Evaluate impacts of dam operations on lake chemistry, and how chemocline structures form and change through time. Monitor cations, anions, and nitrate/phosphate ratios.	GCMRC	2000-2004
	C. Evaluate dam operation impacts to primary and secondary productivity including phytoplankton and zooplankton.	GCMRC	2000-2004
	D. Computer simulation model study to model relative effects of dam operations and non-operational factors	Partial	2000-2001
	E. Assessment of Impacts of dam operations to physical, chemical and biological resources in lake side channels and embayments.	Outside	2000-2001
2. Aquatic Ecosystem Assessments (Addresses MO 2)	A. Develop Conceptual Model to simulate inter-relationship and impacts of dam operations on physical, chemical and biotic resources and other resources (fish, aquatic vegetation, habitat, etc.).	GCMRC	2000-2002
	B. Integration, validation and synthesis of all historic science and monitoring information and data relating dam operations to water quality and other resource change.	GCMRC	2000-2003
	C. Determine linked impacts of changing temperature and chemical regimes due to dam operations on primary and secondary productivity and fish energy cycle.	Partial	2002-2004
	D. Determine effects of physical, chemical and biological water quality changes due to dam operations on long-term fish populations.	Partial	2001-2004
	E. Determine probable relationship of dam operations, selenium levels and lake primary productivity.	Outside	2000
	F. Determine effects of fluctuating lake levels from dam operations on aquatic factors and shoreline vegetation.	Partial	2003
	G. Determine effects of water temperature changes due to dam operations on recreation (swimming, sport fishing).	Outside	2003

THE SOCIO-CULTURAL RESOURCES PROGRAM

The socio-cultural resources program incorporates the cultural resource program and the socio-economic program into one resource program area. These resource areas were combined to provide a more comprehensive treatment of resources that span prehistoric to current times and are meaningful to a broad group of stakeholders. This portion of the plan describes prehistoric and historic, and recreational resources, program areas, program objectives, stakeholder objectives and information needs, and the proposed activity areas for this planning period. Economic/hydropower concerns are also included in this section.

I. PROGRAM AREAS

1) Prehistoric and Historic Resources

Background

Two complementary, but legally separate programs, address cultural resources within the river corridor primarily downstream from Glen Canyon Dam. These are the Programmatic Agreement (PA) program, and the GCMRC cultural resources program. Both programs are described below.

Programmatic Agreement Program

The PA program addresses the legal responsibilities of the BOR and NPS for the historic properties within the river corridor of Grand Canyon National Park and Glen Canyon National Recreation Area as specified in federal cultural preservation legislation. These laws include the National Historic Preservation Act (NHPA), the Archaeological Resources Protection Act (ARPA) and the NPS Organic Act. The responsibilities specified within this legislation can not be delegated or abrogated by these agencies. The BOR responsibilities include assessment and mitigation of the direct affects on historic properties (as defined in the implementing regulations of the NHPA) of the water releases associated with dam operations. The NPS responsibilities include the management and administration of historic properties through resource inventories, resource assessments, and monitoring activities in the river corridor below the Glen Canyon Dam.

These responsibilities are coordinated and described in the Programmatic Agreement (PA) that defines and specifies the legally binding responsibilities of these agencies to maintain compliance with the NHPA. The PA was established as a cooperative effort among Native American tribes, NPS, BOR, Advisory Council on Historic Preservation, and Arizona State Historic Preservation Office. The PA documents general procedures and requirements for mitigating adverse impacts on historic properties including the traditional Native American cultural resources in the Colorado River corridor below Glen Canyon Dam resulting from "dam operations." The document describing the implementation of the PA requirements is the Historic Preservation Plan (HPP).

GCMRC Cultural Resource Program

The GCMRC cultural resource program is charged with designing and implementing monitoring and research activities that assess cultural resource impacts related to "dam operations" as specified in the Grand Canyon Protection Act (1992), the Glen Canyon Dam Environmental Impact Statement (GCDEIS 1994), and the Record of Decision (ROD 1996). Stakeholder objectives and information needs for the program are developed with the Adaptive Management Work Group (AMWG) and the Technical Work Group (TWG) members. The process for identification and development of stakeholders objectives and information needs has been described in a previous section of this plan. These objectives and information needs are then formulated into monitoring and research activities for the GCMRC's strategic and annual plans. The GCMRC provides this project information to the AMWG to assist them in formulating their recommendations to the Secretary.

Based on the GCMRC's authority and responsibility to seek out new information, the socio-cultural resources program includes elements that address monitoring of identified resources that are believed to be currently impacted by "dam operations." These activities form a large part of the socio-cultural resource program that also includes methodologies to obtain and disseminate cultural information including tribal assessments, research and interpretation; and data management and informational education and outreach. The GCMRC socio-cultural program is described in the following section.

The socio-cultural resources program integrates with the other GCMRC programs. The program manager functions as a liaison with the other programs to assess project proposals that may have sensitive cultural content or may impact cultural resources. When these are identified, the proposals are referred to the appropriate parties for comment and assessment. The program manager works to coordinate this review with all parties and to facilitate project evaluation. In this sense, the program manager will serve both liaison and coordination roles.

Integration of Programs

Following the GCDEIS (page 36), the socio-cultural resource activities of the GCMRC are conducted in a manner that ensures integration and compatibility between the PA program as articulated in the HPP and the GCMRC socio-cultural resource program. Both programs provide complementary information and integrate data from program activities.

However, the GCMRC's socio-cultural program is more broadly defined. While the BOR and NPS legal compliance program specified in the PA is primarily limited in scope to previously inventoried resources, the GCMRC program generates new monitoring and research data concerning a broad range of cultural resources including prehistoric, historic and contemporary resources. Examples include archaeological sites, traditional tribal resources (such as ethnobotanical, faunal, and physical resources) as well as currently used recreational resources that have social and cultural value to other groups. The basis for the GCMRC's broader interpretation of cultural resources is found in the GCPA (1992). Information generated under this program is provided to the PA program embers to assist them with their activities.

Projects and activities included within the GCMRC's cultural program are funded through its funding allocations from WAPA power revenues that are currently administered by the BOR and subject to budgetary recommendations by the AMWG and approval by the Secretary.

GCMRC Program activities are formulated from stakeholder objectives and the information needs that were developed in consultation with the members of the AMWG. The tribal, BOR, and NPS PA signatories are members of the AMWG. As members of the AMWG they discuss and prepare recommendations to the GCMRC for needed projects that are consistent with the identified objectives and information needs. They may elect to have projects that include PA activities, incorporated within the GCMRC program by channeling them through the AMWG for their review and approval. Consequently, to the extent that the PA activities coincide with the activities of the cultural program of the GCMRC, they may become fundable GCMRC, subject to scheduling and allocations in the annual program plan. As needed, projects will be prioritized based on GCMRC protocols. These protocols relate to integration and coordination between the interests of the AMWG and the GCMRC; monitoring and research priorities; funding approvals; proposal submittal and technical review; contracting and interagency agreements; report submission; and data archiving and distribution.

PA activities that are not funded under the GCMRC program, remain the responsibility of the BOR and NPS as they are legal PA requirements of those agencies. Funding recommendations and approvals by the AMWG pertain only to GCMRC activities as the AMWG has no authority concerning the content or funding levels of the PA program. PA activities that are not funded as GCMRC activities, return to the legally-responsible agency for implementation and funding.

Figure 6.3 diagrams the relationships between these programs. Path "A" indicates redirection of PA activities into the AMP based on stakeholder approval. Path "B" diagrams the linkage between the GCMRC program and services provided by the PA parties. Information sharing is also shown as a continuous loop between both programs.

Status of Knowledge

The current status of knowledge concerning cultural resources is based on a number of previous investigations within the Colorado river corridor in the Glen and Grand Canyons. Comprehensive overviews of previous investigations are included in Ahlstrom et.al (1993) and Fairley et al. (1994). Archaeological remains were first noted in the river corridor by Euro-Americans during the Powell expeditions in the 1800s (Powell 1875). Traces of archaeological remains were noted in the vicinity of Bright Angel Creek and the Unkar Delta area. In later years, archaeological investigations were noted in the river corridor and on the rims of the canyon (Hall 1942; Haury n.d.). In the 1950s and 1960s, investigations became more focused under the direction of the NPS, in part due to anticipated dam development in areas of the Canyon (Euler 1967; Euler and Taylor 1966; Taylor 1958). In the late 1960s and early 1970s the School of American Research and the NPS conducted excavations in the river corridor and adjacent areas to investigate the prehistoric settlement pattern (Jones 1986; Schwartz 1965; Schwartz et al. 1979, 1980, 1981). Together, these studies provided the initial information that suggested that numerous cultural resources existed within the river corridor.

Intensive archaeological inventories were conducted by the NPS during 1990 to 1991 in preparation of the GCDEIS to assess a range of dam operations (Fairley et.al 1994). These inventories located approximately 475 sites within the assessed area extending from Glen Canyon Dam to Separation Canyon, about 225 river miles and up to the 300,000 cfs flood level. Of the sites within this area, approximately 336 had identifiable impacts that were believed to be related to dam operations. Impacts were categorized as direct, indirect, or potential. Direct impacts included sites where inundation or bank cutting had occurred within the site in recent years. Indirect impacts included: 1) bank slumpage or slope steepening adjacent to the site, 2) arroyo cutting or other erosion phenomena related to base level lowering from river eroded sediments within the site, and 3) effects of visitor impacts at sites due to recreational use patterns.

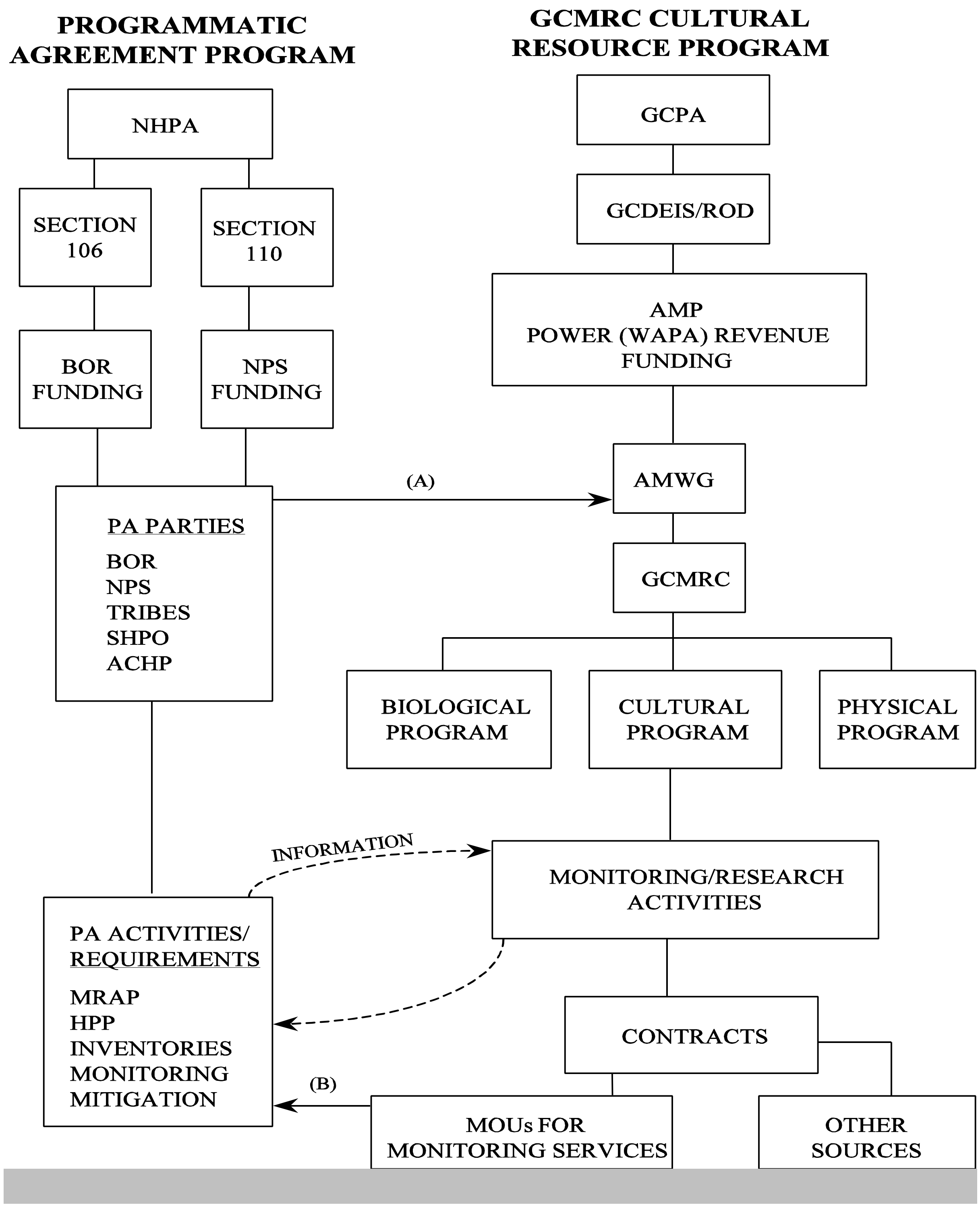


Figure 6.3 Cultural Program Tracking

Potentially impacted sites include those within the 300,000 cfs flood level without direct or indirect impacts currently identifiable.

Participating Native American tribes have also conducted cultural resource inventories to identify resources that have important cultural values to them. These studies were conducted by the Hopi Tribe, the Hualapai Tribe, the Navajo Nation, the Southern Paiute Consortium, and the Zuni Pueblo. Numerous locations of cultural importance were identified and assessed including important biological cultural resources, physical features and locations, and archaeological resources. Assessments were conducted by these tribes to identify impacts resulting from dam operations and to formulate possible treatment options.

Following the above resource inventories to establish baseline conditions, monitoring activities have been conducted to identify changes in resource conditions under the stipulations of the PA program. The NPS conducts monitoring throughout the year and produces annual monitoring reports for the Glen Canyon and Grand Canyon areas. Tribal groups conduct monitoring trips several times a year and assess changes to their traditional cultural resources.

Current monitoring procedures include site visits, photographs, and instrument mapping of sites. Results of these monitoring activities indicate that physical and visitor-related impacts constitute the majority of impacts to the cultural resources. Physical impacts include surface runoff erosion, side arroyo erosion that is often attributed to lateral bank retreat and bank slumpage, changes in vegetation, and in some cases direct inundation of the site. Visitor-related impacts include trails across site areas with resulting erosional effects, camping within site boundaries, graffiti at rock art locations, and collections and piling of artifacts. Animal related impacts have also been observed. Based on the NPS FY 98 field work, two river corridor areas, Reaches 5 (RM 61.5-77.4) and 10 (RM 159.8-213.9), appear to have the highest frequencies of physical and visitor related impacts (NPS, 1998).

Recommendations from monitoring efforts include a combination of preservation options (such as trail obliteration and retrailing, revegetation, and construction of checkdams to halt erosion) and recovery options (such as surface collection, mapping, testing, and data recovery) at features or sites (NPS, 1998).

Three on-going GCMRC projects are providing information in the areas of data synthesis, mainstem flow and deposition modeling, and testing of a geomorphic erosional hypothesis. Compilation of existing data from a number of sources will identify data gaps in previously collected data. In addition, analysis currently underway will provide information on changes in site conditions over time. Empirical data has been collected for the projects addressing mainstem flow modeling and geomorphic hypothesis testing. Project data from the three efforts is expected in FY 99.

2) Recreational Resources

Background

Recreational use of the river corridor has economic and environmental importance. As a major public use within the Grand Canyon, recreation creates jobs and financial support within the region and also has affects on other resources. The preferred alternative in the EIS has considered impacts on recreation and has attempted to enhance the recreational experience (e.g., opportunities to experience wilderness, natural quiet and solitude, etc.) in the river corridor and increase safety. Also of importance are the possible impacts of recreation on other resources. The objectives of the long-term monitoring and research program are to determine whether recreational experiences and safety are affected from dam operations, and whether changes in recreational patterns resulting from selected dam operational conditions have any effect on the downstream resources.

Status of Knowledge

Past studies have focused on issues related to recreational impacts from crowding, and safety and risk of injury relative to flow releases from the dam. Recreation and crowding studies have addressed flow releases, launch schedules, and travel time to estimate numbers of encounters as a proxy for crowding. These studies concluded flow levels affect travel time and that launch schedules have a large effect on encounters (Jalbert 1992, Underhill and Borkan 1986) . River flows also affected available camping beaches which affected the frequency of encounters (L. Kearsley and Warren 1993). Safety studies suggest that flow discharges can be related to white water accidents, and depending on flow stage, some rapids are judged to be more or less dangerous with corresponding levels of risk (Brown & Hahn-Oneill, 1987).

Previous studies at GCMRC have assessed beach campsite area changes resulting from the beach habitat building flow and transition monitoring of riparian plant beach invasions and beach habitat building in Grand Canyon National Park (L. Kearsley 1996). This work has concluded that flow regimes affect the geomorphology of beaches and therefore the recreational experience of camping at these beaches.

An ongoing study at GCMRC is currently investigating 1) recreationalists preferences and opportunities relative to attributes of differing flow regimes, including campsite, travel times, and encounters; 2) changes in preferences from past studies; and 3) the commonality and disparity between preferences and proposed management directions. Data will be available at the end of FY 99.

PROGRAM OBJECTIVES

Program Description

The socio-cultural resource program consists of three primary components that include: 1) a program of monitoring and research activities for a broad range of resources as directed by the AMWG, 2) a tribal projects component and, 3) a cooperative projects component (Figure 6.4).

A) Monitoring & Research Activities This program component consists of monitoring and research activities designed to address the stakeholder objectives and information needs identified through discussions with the AMWG in the program areas. For prehistoric and historic resources, this component does not refer to the activities defined within the scope of the PA program unless these activities are channeled into the AMP by the PA signatories and specifically mentioned.

These activities build on information from monitoring and research activities related to archaeological and traditional tribal resource inventories, remediation activities (such as site recordation, mapping, photography, stabilization, and data recovery efforts), tribal monitoring programs conducted under the PA program , and recreational studies. Data generated from the proposed GCMRC program activities are used to formulate future annual plans as well as modify the long-term plan.

New resources may be identified during activities conducted under this program. These resources may require monitoring and research studies to determine the qualities that may be impacted by dam operations. The Native American tribes, recreational groups, and federal agencies will be involved in these efforts.

This component is formulated from identified stakeholder objectives and information needs that are translated into annual work plans that are developed by the GCMRC. Monitoring and research activities are developed in consultation with the AMWG and TWG representatives. These work plans are transformed into specific work projects that are reviewed by the GCMRC staff and external peer reviewers to arrive at proposal awards.

B) Individual Tribal Projects. A second element of the socio-cultural program includes individual tribal projects that may enhance GCMRC initiated monitoring and research activities.

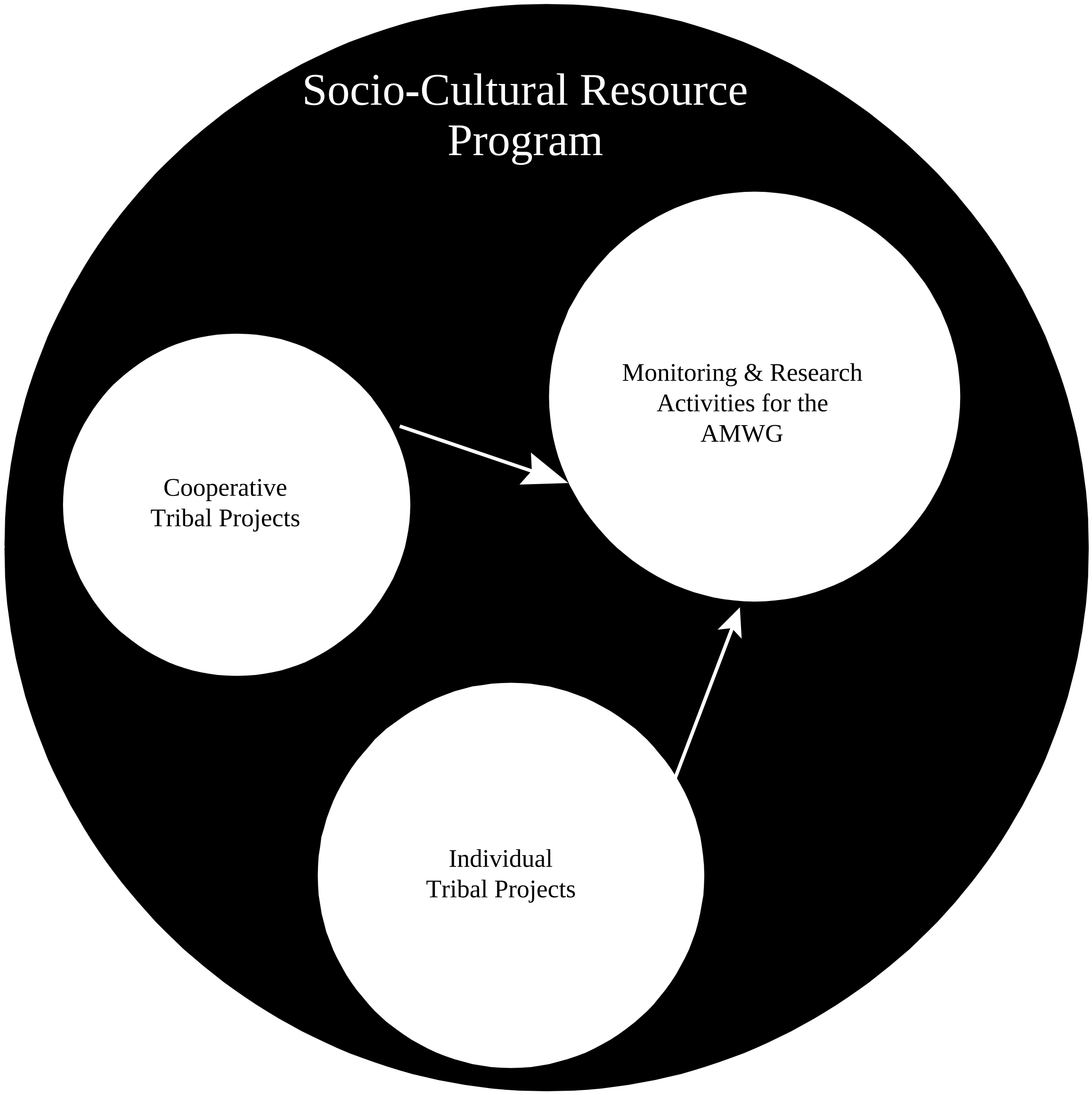


Figure 6.4 Primary Components of the Socio-Cultural Resources Program.

This portion of the program is implemented by tribal members of the AMWG. Tribal groups may design, propose, and implement resource monitoring programs to evaluate the condition of their traditional cultural places and resources within the riverine corridor based on dam operations. These projects are initiated by the tribal groups and submitted to the GCMRC for support based on the activity areas described in the long-term and annual plans. Because the values associated with traditional places are known and understood by tribal individuals, the GCMRC recognizes that Native Americans are the most appropriate authorities to formulate project work plans and programs that address their concerns about dam related impacts to these resources. These projects will provide the GCMRC with a different perspective on resource conditions and impacts. Because of the sensitive nature of these places, specific guidelines are being developed between the tribes and the GCMRC concerning information about resource significance and locations. Some examples of tribally initiated projects may include GIS mapping projects and locational studies, historical documentation and research, traditional analysis of resources, and traditional histories as they relate to dam operations.

Finally, projects that propose integrative and/or alternative investigative studies are encouraged by the GCMRC. These projects may investigate resources that have cultural values to Native Americans but are outside western notions of cultural resources. One example of this type of resource is a sacred plant gathering area that has important cultural values to a particular group but may appear as a biological resource from a western perspective. In addition, the GCMRC is interested in projects that incorporate traditional methods with conventional scientific methods to formulate new investigative methods and insights that reflect Native American perspectives and complement a conventional scientific approach.

If tribal groups are interested in submitting proposals that extend outside the scope of the GCMRC's funding ability, the program manager may assist tribal applicants with portions of the project that may not be directly funded by the GCMRC but are related to the GCMRC's operations by linkages to resources being studied for dam related impacts. In this manner, the program manager will function in a coordinating role for total program integration through assistance in research planning and proposal preparation.

C) Cooperative Tribal Projects Although other program components incorporate cooperative planning and programming for monitoring activities, most of the elements of the monitoring and research projects are individualized to specific tribes.

However, there are potential areas of interest to all tribes in developing and participating in GCMRC projects.

One example of an area of common interest is the development of educational opportunities for Native American students, particularly the participating tribal groups. These opportunities may include the development of cooperative educational agreements between the GCMRC, universities and agencies, and the tribes to involve students in intern programs that are related to all GCMRC resources areas. These activities will complement the educational efforts developed within the PA program. Scientific assessments in the last 15 to 20 years have developed significant information on the resources in the canyon. Within these scientific studies there have been some efforts to utilize these important monitoring and research programs to train new scientists, however, this has not been a focused effort of programming. The Native American community has increasing interest in utilizing ongoing study opportunities to develop improved scientific capabilities among members of their communities. The GCMRC is interested in the participation of the Native American communities in the research process and it will actively work with them to provide opportunities within the cultural program.

Finally, the GCMRC is concerned with the appropriate dissemination of monitoring and research information. Public funding supports the GCMRC's efforts to investigate resource impacts from dam operations and the GCMRC will work with the Native American communities to develop appropriate mechanisms for public outreach. Some examples of projects suggested in this portion of the cultural program include publications in varying formats for information dissemination to tribal members, student outreach field trips and visits, and workshops developed by the GCMRC and Native American hosts to present differing perspectives on canyon resources and dam operations.

The program manager has an additional responsibility that requires increased cooperation with the GCMRC program staff. The program functions as an umbrella program across all tribal resource areas of interest or concern. The cultural resource program manager is required to coordinate all resource programs of interest to Native American tribes with federal agencies, state agencies, etc. It is anticipated that the program manager will accomplish program coordination via strong interaction with other program staff. Although the major part of the cultural resource program will not involve extensive coordination across resource areas, selected areas will require significant coordination. It is expected that all program managers will, through a team effort, keep all other program managers abreast of cultural resource monitoring and research planning and program direction, research support, and integration needs.

In conclusion, the socio-cultural program consists of three major components: 1) monitoring and research activities to respond to objectives and information needs of the AMWG, 2) individual tribal projects, and 3) general Native American projects and issues, such as education opportunities and public outreach. Following the ecosystem paradigm, the socio-cultural program maintains an integrative and inclusive definition of resources as defined by participant groups in the adaptive management program. In addition this program interfaces with other program projects to consider the concerns of tribal groups. Finally, the GCMRC views the program's monitoring and research requirements as opportunities for full tribal participation in the research methodologies and products.

II. MANAGEMENT OBJECTIVES AND INFORMATION NEEDS

1) Prehistoric And Historic Resources

The past work provides a knowledge base to formulate a long-term monitoring and research plan that addresses the AMWG objectives for cultural resources that may be affected by the dam operations. The objectives are listed on the resource sheet located in Appendix A and include the following:

1) Conserve *in situ* all the downstream cultural resources and take into account Native American cultural resource concerns in the Colorado River ecosystem.

2) If *in situ* conservation is not possible, design mitigative strategies that integrate the full consideration of the values of all concerned tribes with a scientific approach.

3) Protect and maintain physical access to and use of traditional cultural properties and other cultural resources where such access and use may be impacted by dam operations. 4) Maintain, and integrate all appropriate cultural data recovered from monitoring, remedial and mitigative actions and incorporate these data into evolving research designs and mitigation strategies for understanding human occupation and use of the Colorado River ecosystem.

The above objectives were developed in consultation with a technical subgroup of the AMWG composed of individuals with resource expertise. Information needs were also developed with the group to assist in meeting the objectives. The information needs can be summarized as the need to 1) develop data and monitoring systems to assess impacts, 2) develop data systems to assess risk of damage and loss from varying flow regimes, 3) assist in the development of tribal monitoring programs for the evaluation of impacts to traditional resources, 4) develop a predictive model of geomorphic processes that are related to archaeological site erosion, 5) develop mitigation strategies such as preservation, stabilization, documentation, remedial activities, etc. for sites with documented impacts from dam operations, 6) characterize resource attributes and significance through directed study. Some of these information needs will be satisfied during portions of this plan while others will continue throughout the planning period. For example, portions of numbers two and four should be satisfied at the beginning of the planning period. The remaining information needs are anticipated to be on-going

2) <u>Recreational Resources</u>

Management objectives for the recreational resources were developed by stakeholders with the goal to provide quality recreation experiences that do not adversely affect natural or cultural resources within the river corridor. Recreation resources include sport fishing, white water rafting, boating, hiking, sightseeing, photography, and hunting..

The management objectives include 1) Provide quality recreation experiences consistent with other resource objectives; 2) Maintain flows (under approved operating criteria) and sediment processes that create an adequate quantity, distribution and variety of beaches for camping, as long as such flows are consistent with management of natural recreation and cultural resource values (other natural resource values); 3) Maintain flows (under approved operating criteria) that minimize impacts to navigability by authorized water craft and for boaters, waders, and campers in the riverine corridor; 4) Maintain flows (under approved operating criteria) and habitat suitable for quality cold water fishery opportunities in Glen Canyon; 5) Maintain flows (under approved operating criteria) and habitat suitable for waterfowl sport hunting and wildlife viewing opportunities in Glen Canyon.

Information needs specified for this resource area in the strategic plan cover issues of camping, beaches, water safety, sports fishing and wildlife (waterfowl) viewing and hunting. A synopsis of specified information needs are: 1) Determine criteria and aspects that are important to, or detract from the recreational experience.; 2) Determine adequate beach quality, character and structure for camping throughout the system; 3) Determine if operating criteria maintains safe and adequate power craft navigability in Glen Canyon and upper Lake Mead; 4) Determine flow regimes necessary to maintain fish populations of 100,000 adult Trout (age class II plus); 5) Define pattern of waterfowl and other wildlife use and conflicts to other uses.

There are many socio-economic resources associated with the Grand Canyon riverine environment including recreation (i.e., boating, fishing, hiking, sightseeing), electric power, and water. Further, due to the vastness and geologic distinctiveness of the Grand Canyon, the Park has acquired national and international recognition, including the designation as a World Heritage site by UNESCO, and all of the resources in the Canyon are considered to be significant to the public.

III. PROPOSED MONITORING AND RESEARCH ACTIVITIES

1) Prehistoric and Historic Resources Proposed Monitoring and Research Activities

Each of the information needs developed with representatives of the AMWG is supported in the long term program by program activities. These activities are organized around the identified needs cited above.

1) Develop data and monitoring systems to assess impacts. Monitoring data has been collected on cultural resources by the NPS for several years. As a result of the GCDEIS process, monitoring activities were increased and became more standardized. This information was synthesized to provide direction for activities in the PA program. Since the cultural resource survey in 1991, the NPS and tribal groups have continued to monitor resources several times a year under the stipulations of the PA program. This information has been gathered and reported by different groups. The information gathered during PA monitoring activities is currently being compiled for the GCMRC's study area and synthesized to indicate areas where additional data may be needed to evaluate sites having the potential of being impacted by dam operations.This synthesis is required under the PA program and will provide GCMRC with information to formulate future projects. It is anticipated that these data will help focus assessment efforts on particular site types or areas that are prone to impacts. In addition, these data may suggest projects that investigate Isolated Occurrences (IOs) as they may represent the last remains of site materials, or they may constitute the first exposures of buried sites or individual episodes of use and occupation within the river corridor. Collectively, IOs yield information about past adaptations and how people interacted with their cultural landscapes. Synthesis data will be available in FY 99.

Other monitoring activities in this area should complement basic monitoring activities that are accomplished under the PA program. Areas of monitoring under the GCMRC program that are not covered by the PA program, include cultural resources that do not fit the narrower definitions of the PA program and work not being conducted under that program. Examples include traditional tribal assessments of ethnobotanical and other cultural resources (landforms, mineral resources, etc.) and stationary camera photographic monitoring related to flow stages and ramping rates in the Glen Canyon Reach where high terraces with cultural deposits seem to be vulnerable to varying flow stages. Data currently being generated by the geomorphic and stage flow and deposition projects will be available early in FY 2000 and should help to refine and focus GCMRC projects.

2) Develop data systems to assess risk of damage at critical threshold levels, and loss from varying flow regimes. The compilation of existing site data from the PA program and the GCMRC physical science program can be useful to predict resource risk factors from varying flow regimes, including inundation impacts and related depositional effects that may benefit resources. Flow regimes and deposition at various stages can be quantitatively modeled for previously unevaluated resources, such as traditional tribal resource locations. Model results can be mapped in combination with resource locations and other descriptive parameters to provide predictive assessment of traditional resources. This information would help to determine inundation frequency as well as critical threshold levels for triggering recommendations for remedial responses. The ongoing mainstem flow and deposition project is testing this model in one area of the river corridor where archaeological resources have been identified. If the modeling work proves useful in this test area, the model can be applied to other areas and other types of important resources.

3) Assist in the development of tribal monitoring programs for the evaluation of impacts to traditional resources. Tribal programs to monitor and assess cultural resources are an important component of resource assessments as these programs supply different but complementary information on resource impacts. These resources may embody a full range of important qualities including data concerning past occupations as well as tribal histories. While archaeological monitors can evaluate the physical impacts to resources, traditional views on resource qualities may evaluate resource impacts differently. These conventional impacts assessments may be related to integrity of the resource, information loss of the resource, and vandalization. For Traditional Cultural Properties (TCPs), resource integrity and loss are defined within the concepts of the group for which they have significance. Rarely can outsiders evaluate these resources using traditional definitions for important resource elements. For these reasons, tribal groups can provide invaluable information concerning resource impacts. This information is complementary to conventional methods and it helps to provide assessments of the full range of important qualities of the resource.

Under the GCMRC program, tribal monitoring programs can enhance the monitoring and research activities developed with the AMWG for a broad range of cultural resources including botanical and physical resources. Monitoring activities should be structured so that they provide tribal perspectives and concerns on the resources included in the GCMRC projects. Finally, general resource locations and areas of concern that may be impacted by project activities need to be mapped. These maps will assist in discussions with the tribes and about their monitoring activities.

4) Test and apply a model of geomorphic processes relative to archaeological site erosion. The existing work linking certain geomorphic process and archaeological site erosion (Hereford et al. 1991) is currently being evaluated. This work hypothesizes that sediment loss related to regulated flows and the absence of natural flooding events, foster arroyo cutting through terraces due to mainstem bank failure and cutbank retreat combined with natural run off processes. These processes remove terrace sediments that contain archaeological deposits. Past site assessments from PA program field work, suggested that additional archaeological site monitoring was needed to occur to test the above hypothesis. This work is currently ongoing and will be applied in a limited area of the river corridor. It is anticipated that refinements to the model, further field testing, and possible application to other areas will occur during this planning period. In addition, sediments deposited from proposed beach/habitat building flows in cultural resource locations need to be mapped and compared to past deposits at resource locations. This information should provide additional data to determine the longer term effects of varying planned flow events on resources.

All of the assessments and activities suggested above provide basic data for describing the conditions of culture resources. These data can be used to formulate research questions that are directed at the relationships between impacts resulting from dam operations and the resource assemblage. These assessments and monitoring activities provide the initial bases for the research related information needs described below.

5) Develop mitigation strategies for the broad spectrum of cultural resources where there are documented dam impacts by monitoring assessments, and 6) Characterize resources through directed studies.

Monitoring activities can indicate that change in resource conditions is occurring. The research activities are formulated to explain the sources of that change as well as characterize the resource. It is proposed that research activities be initiated to determine relationships between resource impacts and "dam operations" when these are suggested from monitoring observations.

Resources studies should be formulated using the research domains developed within the PA programs's Historic Preservation Plan. These domains inform on important aspect s of past occupation within the river corridor. These domains include: dating and chronometrics, demography, subsistence, settlement systems, cultural affiliation, socio-political issues, technology and exchange. These areas provide an intellectual framework to formulate data collection. A full range of methods for data retrieval must be devised. These can include non-invasive techniques such as historical literature searches, traditional oral histories, remote sensing, as well as conventional invasive data recovery efforts. Resources targeted for data recovery should include those in which dam related impacts are suggested although that relationship may not be understood. Other criteria to target resources include the immediacy of the impacts, the probability of data recovery, data utility for other program research /monitoring efforts and resource significance.

While resource significance includes scientific value such as the ability of the resource to inform on the above research domains, traditional values are also a component of resource significance. These values will depend on the resource and the tribal group(s) that identifies the importance of the resource. In this area, tribal participation in providing monitoring information, treatment options, evaluation of proposed activities, and conducting appropriate field activities is critical. Data recovery plans will be structured to answer research questions related to the source of resource impacts and they will be compatible with the existing research domains listed within the Historic Preservation Plan and developed under the PA programs and new domains yet to be developed, as these organize inquiry and inform on past human use and occupancy of the river corridor.

Without the benefit of results from the ongoing projects, specific research endeavors cannot be proposed although some broad considerations have been suggested above. Other general areas of possible research can be suggested based on the information that is currently available.

Projects in this area should address research questions resulting from the synthesis of data that is being collected from ongoing monitoring and remedial actions under existing programs. Examples include research questions focused on human occupation of the GCMRC project area during prehistoric and historic periods using information collected and synthesized under current projects. Specific questions may center on issues of settlement patterns, subsistence practices, and cultural histories of stakeholders within the river corridor. These activities respond to Management Objectives 2,3, and 4 and related information needs. In addition, desired project designs should incorporate scientific and tribal paradigms in the methodologies and interpretations.

Following the compilation of data related to visitor impacts, research questions may center around the relationship between resource accessibility and visibility and degree of impacts identified. Resource accessibility can include access via established trails, non maintained trails, pedestrian /auto, and river. Visitor impacts may tend to correlate with various flow regimes that allow access to areas such as beaches and trails by recreationists.

In the area of physical impacts to resources, research questions may include investigations to determine the relationship between bank failure and cutbank retreat, various flow regimes and resource loss through erosion. Other questions center on the ability of high flows to stabilize predam terrace deposits and the cultural resources they contain. Finally, if predam terrace deposits cannot be stabilized and terrace deposits are effected by dam flows, resource documentation should proceed on cultural resources to be lost from the human record as a result of these operations.

2) Recreational Resources

To determine whether dam operations are affecting the pattern and amount of recreation use in the river corridor, data on use and changes resulting from recreation will be compiled. Such data can be utilized to assess changes in use, but also may help determine causes of some changes in other resources (e.g., fish populations, cultural resources, and beach sizes or quality, etc.). Recreation use data are available from, or can be obtained through, the NPS, Arizona Game and Fish Department, Native American tribes, and fishing guide, angler and boatman surveys, for rafting, angler, and miscellaneous users. Data for white water rafting (including commercial, private and tribal enterprises) would include user days, length of trip, put-in and take-out points, beaches used, and safety (accident) records. Information on angler uses would include commercial and private use above Lees Ferry relative to angler user days, fish catch data, and safety (accident) records. Miscellaneous uses, such as, bird watching, use of riparian habitats (both mainstem and tributaries) for hiking, sightseeing within the Canyon, etc., would be evaluated through NPS and Hualapai Tribe permitting records, Game and Fish surveys, and other means. The results would be summarized and evaluated at specified intervals.

Beach area data will be monitored using aerial video- or photography at the same discharge levels every other year. Changes in beach camping area at high discharge levels, can be determined through digitized video- or aerial photographs and validated on a sample basis through ground truthing coordinated with beach surveys under the sediment dynamics component of the long-term monitoring and research program. Validation of campsite area change can be determined by digitizing the onriver mapping.

To determine possible reasons for changes in recreational use, recreationists' values and concerns would be monitored on a five year basis or following unusual events such as flooding. This information would be gathered via user preference and attitude surveys of appropriate groups. This value determination is separate from values determined using non-use value methodologies. The former deals directly with use and experiences in the river corridor while the latter are based on no direct contact with the river corridor

Program activities that will be conducted in the planning period include the following areas: 1) Use past monitoring, research and cooperative studies to develop synthesis of campsite beach changes through time associated with differing flow regimes, i.e., camping area, vegetation changes, etc.; 2) Research user preferences and attitudes assessing wilderness experience relative to differing flow regimes: 3) Monitor trout anglers use and satisfaction through creel census and cooperative monitoring program with fishing guides and Trout Unlimited: 4) Evaluate effectiveness of new monitoring protocols for long-term assessments of camping beach changes from differing flow regimes: 5) Monitor beach changes and user preferences through cooperative programs with boating guides.

IV. ECONOMIC MARKET ACTIVITIES

Hydropower Supply

Hydropower supply is an integral part of the economy of the region. Changes in power operations resulting from changes in annual dam operations would affect the power supply and its costs. The goal of this program is to maximize the value of long term firm power and energy generation within the criteria and operating plans established by the Secretary under Section 1804 of the Grand Canyon Protection Act. The objectives of this program are to determine the impact of changes in dam operations on hydropower outputs and the concomitant power marketing and economics of the region, a concern of those agencies and organizations associated with hydropower production.

Actual power generation will be monitored on an hourly basis as input to assessing the consequences of dam operations on power economics. Power generation is also a method for estimating water discharge rates and volumes. The data needed to measure and evaluate power production is already routinely collected by the USBR and WAPA and no data gathering is required of GCMRC.

The stakeholder objectives include maximization the value of long-term power and energy generation within the criteria and operating plans established by the Secretary under Section 1804 of the Grand Canyon Protection Act. The information needs include: 1) Continue to monitor the amount of revenues collected from the generation of electrical power at the Glen Canyon Power plant; 2) Continue to account for the financial/economic cost of the operational changes at Glen Canyon Dam due to the ROD including rate impacts to CRSP long-term firm electrical customers; 3) Calculate the financial costs of research flows so that these costs can be declared "non-reimbursable" (as defined by Section 1804 of the Grand Canyon Protection Act); and 4) Monitor any difficulties in operating an integrated electrical system, including regulating a load control area . At the present time, sufficient information is being collected to meet these needs and no activities are planned in this area.

Water Resource

Water resource has associated value with both its quantity and quality. Reservoirs present opportunities to regulate market supply. High water levels in reservoirs and rivers also normally maximize recreation benefit and values. High water quality can also create additional value in water supplies. Water quality is currently monitored in lake Powell as part of a comprehensive study area water quality program that is directed at the effects of water quality on downstream resources.

A comprehensive assessment of both market and non-market costs and values was conducted in Phase II of the GCES. That assessment established an appropriate baseline analysis of Grand Canyon resource values. Also, for the period of study during the 1990s, it established appropriate cost analysis relating to impacts of alternative dam operating criteria.

What has not been accomplished to date is development of an effective Cost/Benefit Analysis (CBA) model that can easily accommodate new economic assessments of any alternative operating criteria proposed for the Dam. A proposed model should accommodate evaluation of all associated market and non-market costs and benefits, including intrinsic and existence values of key resources.

Development of this CBA model should be along design parameters that permit eventual incorporation into a more robust decision support system (dss). Appropriate timing for development of the CBA model should be in year four or five of the first 5 year plan.

Summary

The monitoring and research activities described in this plan respond to stakeholder objectives and information needs. Specific project plans will be described in the annual plans as ongoing information efforts are assessed and evaluated.

The program can be summarized to include three elements. These include: 1) the monitoring and research activities necessary to address the objectives and information needs identified with the AMWG; 2) individual tribal projects; 3) and cooperative tribal projects. The socio-cultural program monitoring activities are devised to provide base line data from which to formulate research questions. Research activities will be proposed on the basis of monitoring data. Individual tribal projects will be supported by the program to involve the tribes in program activities. In many instances, tribes are the most appropriate groups to undertake the activity. The program support for these proposals is intended to foster the development of scientific endeavors by the tribes as well as projects that incorporate traditional perspectives and approaches. Cooperative projects involve educational opportunities for tribal students in the programs activities. In addition, public outreach is included in this area. It is anticipated that informational channels will be developed in consultation with the tribes and that they will be actively involved in the information dissemination and interpretation.

There are several issues that can and will amend this plan. These include changes in the knowledge base of the cultural resources. This may result from the discovery of new resources within the area, unexpected and/or accelerated impacts to resources, and changing AMWG objectives. All of these issues may result in redefining priorities for the program.

INFORMATION TECHNOLOGIES

INTRODUCTION

The GCMRC has extensive historical data and information collected over many years relating to the condition of resources in the Colorado River ecosystem. This information represents an extremely valuable asset to researchers, managers, and interested stakeholders, but has yet to be developed into an ecologically integrated database. Its potential for problem solving, improving management guidelines, modeling relationships, or increasing understanding of the various resources and systems under study justifies an aggressive program of information acquisition, management, and subsequent analysis.

The goal of the Information Technology Program (ITP) is to *satisfy the information needs of stakeholders, scientists, and the public relative to the Colorado River ecosystem* in terms of content and delivery. Key to achieving this goal is the development and maintenance of three core information technologies: 1) a data base management system (DBMS) for tabular information and other electronic non-spatial information, 2) a geographic information system (GIS) for electronic spatial information, and 3) a library for hardcopy information. Content of these systems will consist of all information gathered as the result of GCMRC investigations, both past and present, and additional information relating to the Colorado River ecosystem.

Data in itself is of little use without sufficient information as to its context, quality, and comparability. Therefore, data standards must be developed which preserve the context under which the data was collected and ensures its quality and comparability from year to year, place to place, researcher to researcher, and discipline to discipline. Future data collection efforts supported by the GCMRC will incorporate strict data standards and protocols that provides consistency in data collection, storage, and delivery from disparate sources.

Delivery of electronic content will be automated where possible using user-friendly World Wide Web browser interfaces. Library content, while not deliverable across the Internet, will be cataloged and searchable electronically utilizing similar interfaces.

Warehoused data will conform to the National Information Infrastructure (NII), the National Biological Information Infrastructure (NBII), and the National Spatial Data Infrastructure (NSDI). Guidelines and protocols promulgated by these infrastructures will be incorporated into the overall database design and delivery systems whenever possible.

DBMS, GIS, and library operations together form the core information system infrastructure for storing and retrieving information at the GCMRC. Data standards and protocols ensure the quality and compatibility of the information contained within those systems. World Wide Web browsers provide intuitive, consistent interfaces to the information. However, information technology at the GCMRC goes beyond the content and delivery of information. In addition, the ITP also provides:

- Computer support to GCMRC staff
- Survey support to researchers
- Outreach to stakeholders, scientists, and the public
- Development of remote sensing applications

These ancillary services augment the core information infrastructures by providing the support, training, technology transfer, and development necessary to provide a comprehensive ITP.

Information Flow

The ITP becomes involved with scientific investigations at the point of award (fig. X). At this point, information flows bi-directionally between the researchers and the ITP. The ITP provides the researcher with relevant background literature, scientific and remotely sensed data, and survey and other spatial data. The researcher identifies to the ITP the type and attributes of tabular, spatial, and sensitive data they are collecting. Quality control and assurance plans are reviewed and approved. Appropriate protocols and standards for data collection and delivery are incorporated into the contract before award. When GCMRC receives a deliverable from a researcher containing data or other information, the ITP reviews it for completeness and conformance to the standards and protocols and incorporates it into the appropriate data system on a provisional basis. The data is quality assured and then made available to stakeholders, researchers, and the public through delivery systems.

Data Base Management System

A comprehensive and versatile DBMS is the first of the three core information technologies being used by the GCMRC. Its purpose is to store and deliver all tabular and other electronic non-spatial information gathered as the result of GCMRC investigations, both past and present. The ITP of the GCMRC is currently charged with inventorying, organizing, archiving, and developing delivery systems for many years worth of environmental data collection activities representing a vast array of disparate data including physical, biological, cultural, socio-economic, and climatic information. Some data resides on mature DBMS systems but much of it is stored on floppy disks or hard disks on personal computers using PC type spreadsheet and database formats. Although the objective of the information technology program is to provide a centralized database management system (DBMS), it is our policy not to duplicate data warehousing already provided by other entities. In these circumstances it is preferable to interrogate the off-site database remotely when possible. However, the GCMRC will act as a clearinghouse of data owned by other entities in the case where remote database interrogation is not possible. The challenge facing the ITP is how to bring together years of disparate historical data collected by multiple entities located in databases across the southwest in an organized fashion and then deliver it transparently to an equally disparate group of stakeholders for decision making and modeling purposes.

Aside from application of information technology to the warehousing of data, but no less important, is the ability of the information users to easily access, query, and obtain data from the information system. A process needs to be established by which the information user knows how to find and obtain the information he/she is looking for. Therefore, an additional key area of concern is adequate documentation and training in the use of the information system. Successful application of information technology, a well defined process for obtaining data, and thorough documentation and training culminates in an information system that is accessible and easy to use.

Delivery of electronic content will be automated where possible using user-friendly World Wide Web browser interfaces. When possible, a common interface will be developed which will facilitate dissemination of data to all interested parties

The Oracle data base engine has been selected for GCMRC data base development. Oracle is a state-of-the-art data storage and delivery system that can function either as a centralized or distributed data base and incorporates a high degree of information technology integration. Important features of the DBMS are:

All data will be ecologically integrated. Meaning that data will be stored in a consistent format relative to time, space, researcher, and discipline. This is essential for comprehensive ecological analysis. Appropriate data standards and protocols will be developed to regulate this feature.

Spatial data will be geographically integrated. Although the data base will not contain a spatial data analysis engine, the GIS used by the GCMRC will be highly integrated with, and dependent upon, the data base for storing attribute data associated with spatial features. Data contained in the database will; however, be spatially referenced within the data base where appropriate.

Public data will be freely available. Sensitive data will be protected. User accessibility will be configurable item by item.

The data base will be searchable over the Internet using browser interfaces. Intuitive browser interfaces will be the primary method used to interrogate the database.

The GCMRC data base development will occur over a two year period ending in December, 1999. Eleven benchmarks have been established to track the progress of the data base development:

1. Select database software and hardware platform
2. Install software and document the installation procedure
3. Conduct data inventory and acquire example data sets
4. Evaluate existing environmental databases
5. Define data standards for tabular data
6. Identify attributes of data to be included in the data base
7. Program data base structure
8. Populate the data base
9. Develop user interfaces
10. Develop Web interfaces

Document administrative procedures

Benchmarks 1 and 2 are completed with work in progress on 7. Once the data base has been designed, populated, and documented, the cost of this effort will drop substantially.

Geographic Information Systems

A GIS is the second of the three core information technologies being used by the GCMRC. Its purpose is to provide spatial analysis capabilities to GCMRC staff and stakeholders and maintain a library of GIS thematic coverages of the study area. GIS is an important analytical tool for integrating and comparing spatial data.

The GCES had significant accomplishments in GIS system development and establishment of meta-data protocols. GIS activities were concentrated along 17 reaches of the Colorado River identified as GIS Sites 1 - 17 (fig. Y). Each GIS Site has up to 20 thematic coverages associated with it depicting spatial relationships of biological, cultural and cultural resources. Considerable tabular attribute data exists as part of these data sets. These data sets are known as ?base data?. In addition, there exists other GIS data sets which were constructed as part of past GCES supported investigations and delivered as part of a final product. These data sets are known as ?contributor data? The base and contributor GIS coverages represent a significant effort by GCES which may have broad application for research being conducted in the Grand Canyon. Efforts are now underway to catalog, describe, and distribute base and contributor data.

The GIS group is working to increase the GIS coverage of the Grand Canyon by using state-of-the-art mapping techniques discussed under the Surveying operations.

The GIS program is committed to the principles and objectives of the NII and NSDI. As such, guidelines and protocols promulgated by these infrastructures will be incorporated into the overall program design and development with specific consideration given to GIS metadata standards.

Library Operations

Library operations provide the last of the three core information technologies being used by the GCMRC ITP. Its purpose is to facilitate research by providing a centralized repository for hard copy information such as books, reports, maps, photography, and videos. The scope and purpose of the library should be to collect, archive and deliver those materials that assist the center in its efforts to administer long-term monitoring and research.

Inherent in the administration of plans is the delivery of materials that facilitates monitoring and research activities. Ensuring that these materials, that form the basis for research and monitoring efforts, are available to researchers funded through GCMRC is a primary purpose of the library. Materials utilized in research and monitoring efforts include hard copy documents, photographs, slides, videotapes, and ARC/Info coverages. A loaning policy of these materials is developed in a manner that is most parsimonious to all researchers, with underlying GCMRC staffing resources determining the ability to deliver and track loaned materials. Delivery of materials also emphasizes technologies that permit remote multi-user access.

Secondary to providing funded researchers access and use of the library's materials is providing non-funded researchers and the general public access to documents unique to GCMRC's holdings (duplicate documents available at other institutions provide non-funded researchers access to these materials). The singularity of a document requires special policy concerning the borrowing of these materials. Because these unique documents are considered part of the public domain, their availability to the public is required. Lending policies concerning these documents and materials are developed to insure that the loss of these materials is minimized.

Collection of materials for the purpose of research and monitoring efforts are coordinated with program managers and information technology managers. Criteria for the accession of materials include:

1. Applicability of materials to specific research efforts and to overall research and management goals; adequacy of the facility and equipment needs of the GCMRC to house materials;
2. Ability of the staff to archive and deliver materials;
3. Availability of funding for materials (e.g., general reference books, government publications, CD-ROM's, etc.).

Collection also includes the accessioning of documents that are the product of research funded by GCMRC.

Library holdings included the following:

1. Hard copies and electronic copy of final funded research reports.
2. Reprints of articles resulting from funded research.
3. Books resulting from research efforts associated with GCMRC.
4. Books and articles related to Grand and Glen Canyon.
5. Books and articles related to natural and controlled riverine and environments.
6. Photographs and slides developed by GCMRC staff (aerial and field documentation).
7. CD-ROM versions of aerial photographs and slides.
8. Videotapes (overflights, programs related to Glen and Grand Canyon).
9. Maps (topographic, flightline maps, Arc/Info Coverages, Orthophotos).

Archival materials are one of a kind, or hard to replace items (e.g., original aerial photographs, slides, videotapes). Utilizing imaging technology (e.g., CD-ROM's) and electronic media to develop copies of archived materials should always be investigated and promoted so that copies of these materials can be made available to the general collection, and thus reducing the incidence of loss of unique and irreplaceable materials.

The GCES made great strides in the establishment of the library in 1993 when a research librarian was hired to organize and maintain it. However, the librarian resigned in May of 1997 during the transition from GCES to GCMRC and the position was not immediately backfilled.

There have been valid concerns about the condition of the library since that time. New holdings were being stacked on shelves, desks, or placed in boxes for safe keeping. There was no formal monitoring of the library or check out process to track the whereabouts of library materials. Fortunately, that situation has since been corrected and great strides have been made in making the library a functional entity within the GCMRC.

A library committee was assembled in October of 1998 and met to decide what actions should be taken to update and maintain the library. Over several months, the committee produced a strategic plan with recommendations for the restoration of the library. The library content and strategic plan was reviewed by two outside consultants who produced written comment and recommendations of there own. Since that time, a student has been hired from Northern Arizona University to oversee the day-to-day operations of the library and reorganize its content. Library automation software has also been obtained and the library content is being indexed using this software on a time available basis.

Current goals the library seeks to obtain are:

1. Establish library policy for material use and checkout
2. Catalog library contents using the Dewy Decimal system
3. Facilitate the day to day library operations by using automation software
4. Provide electronic searching capabilities of library content over the Internet
5. Provide more information electronically over the Internet

Once these goals have been achieved, the library should be able to serve a greater number of constituents in less time with better service at a reduced cost.

Remote Sensing

In May of 1998 a remote sensing protocols review panel (PEP) was assembled to evaluate remotely sensed monitoring and research methodology currently used by the GCMRC and recommend alternative remotely sensed technologies which might better meet program information needs. The result of this effort was a 17 page report with recommendations of remotely sensed technologies which will benefit resource monitoring and research in the Canyon (Final Report, GCMRC Remote Sensing Protocols Review Panel, June 15, 1998). Revised management objectives established by the TWG that could benefit from the application of various remotely sensed technologies were identified.The revised management objectives along with recommendations provided by the PEP will provide direction for the GCMRC remote sensing and GIS programs.

The goal of this plan is to establish a guide for the development and implementation of remote sensing and geographic information system (GIS) into the monitoring and research programs associated with the physical, biological, and cultural monitoring of dam related effects within the Colorado River ecosystem. Objectives of this plan include using black and white, color aerial and near-infrared aerial photography along with HYDICE, LIDAR, and other remote sensing platforms to map and analyze the physical, biologic, and cultural resources of the ecosystem. GIS will assist the monitoring scientists and managers in determining the long-term trends associated with dam operations.

To accomplish the above goals, with the approval of the TWG and AMWG, the GCMRC is planning an aggressive program intended to evaluate remotely sensed data collection and processing techniques recommended by the PEP across all resource areas currently being monitored in the Canyon. The GCMRC staff in conjunction with qualified contractors will utilize the latest available remote sensing, image processing, and mapping technologies to generate thematic GIS coverages to be used for quantifiable resource analysis and prediction. The objective of the program is to provide a cost-effective means of resource monitoring in the Canyon with reduced impact and expanded monitoring in terms of resource components and geographic extent. Relationships will be developed between sensor, ability to answer the management objectives, and cost. The developed relationships will guide the implementation of the remotely sensed monitoring program in FY 2003.

The GCMRC remote sensing evaluation program will begin in FY 2000 and continue for three years. Remote sensing technology selected for use in routine resource monitoring will be implemented in FY 2003. However, it is anticipated that some technologies will be evaluated on an accelerated schedule, perhaps as soon as FY 1998-99, due to pressing needs for technological development in specific monitoring areas or opportunistic circumstances. The GCMRC intends to continue the annual acquisition of aerial photography until other remotely sensed data sets are identified and implemented into the monitoring program.

Remote sensing technologies recommended by the PEP and proposed to be initiated in FY 1998-99 are:

1. photogrammetric monitoring of terrace stability of archeological sites and sand bar volumes
2. stream-bed classification using QTC-view digital processing system
3. color infrared aerial photography for determining vegetative changes

4. multi-beam hydrographic data collection for bathymetric channel mapping
5. HYDICE hyperspectral remote sensing data collection for resource monitoring
6. LIDAR remotely sensed terrestrial topographic mapping of the canyon corridor
7. GPS as a means of extending survey control outside the existing 17 established GIS sites

In early FY 99, a three-dimensional model and a DEM of the Glen Canyon reach will be completed. The collected images will be geo-referenced and ortho-rectified and image-processing techniques will be developed. The derived techniques for each collection method will be used to quantify the physical, biological and cultural resources.

Panel Recommedations, References to PEP report, GCMRC actions, timelines, status and future needs, and estimated costs matrix for evaluating remotely sensed technologies are presented in Table 1. The total estimated cost of the program is $2,450,000 over a five-year period and includes:

1. the evaluation of airborne terrestrial mapping technology
2. the evaluation of eight multispectral/hyperspectral airborne sensors, three airborne photographic techniques, and four high resolution satellite imagery for resource monitoring
3. analysis of existing remotely sensed data sets
4. evaluation of image processing techniques
5. the development of remotely sensed data collection protocols

Sensors will be evaluated over selected representative reaches of the Colorado River corridor to reduce costs. The sensors must be able to answer the questions formulated by the revised management objectives. The information gathered will be assessed for accuracy and will enable the center to answer key questions relating to the future use and application of the tested images and analysis and mapping techniques. An anticipated result of the initial remote sensing and GIS program would be to establish a three to five year rotating schedule of data acquisition. However, the frequency and resolution necessary for specific resource monitoring in the Colorado River corridor has yet to be determined.

The proposed remote sensing and GIS strategic plan represents a bold undertaking by the GCMRC which, when completed, will provide the basis for comprehensive resource monitoring in the Colorado River system and will enable managers to make sound resource management decisions. Investigation of the application of these technologies to the GCMRC monitoring program may require additional data processing software, expertise, and perhaps outside consulting. Initial costs associated with the process evaluation and development of the remotely sensed data sets and a GIS database designed to answer the revised management objectives may appear to be high; however, the long term benefit associated with remote sensing may more than offset the initial cost. Remote sensing means: less river trips, less impact, more resource monitoring components, and greater geographic area monitored per dollars spent. The GIS will provide a predictive tool for management decisions. Historical data sets can be evaluated to help solve unanswered question. The cost of remotely sensed data has continued to decline over recent years. New sensors are being developed and data inventories grow. The present high costs cannot be expected to continue throughout the long term monitoring program of the Grand Canyon.

Surveying

In 1990 when GCES began the development of the GIS sites, it became necessary to establish topographic control for these sites as well as all other research related mapping in the Grand Canyon. The development of sound topographic and mapping control required good survey control to build these spatial data sets. However, as a result of extremely difficult logistics and access to the river corridor, reliable geodetic control points had never been established.

BOR remote sensing division contracted Horizon's mapping to establish GIS map coverage's using photogrammetric methods. David Evan's and Associates established GPS control points, and ground control points were traversed and paneled by Banner and Associates.

In 1991 Joseph Mihalko (NPS surveyor) occupied the Banner ground control points for a soil mapping project by the USGS. He found that the control points did not meet their claimed accuracy and precision. As a result, GCES established a survey department to correct all previously established survey control as well as meeting all the research needs of the future.

Global Positioning Systems

Global Positioning Systems have become a standard for survey operations worldwide. However the Grand Canyon provides for some very marginal satellite availability in the standard use of GPS. In the past very careful attention and planning have been required for successful GPS data acquisition.

For the most part GPS has been and is utilized to establish high order control points in the Canyon. This requires that a receiver or receivers be placed at known control points on the rim or in the canyon. Then additional receivers are used to set new points. All receivers must view the same satellites during the session. Using post-processing software the data can be resolved. This technique is called "static differential" and it yields the highest possible accuracy using GPS.

Another GPS application that we plan to employ is RTK GPS (Real Time Kinematic). RTK has shown very good promise in setting centimeter level accuracy with very short occupation time. This requires one receiver at a known base station and a rover with a real time data link between them. Unlike a conventional survey instrument, you do not have to have line of sight between receivers. Another advantage is that one surveyor on sight can operate RTK. RTK will be used for many types of control surveys to include setting panels for aerial photogrammetry. RTK can also be used to replace conventional survey methods for general topography. This can be a real advantage when dealing with a sensitive area such as a cultural site where a conventional survey can be destructive to the environment. Photogrammetric control can be easily set using RTK and all monitoring can be accomplished using remote applications such as aerial photography.

Conventional Survey Operations

Conventional survey practices have been the most common means of surveying in the canyon. Conventional usually means the use of a Total Station and a rodman. Conventional Traverse control is done by starting at a GPS or known reference point, setting a series of line-of-sight points and closing out at the origin or another GPS point or points. Conventional survey methods will always be required to fill-in where satellite visibility is impossible. Conventional methods are used for all types of location surveys to include topo, and site positioning. Another emerging conventional survey method is the use of a Robotic Total Station. A Robotic Total Station automatically tracks the rodman during the survey. The point data is transmitted via radio telemetry to an electronic data collector carried by the rodman. The advantage is that one surveyor can complete a topographic or location survey.

Hydrographic Survey Operations

In 1993 the GCES survey department began the development of a hydrographic mapping program to facilitate all monitoring efforts requiring sub-aqueous measurements. The hydrographic data collection methods was designed to develop required monitoring products such as topographic maps, digital terrain models, aquatic habitat models, sediment aggregation and degradation, hydrologic stage discharge modeling, and cross-section analysis. The survey staff purchased and continued to developed the “Super Hydro” hydrographic mapping system as the best "state of the art" equipment to facilitate the monitoring requirements.

The horizontal (X, Y) positioning of the depths and other remote sensing data sets are provided by the Super Hydro shore station. Many types of positioning systems were considered and the Super Hydro range/azimuth shore station was by far the only reasonable solution for a harsh canyon river environment. The shore station acts as a dynamic survey total station by continuously tracking an Omni-directional target on the boat. The boat receives the positional data from the shore station via radio telemetry at a rate of 4 times per second. The boat computer instantly converts the spherical coordinate measurements into Cartesian or geodetic coordinates for real time computer screen navigation allowing precise transect repeatability as well as accurate depth positioning. The following are the unique reasons why the Super Hydro shore station have made the hydrographic mapping program a success:

- 4 Hz update rate. A necessary requirement that enables the boatman to successfully position the boat in high current or turbulent river conditions. This high-speed update rate also allows for densely saturated data collection to define details of the river channel as required for endangered species habitat analysis.
- Precise horizontal and vertical positioning. The Super Hydro shore station can horizontally position a moving target within one half a meter and 20 cm 90% of the time at a range of 500 meters. Vertical tracking precision can achieve a 10 to 15 cm error 90% of the time at 500 meters. These precision values can vary based on the skill of the operator. Most of the other available positioning systems accuracy is in the 1 to 2 meter range. This is usually acceptable in an open water (oceanic) environment but cannot meet our river mapping requirements. Furthermore, our established protocol tracks the water surface as a real time measurement as independent monitoring of the river stage. Therefore it is extremely important to be able to accurately measure the vertical component from the shore station.
- All coordinate information is referenced from a single control point. Other types of positioning systems require multiple control points which can be logistically not available or out of view of the mapping area in a canyon river environment.
- Range/azimuth systems operate with the same practices and procedures as standard survey total stations. This minimizes training of staff and volunteer surveyors.

- Range/azimuth systems provide line of sight access to mapping areas regardless of the available GPS satellite window. RTK (real time kinematic) GPS techniques have dramatically improved the positional accuracy of DGPS (differential global positioning), however it is nearly impossible for a boat running transect lines across the river to maintain lock on the same 4 to 5 required satellites as the base station. This results from high canyon walls bordering the river edge thus limiting visibility to common sets of satellite constellations

Existing Hydrographic Equipment Summary

The Hydrographic fleet is comprised two 18-foot mini-snout utility/sport boats. These boats have been specifically designed for surveying and hydrographic mapping applications. Their twin floatation tube design eliminates the need to compensate for heave, pitch and roll error inherent with hydrographic depth measurements. Each boat is equipped with two custom saddle tanks with the fuel capacity to easily handle repetitive transects and fuel intensive river up-running. Each boat also is equipped with an aluminum equipment box and wooden decking to accommodate a survey crew and equipment.

Each boat is equipped with mounting hardware for the custom hydrographic "swivel mast" assembly. This adjustable mast is designed to house a positioning laser target or GPS antenna on top, and a submerged transducer or remote-sensing device on the bottom. The combination of high boat tube buoyancy, and an adjustable transducer draught, the hydro boat can collect depths as shallow as one foot below water surface.

The 18-foot mini-snouts are also ideal for conventional survey applications because they combine the mobility of a sport boat with the ability to carry a large payload of survey equipment and crew.

Routine hydrographic survey applications usually require one boatman, one surveyor, and one to two crewmembers. Deployment of a hydrographic rig requires one truck, and one trailer. Equipment assembly usually requires one full day of loading at the warehouse, two to four hours to rig, and one to two hours to set up and configure hydro equipment and instruments. These time estimates are less if not going downstream, i.e., working in the Lee's Ferry area.

De-rigging is the same time estimates in reverse.

The basic hydrographic components are comprised of a ship station and a shore station. The shore station is a survey grade range/azimuth instrument equipped with an endless tangent for dynamic tracking. A compact field computer processes the spherical data in real time and transmits them to the ship station via radio modem.

The ship station is equipped with a field-ruggedized computer to control, consolidate, and process all incoming data. Depths are measured with a high frequency acoustic echosounder. A radio modem receives incoming navigation data sent by the shore station. A power box combines a large 12-volt marine battery with a mini generator to maintain clean electricity to all the sensitive electronics. The aforementioned equipment is a custom design specifically for a harsh shallow water river environment.

Future Hydrographic Equipment

The GCMRC survey department recognizes the need to minimize the impact of data collection on the river environment. We are currently exploring boat design modifications that would allow us to operate with a four-stroke engine and still maintain the horsepower required to hold the boat stable in fast water during transect operations. Another benefit will be the development of the multi-beam system, which will only require 2 to 4, passes down the center of the channel. The current single beam system can require over 100 transect lines to form a grid on a site.

An important long-term requirement of the GCMRC hydrographic mapping program is to establish a complete hydrographic base map of the Colorado River corridor in the Grand Canyon within a 5-year period. Our current single beam sounder (hydro-acoustic transducer) technology limits our methods to a checkerboard grid system that typically produces 1 to 2 miles of river channel per day. Although our existing system was state-of-the art a few years ago, it would not be reasonable or cost effective map 250 miles of river within 5 years. However, advances in technology along with lowering costs of high power computer processing have made it possible to develop a multi-beam system for canyon river applications. A portable multi-beam system has the data collection rate of 200 depths per second while it collects a swath from an array of transducers. A boat would only be required to run a few passes up and down the channel for complete coverage. Our current system requires hundreds of transect lines per site that still miss depths between lines whereas a multi-beam system collects 100% coverage with an order of magnitude improvement in mapping detail and resolution. A multi-beam system could effectively map continuous river channel of 5 to 8 miles per day as well as monitor existing research sites at a much higher resolution. Although the components and development of a multi-beam system are expensive, they would prove to be a saving when the cost of multiple river trips, personnel deployment, and logistics are considered under our current abilities.

Before a multi-beam system can be realized, there are a few intermittent steps that need to be developed. A multi-beam system requires many positional calculations to take place. A processor must account for angle and distance to position the depth as well as motion sensor data to account for heave, pitch, roll, and yaw of the vessel. Add device communication latency time tags as well as multiple depth sound velocity corrections. The aforementioned is not possible without extremely accurate positional tracking. Existing operations of open water multi-beam systems accomplish the required positional accuracy with RTK GPS designed to measure X, Y, and Z at 2cm precision. However, RTK GPS is not a usable option in our unique canyon river environment as demonstrated above. The only option available to us that can achieve the required accuracy is an Automatic Tracking System (ATS) or also called a Robotic Total Station which is currently being used.

FY1999 Through FY2004 Work Plan (Five Year Plan)

The Survey department will use all of the aforementioned technologies and protocols to move toward accomplishing the following objectives:

1. Satisfy all RFP requirements. Based on 1998, the survey department will deploy crew and equipment for four separate RFP down-river trips for terrestrial and hydrographic data collection. The individual programs funding the research cover the survey costs of these trips.
2. Complete a high precision Control Network through the entire river corridor. In order to achieve spatial-positioning of research sites in the canyon, a distribution of control points must be accessible from the river by surveyors and/or researchers. To date approximately 100 miles of continuous control has been achieved in GIS study areas as well as a few connecting areas. It is the goal of the survey department to fill in the remaining 150 miles during this four-year period. This can be accomplished with some carefully orchestrated GPS sessions utilizing outside and inside expertise. This must be combined with some high accuracy conventional traverse work to fill in the areas with limited satellite visibility. All control surveys have and will continue to undergo a rigorous Least Squares adjustment routine to ensure data QAQC. The Survey department will deploy 4 to 6 independent down-river trips per year related to control/traverse and hydrographic channel mapping. In

addition, there will be two one-week excursions per year to Glen and Paria reaches to complete a series of monitoring surveys and channel mapping. Our goal is to add 40-50 miles of control per year.

3. We will deploy 2 to3 aerial photo/remote sensing control trips per year to replace the majority cultural mapping ground surveys. Other sites for use of this remote photogrammetric technology will also be included in these three trips. Remote sensing will replace labor-intensive ground surveys whenever possible. The survey department especially promotes the use of photogrammetry for large or sensitive sites. One surveyor using RTK GPS can set panel control on a site in a matter of hours. With a planned or existing over-flight the site can be stereo rectified to a high resolution equal to a ground topo that could take up to a week using conventional ground topographic methods. Setting panel control would also be used for other various remote sensing applications and ground truthing. Remote sensing methods such as Photogrammetry and/or LIDAR (LIght Detection and Range) will be necessary to terrestrially map the entire river corridor within a 5-year window.
4. The GCMRC Hydrographic Mapping Program will undergo an aggressive effort to map the channel. The current survey program is developing a multi-beam application for river corridor use to be operational by the middle of the year 2000. The current single beam system, although very effective, would prove to be too labor intensive to map the entire channel. The current system requires individual transect lines to form a grid. As a multi-beam sprays a wide swath that achieves 100% coverage of the channel bottom. A multi-beam would only require 1-2 transect lines down center channel while collecting 2000 points per second. Other hydrographic applications being developed include a sub-strait classification device (QTC VIEW) as well as an acoustic Doppler (ADCP). Hydrographic channel mapping will begin with the GIS sites and will continue, as control is set.
5. Terrestrial ground topography will continue on as needed basis as stand-alone or to accompany another survey. For example waters edge will be collected on all hydro surveys. When possible one surveyor using RTK GPS or a robotic total station or a combination of both will collect topography. In the case where conventional total station surveys are required for a robust point density, a fast operator and multiple

rodmen will be utilized (NAU sandbar). Electronic data collectors will be optimized whenever possible for high production.

6. Continue to develop a survey database for easy access and a seamless GIS interface. Development of archival protocols for GIS/Database interface for control, mapping products, and metadata. These costs are office supplies and are covered under misc. survey equipment.
7. Research and implement any current or developing management objectives in the execution of sound survey practices and procedures.

All survey control points, data, site maps, and other survey related information is documented and archived in the GCMRC survey department. GIS sites are archived using FGDC standards of metadata. All positional survey coordinates are archived in the Arizona State Plane Coordinates (Central) system. Control points are photo documented as well as described by river mile, GIS site, etc. All survey control is made available to anyone with a legitimate need for spatial positioning. Survey products are usually submitted to specific research projects funded by GCMRC. Independent survey operations such as control are archived internally and provided to researchers as needed.

Environmental Impact

The GCMRC survey department tries to minimize all potential impacts to the Grand Canyon river environment. Whenever possible, we try to utilize all existing control/survey monumentation. This includes bolts, X-cuts, nails, and survey monuments. However, in some cases it is necessary to set new points. These points are very carefully selected to be unnoticeable by the average person. We try to select natural features in the rock to use as control points. On occasion, when absolutely necessary, we will scribe a small X on a rock. Extreme care is always taken to avoid any survey operations on or near cultural sites unless that site is specifically being mapped. While mapping cultural sites we are almost always accompanied by an archaeologist, usually NPS.

Another potential impact on the environment is the deployment of photogrammetry targets as ground control. These targets are laid on known control points for stereo rectification of aerial photography as well as other remote sensing applications. These panels provide a much less intrusive operation on a site than physically doing a ground survey. The panels are usually removed from the site within a month or the next GCMRC river trip.

Estimated Costs To Achieve the Objectives

FY1999 Cost Summary

Satisfy all RFP requirements. Based on 1998, the survey department will deploy crew and equipment for four separate RFP downriver trips for terrestrial and hydrographic data collection. The survey costs of these trips are covered by the individual programs funding the research.

Control and channel mapping. The Survey department will deploy four independent downriver trips related to control/traverse and hydrographic channel mapping . The logistic cost of these four trips will be $45,000. In addition, there will be two one-week excursions to Glen and Paria reaches to complete a series of monitoring surveys and channel mapping. These two Lee's Ferry excursions will cost $3000 in lodging and per diem of field personnel. Our goal is to add 40-50 miles of control and complete 6-8 GIS Area hydrographic channel maps. Total logistic costs for the aforementioned is $48,000.

We will deploy two aerial photo/remote sensing control trips to replace the cultural mapping ground surveys. Other sites for use of this remote photogrammetric technology may also be included in these two trips. Total logistic costs for these trips is $22,000. *(P.A.)*

Training seminars and conferences for Mark Gonzales, Steve Lamphear, and Keith Kohl to include registration fees and travel will total $10,000.

All data processing and mapping products associated with the aforementioned trips. Costs are in-house office work of standard overhead.

Development of archival protocols for GIS/Database interface for control, mapping products, and metedata. These costs are office supplies and are covered under miscellaneous survey equipment.

Continued remote sensing protocol development to include terrestrial and hydrographic.

TOTAL LOGISTIC AND TRAVEL COSTS? $80,000

1999 Equipment Costs

2 GPS 4800/SSI rover units w\everest tech	$50,000
Pac crest RTK amps w/ cabling	2,000
Geodimeter robotic DC remote package	6,000
Husky fs/2 universal data collector	4,500
QTC view seabed classification system	19,000
TSS hydrographic motion sensing	20,000
SDI hydrographic monitoring computer	15,000
Hydro acoustic calibration sensor	2,000
Mapping software upgrades, maintenance	5,000
Horizons stereo rectification/arch sites	*(P.A.)* 16,000
Criterion GIS data collection laser	8,000
Misc. survey equipment/hardware	(long list) 12,800
GPS training/consulting	5,000
Trailer for hydro boat	2,500
TOTAL	$ 168,200

FY2000 Through FY2004 Estimates

1. Logistic costs at 80,000 per year as per FY99 scenario.
2. Total Capital equipment costs of 300,000 to include multibeam sensor as well as GPS equipment.
3. Survey operations maintenance costs of 25,000 per year to include tripods, batteries, data collectors, boat hardware, etc.
4. Training costs of 10,000 per year.

TOTAL ESTIMATE $ 760,000

Data Standards and Protocols

The purpose of data standards and protocols is to provide consistency in data collection, delivery, and presentation from disparate sources. Development of data standards and protocols ensures that data contained in the information system is valid data and that the data can be integrated with data collected by at different places at different times by different researchers in different disciplines. Data standards define field descriptors within the database such as definitions, formats, units, significant figures, decimal places, etc. Protocols define standard operating procedures for data collection, entry, and verification, which include quality control and quality assurance procedures, that guarantee the integrity of the warehoused data. A data standards committee will be formed which regulates this activity.

The ITP embraces the principles and objectives of the National Information Infrastructure, the National Biological Information Infrastructure, and the National Spatial Data Infrastructure. Guidelines and protocols promulgated by these infrastructures will be incorporated into the overall database design and delivery systems whenever possible. Implicit in the plan is support of the objective to increase access, sharing, and application of data among public and private cooperators and partners. The program recognizes that guidelines and protocols have not been established for all aspects of biological and spatial data warehousing. When lacking, the plan allows establishment of its own guidelines and protocols that will adhere as closely as possible to the intent and spirit of the infrastructures.

The ITP is committed to making public data freely available to stakeholders, researchers, and the public while at the same time protecting sensitive and confidential data provided by private entities for the purpose of evaluating the Colorado River resources. Cooperation among contributing Tribes, institutions, and state and federal agencies investigating resources in the canyon concerning timely transmittal of data relating to the GCMRC study area is essential. Scientists will be expected to provide their data to GCRMC after a reasonable period of exclusive use, which is currently being addressed by the TWG working group on data protocols. Concerning some data, such as archaeological-site data the Indian Tribes define as sensitive, or information on localized endangered species, a level of confidentiality will be necessary.

System Administration of Computers and Networks

Computer hardware and operating systems at the GCMRC will largely be a combination of state-of-the-art Intel processors running Windows NT. Each workstation will have a core suite of software applications available that will include mainstream off-the-shelf integrated office products such as a word processor, spreadsheet, graphics, database, browser, etc. Additional software needed for specialized scientific data processing will also be available. To the extent possible, hardware and software will be standardized throughout the GCMRC. The information technology program anticipates standardization will facilitate inter-office exchange of information and reduce the administrative effort of hardware and software support to a level sustainable in-house.

A primary objective of the plan is to improve overall system performance, reliability and maintenance. The information technology program believes that this can best be achieved by having competent individuals in-house trained in the administration, maintenance, and troubleshooting of the computer system. However, computer administration comes at a high cost in terms of manpower and expertise. A brief analysis of the current GCMRC computer environment has identified that most problems occur at the application - operating system - local area network layer and that few problems occur at the wide area network, or Internet, layer. Internet connectivity infrastructure can be very expensive. Therefore, it makes fiscal sense that Internet connectivity and associated services such as DNS, mail, and news will continue to be administered by entities outside the GCMRC, most notably the U.S. Geological Survey in the case of the Flagstaff Field Center office location (Gemini Drive) and U.S. Bureau of Reclamation in the case of the downtown Flagstaff (Bank of America) office location.

Outreach

Outreach provides the GCMRC interface to stakeholders, scientists, and public for activities and information dissemination. Additional outreach activities include:

1. Instructions and training in the use of database interfaces
2. Assistance in the application of information technology
3. Comprehensive World Wide Web presence
4. Assistance in overcoming technology barriers
5. Public announcements
6. Public presentations

CHAPTER 7

SCHEDULE AND BUDGET

SCHEDULE

The strategic plan outlined in this document addresses monitoring and research for a five year period: Fiscal Year 2002-2004; i.e., October, 1998 - October, 2003. Each year, in April, an Annual Plan will be drafted to guide implementation of specific elements of the Strategic Plan for the following fiscal year.

A science plan must be flexible under any circumstance. A science plan developed for an adaptive management and science program assumes significant flexibility as a design parameter. Configuring plans and funding should be specified in each Annual Plan.

This Strategic Plan is designed to guide specified synthesis, monitoring and research of the Colorado River ecosystem as part of the Glen Canyon Dam Adaptive Management Program.

BUDGET

The budget process for funding the GCMRC involves a transfer of funds from the Western Area Power Authority (WAPA), a federal government entity, through the Bureau of Reclamation, to the GCMRC, an administrative unit of the Office of the Secretary, United States Department of Interior. The budget for GCMRC is within the budget for the Adaptive Management Program (AMP) called for under the Grand Canyon Protection Act. To accommodate the transfer, the Upper Colorado Region of the Bureau of Reclamation, Salt Lake City, facilitates the Adaptive Management Program and is the budget office for the GCMRC.

The budget for the Bureau of Reclamation GCES program during a period of comparable work activity (1990-1996) to that being requested of GCMRC was approximately $12 million/year with an annual high of approximately $16 million and a low of $7 million. The fiscal year 2000 budget for the Adaptive Management Program has been recommended to the Secretary by the AMWG at $7.9 million. This includes activities in Lake Powell which have been added to the base program and $400,000 for investment in remote sensing technology which is expected to end in FY2002.

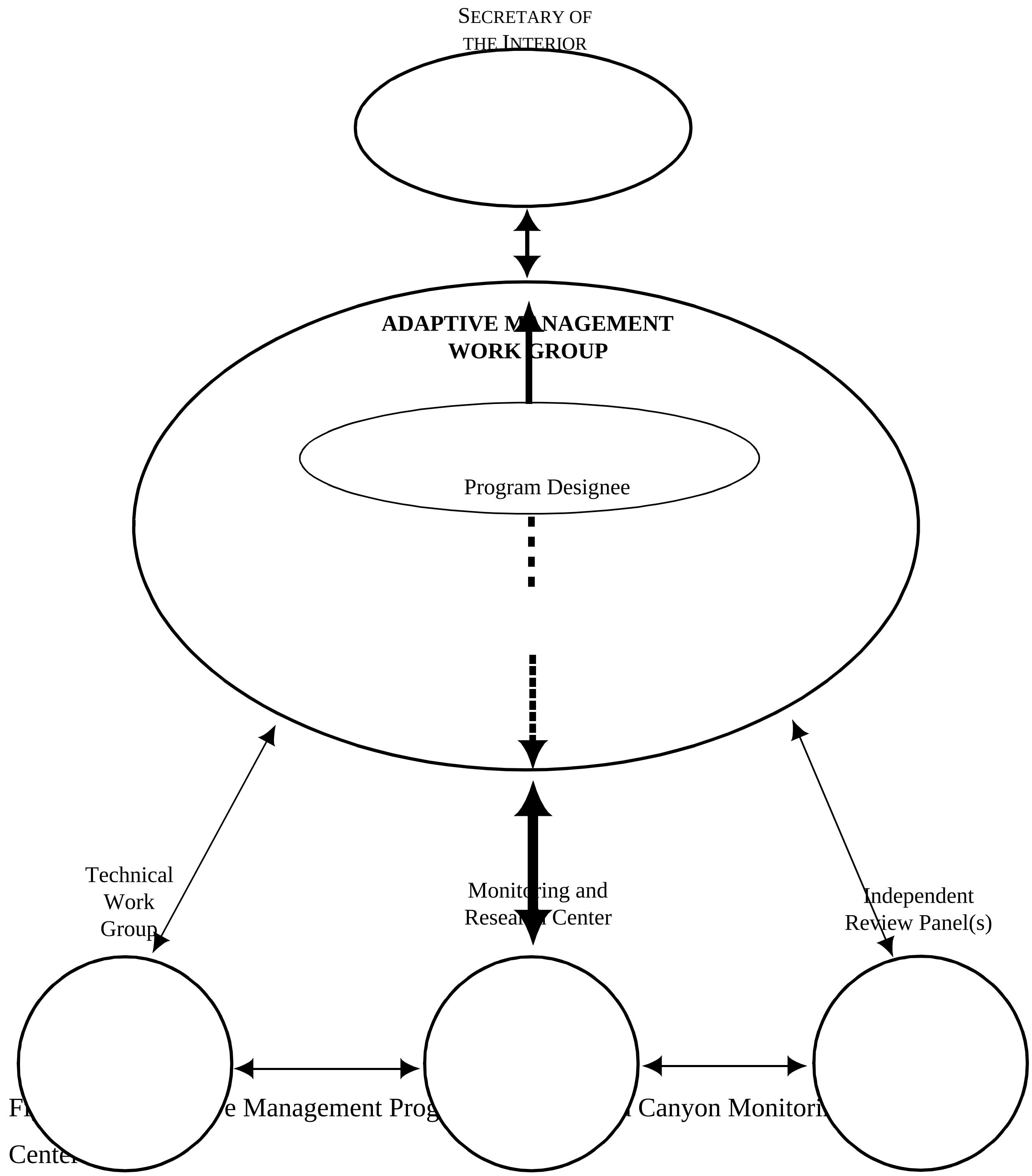
Of the total $7.9 million per year GCD AMP budget allocation approximately $5.8 is for GCMRC activities.

The Adaptive Management Program is comprised of four primary entities (Figure 7.1), The Upper Colorado Regional Office of BOR (Salt Lake City) administers the AMP for the Secretary. This involves services provided to the Secretary's designee, the Adaptive Management Work Group (AMWG), the Technical Work Group (TWG) and the GCMRC.

The BOR, for example, provides all administrative services for all meetings called by the Secretary's designee, especially those of the AMWG and TWG. This can involve payment of members travel expenses, fees for meeting rooms, speakers, etc. The BOR also provides direct services to the GCMRC, including personnel, budgeting, contracting, purchasing, etc. Since the GCMRC is not an official entity of BOR, these services are purchased at competitive prices with similar services available from other agencies.

The GCMRC staff provides administrative, management, technical, scientific, service and other support to the research program under its direction. In general, the monitoring and research programs will service approximately 25-40 separate research contracts and/or cooperative agreements each year. Within external research contracts the GCMRC provides logistics, surveying, GIS and data management support. For example, logistics support for all GCMRC supported research trips through the Grand Canyon each year costs approximately $600,000.

The above annual budget levels noted for the GCMRC's five year Strategic Plan is only for program requirements in which GCMRC is currently active and for which GCMRC is currently responsible. Although this does include biological opinion-related activities, it does not incorporate other potential program areas such as monitoring and research programs required to evaluate impacts of flash boards or the operation of selective withdrawal structures on Glen Canyon Dam.


SECRETARY OF
THE INTERIOR
ADAPTIVE MANAGEMENT
WORK GROUP
Program Designee
Technical
Work
Group
Monitoring and
Research Center
Independent
Review Panel(s)

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APPENDIX A

DRAFT

GLEN CANYON DAM MANAGEMENT OBJECTIVES

May 1, 1998

INTRODUCTION

Initial development of Objectives, Information Needs and Management Actions can and usually does occur by individual stakeholders. However, discussion and agreement on Management Objectives, Information Needs, and Management Actions to be included in the Adaptive Management Program must occur in an open forum of the Technical Work Group (TWG). Final approval of Management Objectives, Information Needs and Management Actions to be used in developing Grand Canyon Monitoring and Research Center (GCMRC) monitoring and research plans is by the Adaptive Management Work Group (AMWG).

PURPOSE

The purpose for developing Management Objectives is to define measurable standards of desired future resource conditions which will serve as objectives to be achieved by all stakeholders in the Glen Canyon Dam Adaptive Management process. These Management Objectives are framed within the Preferred Alternative and implemented by specific dam operating criteria and other actions taken by the Secretary to protect, mitigate adverse impacts to, and improve the values for which the Glen Canyon National Recreation Area and Grand Canyon National Park were established.

Stakeholder Information Needs define the specific scientific understanding required to obtain specified Management Objectives. These will be reviewed by the National Research Council for FY97 and FY99.

Management Objectives and Stakeholder Information Needs are the basis for development and implementation of long-term strategic and annual monitoring and research programs. Research plans are developed annually and must address specified Stakeholder Information Needs.

The GCMRC and TWG will report annually on progress related to individual Management Objectives, Information Needs, and Management Actions, and will revise Management Objectives, Information Needs and Management Actions as needed.

BACKGROUND

The Glen Canyon Dam Final Environmental Impact Statement states that an Adaptive Management Program (AMP) will be initiated following the issuance of a Record of Decision by the Secretary of the Interior. The concept of adaptive management is based on the recognized need for operational flexibility to respond to future monitoring and research findings and varying resource conditions. The AMP will monitor the effect of the operating criteria adopted by the Secretary as a result of the Environmental Impact Statement process and determine if the anticipated results (Management Objectives) in the Preferred Alternative of the Environmental Impact Statement and the Record of Decision are being reached. If it is found that the objectives are not being reached, the AMP will develop proposals for modifying to the Glen Canyon Dam Operations, modifying the Management Objectives, and/or the exercise of other authorities under existing laws to achieve the anticipated results (Management Objectives).

Principles which guided the design of the Adaptive Management Program (AMP) include:

5. Monitoring and research programs will be designed by GCMRC in direct response to objectives and information needs of the Adaptive Management Work Group (AMWG).
6. A process is required to coordinate and communicate AMWG information needs to researchers and to develop recommendations for decision making.

The AMWG recognized the desirability of beginning the process of clarifying and consolidating the management objectives of organizations that participate in the AMP in order to clearly identify information needs to researchers. Initiating this process facilitates and expedites monitoring and research designs.

PROCESS

The procedure selected for development and approval of (Stakeholder) Management Objectives and Information Needs is as follows:

Defining Goals, Objectives and Information Needs. Defining terms were developed by Stakeholders as a guide to articulation of Goals, Objectives, Information Needs and Management Actions as follows:

TERM	DESCRIPTORS
Goals	- Directional Statement - Qualitative - Rarely Attained - Generic
Objectives	- Defines desired Future Resource Condition - Quantifiable - Has Timelines with Target Dates - Concise - Within Legal Boundaries
Information Needs	- Uses Information Collection Process - Results in Product, Outcome, Report, Model, Data - Incorporates Data Collection, Analysis, Synthesis, etc. - Accomplishment associated with Management Objective
Management Actions	- A Management Activity: - Has Timeline and Target Completion Date - Help achieve a Management Objective - Within Legal Boundary

Development of Objectives, Information Needs and Management Actions. The Management Objectives are initially designed to be in accord with the Environmental Impact Statement: these objectives do not necessarily define the ideal desired future resource condition. Rather, they describe, clarify and detail the resource objectives described in the EIS for the preferred alternative. Under the operating criteria signed by the Secretary, the GCMRC will monitor the resources and periodically inform the TWG and AMWG regarding the condition of the resources. If the operation of Glen Canyon Dam under the criteria fail to meet these objectives the AMWG will either recommend operational changes to the Secretary

The following draft Management Objectives, Information Needs and Management Actions are still in development and were presented to the AMWG at its July 1998 meeting for approval. They are being designed to guide GCMRC program planning through the period FY1999-2003 and will be reviewed annually.

ECOSYSTEM ASSESSMENTS

MO 1: Develop a conceptual model of the Colorado River ecosystem.

IN 1.1 The conceptual model will be used to:

(1) guide monitoring and research planning,
(2) more clearly define critical attributes and linkages within and between resource categories,
(3) promote improved understanding of key factors that drive changes in the systems,
(4) make qualitative assessments of resource change resulting from alternative dam operations, and
(5) provide information to stakeholders and managers regarding the potential impacts of alternative dam operations on Lake Powell and the Colorado River ecosystem and associated resources.

BIOLOGICAL RESOURCES

A. AQUATIC RESOURCES

Goal: To protect, restore, and enhance native fish populations in Glen and Grand Canyons, as well as recreationally-important cold water sportfish populations in Glen Canyon, and the aquatic foodbase upon which they depend.

Definition: Aquatic resources include invertebrates, algae, macrophytes, and fish, with specific concerns for Threatened and Endangered Species, and plant and animal matter contributing to the primary food base.

MANAGEMENT OBJECTIVES, STAKEHOLDER INFORMATION NEEDS, MANAGEMENT ACTIONS

A.1 - Aquatic Food Base

Definition: The aquatic food base is comprised of organisms originating from aquatic and riparian sources. It includes organisms such as *Cladophora* and other aquatic plants including macrophytes, diatoms, detritus, aquatic and terrestrial insects, and may include fish.

MO 1: Maintain and enhance the aquatic food base in the Colorado River ecosystem to support desired populations of native and non-native fish. At a minimum, maintain continuously inundated areas for *Cladophora* and aquatic invertebrates at or above 5,000 cfs discharge levels from Glen Canyon Dam.

IN 1.1 Determine status and trends in aquatic food base species composition and population structure, density and distribution and the influence of ecologically significant processes.

IN 1.2 Determine the effects of past, present, and future dam operations under the approved operations criteria on the aquatic food base species composition, population structure, density, and distribution in the Colorado River ecosystem.

IN 1.3 Determine the aquatic food base species composition, population structure, density, and distribution required to maintain desired populations of native and non-native fish in the Colorado River ecosystem.

(IN's 1.7 through 1.12 were moved to Appendix Biological Resources 1)

A.2 - Trout

MO 2: In the Colorado River downstream of Glen Canyon Dam to the confluence of the Paria river, sufficient ecological conditions (such as habitat, foodbase and temperature) should be maintained, which in conjunction with management by Arizona Game and Fish will produce a healthy self-sustaining population of at least 100,000 Age II+ rainbow trout that achieve 18 inches in length by Age III with a mean annual relative weight (Wr) of at least 0.90.

IN 2.1 Determine ecosystem requirements, population character and structure to maintain naturally reproducing populations of Age II plus fish at 100,000 population levels in Glen Canyon.

IN 2.2 Determine trends in rainbow trout population size, character and structure in Glen Canyon.

IN 2.3 Evaluate harvested and field sampled rainbow trout to determine the contribution of naturally reproduced fish to the population in Glen Canyon.

IN 2.4 Determine the availability and quality of spawning substrates in the Glen Canyon reach, necessary to sustain the rainbow trout fishery.

IN 2.5 Determine the growth and condition of rainbow trout in Glen Canyon.

IN 2.6 Define criteria (e.g., temperatures, flow regimes, contaminants, metals, nutrients) for sustaining a healthy rainbow trout population in Glen Canyon.

IN 2.7 Determine the trophic relationship between trout and the aquatic food base including the size of the aquatic food base required to sustain the desired trout population in Glen Canyon.

A.3 - Native Fish:[5]
HUMPBACK CHUB (HBC)

MO 3: Enhance the Little Colorado River population of HBC above 1987 levels determined by April/May hoop-net monitoring in the lower 1,200 meters of the Little Colorado River. (Focused at fish >200mm, and should include a fish health assessment.) Maintain or enhance levels of recruitment of HBC in the Little Colorado River.
MO 4: Maintain or enhance levels of recruitment of HBC in the mainstem as indexed by size frequency distributions and presence and strength of year-classes. (Focused at young-of-year and juvenile fish, and should include a fish health assessment.)

(IN 3/4 relates to MO's 3 & 4)

IN 3/4.1 Determine adult HBC populations and evaluate life history schedules, population health, and reproductive success. *(Fall 97 RPM 1)*

IN 3/4.2 Determine levels of recruitment of humpback chub in the mainstem and the LCR.

IN 3/4.3 Develop and implement a program to evaluate effects of factors limiting overwintering survival of young-of-year HBC in the Grand Canyon (Fall 97, RPM 1). The program shall evaluate the effects of future test flows

[5] Note that Critical Habitat has been designated in GC for both razorback sucker and humpback chub. As Critical Habitat for razorback sucker, GC may have a role in recovery as a reintroduction site. Such actions would need to be guided by the recovery plan (now in prep) or regional implementation plans.

(i.e., 25,000 cfs and greater) from October through February on young-of-year HBC recruitment and over-wintering survival, habitat restrictions, predation, reduced sediment loads, and cold water temperatures. (Fall 97 Test Flow T&C 1) This is to include specific hypotheses as follows:

a. test flows do not significantly reduce densities of young-of-year HBC; and (Fall 97 Test Flow T&C2)

b. test flows do not significantly affect/alter nearshore habitats used by native fishes. (Fall 97 Test Flow T&C 2)

IN 3/4.4 Determine and identify surrogate native or non-native fishes for evaluation of health factors for HBC and investigate trends in diseased fish.

IN 3/4.5 Develop a habitat suitability and availability index, which may include backwaters and near shore habitat, using existing data for HBC. Determine the effects of mainstem hydrology on the number of nearshore rearing habitats, environmental conditions in these habitats, and their successful utilization by HBC. (RPM 1.C.iii)

IN 3/4.6 Evaluate impacts of sampling methods and recreation use (e.g., habitat change, hooking mortality) on humpback chub populations.

IN 3/4.7 Determine origins of fish food resources, energy pathways, and nutrient sources important to their production, and the effects of Glen Canyon Dam operations on these resources. (RPM 1.C.vi) Evaluate linkages between the aquatic food base and the health and sustainability of HBC populations.

MA 4.1 Limit future test flows (i.e., 25,000 cfs and greater) from October through February until a program has been designed and implemented to evaluate and assess factors determining young-of-year HBC recruitment and over-wintering survival. *(Fall 1997 RPM 1)*

MA 4.2 Conduct BHBFs during periods that avoid concentrations of young-of-year HBC *(1996 BHBF, HBC RPM 1)*

MA 4.3 Report the results of the monitoring, including complete and accurate records of all incidental take that occurred during the course of the 1996 BHBF to the Service the same date that a draft and final is submitted to Reclamation. Progress reports provided to Reclamation will also be provided to the Service. This report will also describe how the terms and conditions of all reasonable and prudent measures in this incidental take statement were implemented, including any deviations from the test flow and explanation for need to change. *(1996 BHBF T&C 2)*

IN 3/4.8 Determine effects on physical habitat used by young fishes, food base, and direct effect on larval, juvenile, and adult native and non-native fishes of 1996 BHBF. Develop methods to detect changes in numbers of HBC or their habitat from 1996 BHBF. (1996 BHBF HBC RPM 3)

IN 3/4.9 Develop a method to determine the number of HBC suspected to be lost during special flows and the relationship of this loss to the Grand Canyon population. (T&C 2)

IN 3/410 Develop a strategy to sustain notable year classes of HBC that are susceptible to being transported downstream into unfavorable habitats. (T&C 2)

IN 3/4.11 Acquire an understanding of the frequency of HBC year classes in the system susceptible to being transported downstream into unfavorable habitats and impact of flows on that year class. (T&C 2)

IN 3/4.12 Determine impacts of flows on young HBC during study flows, and develop methods of detecting changes in numbers, to assist in establishing levels of incidental take. (RPM)

IN 3/4.13 Develop biological criteria governing the implementation of special flows that will assure that the level of incidental take of HBC is not exceeded. (RPM)

IN 3/4.14 Evaluate all test flows in RPM, using monitoring and research programs and, determine potential impacts to threatened and endangered fish.

MO 5: Remove jeopardy for the HBC in the Colorado River ecosystem *(B.O. 1994)*.

MA 5.1 Evaluate and implement, as appropriate, a selective withdrawal program for Lake Powell waters (RPM 1.B).

IN 5.1 Determine a set of possible temperature changes in the mainstem Colorado River resulting from implementing selective withdrawal (RPM 1.B.i).

IN 5.2 Determine the anticipated effects on HBC and other native populations which may result from installing a selective withdrawal structure for thermal modification in the mainstem of the Colorado River downstream of Glen Canyon Dam. Determine the range of temperatures for successful larval fish development and recruitment and the relationship between larval/juvenile growth and temperature (RPM 1.B.ii).

IN 5.3 Determine the effects of dam operations under the approved operating criteria, including installing a selective withdrawal structure for thermal modification in the mainstem of the Colorado River downstream of Glen Canyon Dam, on:

a. reproductive success, growth, and survivorship of Grand Canyon fishes;

b. parasites and disease organisms of endangered and native fishes in the Colorado River ecosystem;

c. temperature induced interactions between native and non-native fish competitors and predators; and

d. the effects of temperature, including seasonality and degree, on *Cladophora* and associated diatoms, *Gammarus,* and aquatic insects. (RPM 1.B.iii, 1.B.iv, 1.C.i and 1.C.vii)

IN 5.4 Evaluate effects of withdrawing water on the heat budget of Lake Powell, effects of potentially warmer inflow into Lake Mead, and the concomitant effects on the biota within both reservoirs. Evaluate the temperature profiles along with heat budget for both reservoirs Evaluate effects of reservoir withdrawal level on fine particulate organic matter and important plant nutrients to understand the relationship between withdrawal level and reservoir and downstream resources. (RPM 1.B.v and 1.B.vi)

IN 5.5 Evaluate when to release warmer temperature water, what seasonal pattern of releases to use to avoid establishment of permanent backwater areas, and how best to use floods, to limit expansion or invasion of non-native fish species. (RPM 1B)

MA 5.2 Develop a management plan for the LCR to protect HBC spawning population and habitat.

<u>MO 6:</u> Establish a second spawning aggregation of HBC downstream of Glen Canyon Dam (RPM 4).

IN 6.1 Develop criteria for defining self-sustaining populations of HBC.

IN 6.2 Assess feasibility of establishing a second population of HBC downstream of Glen Canyon Dam including other current aggregations.

MA 6.1 Develop and implement, as appropriate, a plan for establishing a second population of HBC.

<u>RAZORBACK SUCKER (RBS)</u>

<u>MO 7:</u> Remove jeopardy for the Razorback Sucker in the Colorado River ecosystem.

IN 7.1 Determine opportunities to establish RBS in the Grand Canyon (e.g., possible development of spawning and rearing areas). (RPM 3)

<u>FLANNELMOUTH SUCKER (FMS) & OTHER NATIVE FISH</u>

<u>MO 8:</u> Achieve healthy, self-sustaining populations of flannelmouth sucker, bluehead sucker, and speckled dace in the Colorado River ecosystem, with special emphasis on flannelmouth sucker in Glen Canyon based upon the capability of the habitat to support those fishes.

IN 8.1 Determine the status of flannelmouth sucker, bluehead sucker, and speckled dace in the Colorado River ecosystem, with special emphasis on flannelmouth sucker in Glen Canyon.

IN 8.2 Determine population dynamics, distribution, and other life history traits of native fish species.

IN 8.3 Determine historic and current character and structure of native fish populations.

IN 8.4 Determine historic and current ecosystem requirements (habitat, spacing, food source, interdependencies, etc.) of native fish species.

IN 8.5 Determine and define impacts of alternative flow regimes on native fish population character and structure.

IN 8.6 Determine requirements to maintain/enhance self-sustaining populations of native fish.

(IN's 10.1 through 10.14 were moved to Appendix Biological Resources 2)

<u>MO 9:</u> Attain riverine conditions, including appropriate habitat, that support all life stages of endangered and native fish species.

IN 9.1 Design experimental flows and studies to include high steady flows in the spring and low steady flows in the summer and fall during low water years (RPM 1.A). Improve the mean for determining the definition of a "low water year" that would initiate research flows in a given year.

IN 9.2 Quantify to the extent possible the effects of spring high steady flows and summer and fall low steady flows on endangered and native fish (RPM 1.a).

IN 9.3 Determine relationships among tributary hydrology, reproductive success of fishes, and the abundance of fishes in mainstem rearing habitats (RPM 1.c.ii).

IN 9.4 Assess biotic interactions between native and non-native fishes, particularly those that occur in nearshore rearing habitats affected by dam operations (RPM 1.C.iv).

A.4 - Native /Non-Native Fish Interactions

<u>MO 10:</u> Minimize, to the extent possible, competitive and predatory interactions between native and non-native fishes.

IN 10.1 Define areas and conditions of existing and potential interactions

IN 10.2 Determine key attributes associated with competitive and predatory interactions

IN 10.3 Determine methods for minimizing competitive and predatory interactions with or without isolation

IN 10.4 Determine the species composition, relative abundance, and size class structure of non-native fishes in the Colorado River ecosystem and important tributaries

IN 10.5 Identify existing and potential sources of interaction (predatory, competitive) between extant non-native fishes and native fishes of the Colorado River ecosystem and important tributaries

IN 10.6 Evaluate the effects of various flow regimes under the approved operating criteria, including beach/habitat building flows, habitat maintenance flows, and endangered fish research flows on the distribution and abundance of native and non-native fishes in the Colorado River ecosystem and important tributaries

B. TERRESTRIAL and RIPARIAN RESOURCES

Goal: To maintain a diversity of terrestrial and riparian species, including where possible existing remnants of native communities, associated with ongoing natural evolutionary and ecological processes giving priority to native species (i.e., those occurring not directly because of man).

Definition: Terrestrial and riparian resources include, among other things: vegetation, insects, amphibians, reptiles, avifauna, and mammals. Riparian and terrestrial vegetation includes both native and non-native plant species, and include natural species; balanced successional stages; unique plants and threatened and endangered plants.

MANAGEMENT OBJECTIVES, STAKEHOLDER INFORMATION NEEDS, MANAGEMENT ACTIONS

B.1 - General Terrestrial Resources

MO 11: Protect, restore, and enhance survival of native and special status species (federal, tribal, and state designations). Ensure that the required habitat for these species is preserved.

IN 11.1 Define and specify ecology of native faunal components, especially threatened and endangered species; including evolutionary and environmental changes, natural range of variation, linkages, interdependencies, and requirements.

IN 11.2 Determine species population characteristics to detect departures from natural range of variation.

IN 11.3 Determine changes, declines in special status species and characterize ecosystem changes to benefit species.

IN 11.4 Identify and characterize riparian wildlife habitat types along the river corridor.

IN 11.5 Develop a comprehensive wildlife habitat map (using remote sensing and GIS) for the river corridor for high priority species (mammals, amphibians, reptiles, birds).

IN 11.6 Evaluate/monitor leopard frog populations within Glen Canyon. Determine effects of dam operations on these populations (flooding, desiccation, loss of habitat).

IN 11.7 Determine feasibility of establishing other populations of leopard frogs within the river corridor.

IN 11.8 Identify and evaluate other sensitive amphibian and aquatic reptilian species, i.e., red spotted toads, Woodhouses toads, canyon tree frogs.

MO 12: Maintain a natural age-class distribution of wildlife species throughout the majority of natural range in Glen and Grand Canyons, emphasizing the need to recruit into breeding age classes.

IN 12.1 Identify terrestrial species potentially affected by dam operations and determine effects on distribution, abundance, and population structure.

IN 12.2 Determine species' natural ranges (pre and post dam).

IN 12.3 Determine historic age class distribution (pre and post dam).

IN 12.4 Assess natural range and age class disruption, changes, constraints, probable long-term viability implications to species; assess alternate habitat, ecology associations (specifically age class); and ecosystem associations.

IN 12.5 Determine impacts of alternative operating criteria on ecosystem and ecology requirements of species.

B.1. - Avifauna

MO 13: Protect, restore, and enhance survival of native and special status avifauna.

IN 13.1 Define and evaluate food chain associations, interdependencies, requirements, etc. for native avifauna, including the Peregrine Falcon, Southwestern Willow Flycatcher, and other special status species (e.g., Yellow-billed Cuckoo).

IN 13.2 Determine impacts of dam operations under approved operating criteria on avifauna food chain associations.

IN 13.3 Determine peregrine falcon breeding sites in Glen Canyon and Grand Canyon.

(Conservation Recommendation 2)

IN 13.4 Study peregrine falcon population dynamics and determine their relationship to the changing riparian ecosystem for meeting life stage requirements. (Conservation Recommendation 3)

IN 13.5 Determine bald eagle habitat utilization and foraging patterns and their relationship to dam operations under approved operating criteria and perform additional bald eagle monitoring where deemed feasible. (Conservation Recommendation 4)

B.2 - Kanab Ambersnail

MO 14: Sustain populations of Kanab ambersnail wherever they currently exist within the Colorado River ecosystem.

IN 14.1 Determine specific habitat characteristics required by the KAS. (T&C 3--p.41)

IN 14.2 Determine special flow impacts on Kanab ambersnail to assure that the level of incidental take is not exceeded. (I. T. - p.40)

IN 14.3 Complete a census of the population and characterize the habitat. Once habitat requirements are determined, other potential habitat sites within the Grand Canyon corridor will be surveyed to determine species presence and recovery potential. (Conservation Recommendation 5--p.43)

IN 14.4 Survey KAS habitat before and after any flow greater than 25,000 cfs to determine population and its species response to disturbance and ability to recover. (T&C 4, p.42; and RPM)

IN 14.5 Determine Kanab Ambersnail life history schedule for populations in the Colorado River ecosystem. (Conservation Recommendation 5)

IN 14.6 Evaluate and monitor KAS populations within the Colorado River ecosystem. Determine ecological characteristics susceptible to changes in dam operations, i.e., population size, habitat needs, life history requirements.

MA 14.1 Protect the habitat necessary for the survival of the existing population of Kanab ambersnail. (Incidental Take--p.40)

MA 14.2 Do not allow high flows, or a controlled flood, to destroy more than 10% of the existing KAS occupied habitat in Grand Canyon. (Incidental Take--p.40)

MA 14.3 Develop agreed upon research protocol and conduct research in such a manner as to minimize disturbance to the KAS population and habitat. (T&C 3--p.41)

MA 14.4 Before another BHBF (45,000 cfs or greater), Reclamation will enter into informal consultation with the U.S. Fish and Wildlife Service and Arizona Game and Fish Department to:

MA 14.4a evaluate the test flow studies (RPM 2, 1996 BHBF);

MA 14.4b evaluate the establishment or discovery of a second population of Kanab ambersnail in Arizona (RPM 2, 1996 BHBF); and

MA 14.4c evaluate incidental take. (RPM 2, 1996 BHBF)

MA 14.5 Continue coordination with the Interagency Kanab Ambersnail Working Group to establish or discover a second population of the Kanab ambersnail in Arizona. (Fall 97 Flow T&C 4)

MA 14.6 Monitoring of the project area and other areas that could be affected by the proposed action shall be done to ascertain take of individuals of the species and/or of its habitat that causes harm, harassment, or death to the species. This monitoring will be accomplished using the following protocol:

MA 14.6.a "A Draft Proposal to Assess, Mitigate and Monitor the impacts of an Experimental High Flow from Glen Canyon Dam on the Endangered Kanab Ambersnail at Vaseys Paradise, Grand Canyon, Arizona" (Stevens *et al.* 1995b).

MA 14.6.b In order to more accurately determine elevation of river stage at the range of flow that will be experienced during the test flow, and for use in developing a stage discharge relationship for future flow, the placement of a stage recorder, such as a pressure transducer coupled to a recorder should be deployed, if possible, in the mainstem at an appropriate site near the Kanab ambersnail population. The U.S. Geologic Survey should be contacted regarding the possibility of changing the location of a stage recorder to be used in test flow studies to the Kanab ambersnail site.

MA 14.6.c SALVAGE PROTOCOL. Kanab ambersnail specimens found dead, or taken as part of research activities, shall be collected and held as specified in the AGFD and NPS permit, with final deposition in a suitable museum collection such as at Northern Arizona University (1996 BHBF KAS T&C 1)

IN 14.7 Determine changes in populations, health, and character of Kanab ambersnail, due to dam operations(?)

<u>MO 15:</u> Establish or discover and ensure the continued existence of a second population of Kanab Ambersnail in Arizona.

IN 15.1 Determine genetic similarities and differences among populations of Kanab ambersnail.

IN 15.2 Investigate the transplant success of vegetation important to the Kanab ambersnail:

IN 15.2a Investigate success of temporarily removing *Mimulus*, *Nastertium*, or other appropriate vegetation into a temporary holding facility, and replanting. (1996 BHBF CM 5a)

IN 15.2b Investigate success of temporarily/permanently relocating *Mimulus*, *Nastertium*, or other appropriate vegetation. (1996 BHBF CM 5b)

MA 15.1 Minimize future take and support salvage and refugia population(s) of KAS (Fall 97 Test Flow CM 1)

MA 15.2 Provide logistical support to the Arizona Game and Fish Department's proposal to establish vegetation for the refugium population of the Kanab ambersnail at the Phoenix Zoo, and subsequent support for the transfer of ambersnails when permit and weather conditions permit. (Fall 97 Flow T&C 2)

B. 4 - Vegetation

<u>MO 16:</u> Maintain, enhance or restore vegetative communities made up of diverse groups of native riparian and upland species with special emphasis on preservation of unique plant communities and special status species at different stages of succession and at different elevations above the water line.

IN 16.1 Determine distribution and abundance of native and non-native riparian and upland vegetation, including federal-, state- and tribal-listed sensitive species, old high water zone, new high water zone, and nearshore marshes.

IN 16.2 Identify and quantify the OHWZ (above 150,000 cfs) and NHWZ (between 45,000 and 150,000 cfs) vegetation types (communities) within the Colorado River ecosystem:

1. Develop a comprehensive vegetation map for the Colorado River ecosystem.

2. Determine populations dynamics and changes due to dam operations under approved operating criteria.

3. Determine habitat requirements and reproductive biology of principal species.

IN 16.3 Determine change in extent or abundance of the OHWZ and NHWZ plant communities. Link monitoring to site specific studies to determine species diversity.

IN 16.4 Determine the effects of current and proposed dam operations under approved operating criteria on these communities.

IN 16.5 Determine the ecology of the principal woody species (reproduction, establishment) within the OHWZ. Quantify the effects of dam operations under approved operating criteria on this ecology.

IN 16.6 Evaluate impacts of dam operations under approved operating criteria on establishment of and impacts from exotic plant species.

CULTURAL RESOURCES

Goal: To preserve cultural resource in situ wherever possible, and develop, knowledge of the resource for future generations.

Definition: Cultural resources include prehistoric and historic archaeological sites, structures and properties of interest to all Americans. Of particular importance are traditional cultural properties, sacred sites, collection areas, and other resources that are important to Native Americans in maintaining their cultural heritage, lifeways, and practices. Cultural resources are nonrenewable and irretrievable if lost.

MANAGEMENT OBJECTIVES, STAKEHOLDER INFORMATION NEEDS, MANAGEMENT ACTIONS

MO 1: Conserve *in situ* all the downstream cultural resources and take into account Native American cultural resource concerns in the Colorado River ecosystem.

IN 1.1 Monitor cultural sites potentially impacted by Glen Canyon Dam operations to determine present condition and rate of change to assess: types of degradation, threats; rates of degradation; define immediacy of threats to resources; protection methodologies; protection, monitoring and research costs

IN 1.2 Develop data systems to assess variable risk of damage/loss of differing resources/sites from preferred and alternative strategies and operating criteria

IN 1.3 Characterize all cultural resource sites as to the specific associated management/research needs, i.e.; preservation, stabilization, documentation, etc.; under alternative operating criteria

IN 1.4 Preservation, stabilization and/or documentation of cultural resources as impacted by sediment resources associated with alternative operating criteria

IN 1.5 Preservation, stabilization of flood terraces holding cultural resources

IN 1.6 Evaluate flood terrace stability necessary to maintain cultural resources and terraces at pre-dam conditions

IN 1.7 Evaluate methodology for correlating recreational sites use and cultural resource impacts.

MO 2: If *in situ* conservation is not possible, design mitigative strategies that integrate the full consideration of the values of all concerned tribes with a scientific approach.

IN 2.1 Characterize through scientific study and data development all assumed historical and current values, including scientific values, of resources to tribal nations and to general public

IN 2.2 Develop research designs and costs associated with data recovery

<u>MO 3:</u> Protect, and maintain physical access to and use of traditional cultural properties and other cultural resources, where such access and use may be impacted by dam operations.

IN 3.1 Characterize historic and current traditional cultural associations of all sites associated with impacts of dam operating criteria

<u>MO 4:</u> Maintain and integrate all appropriate cultural data recovered from monitoring, remedial, and mitigative action and incorporate these data into the evolving research designs and mitigative strategies for understanding the human occupation and use of the Colorado River ecosystem.

IN 4.1 Develop evolving research designs and/or other methods including synthesis of existing available data and GIS for understanding human occupation and use.

SOCIO-ECONOMIC
(HYDROPOWER)

Goal: To maximize the value of long term firm power and energy generation within the criteria and operating plans established by the Secretary under Section 1804 of the Grand Canyon Protection Act.

Definition: A product of the Glen Canyon Power plant is electrical generation. The facility contributes significant power to rural electrical associations, public municipalities, irrigation districts and Federal and State facilities in the Southwestern and Rocky Mountain areas of the United States.

MANAGEMENT OBJECTIVES, STAKEHOLDER INFORMATION NEEDS, MANAGEMENT ACTIONS

MO 1: Maximize the value of long-term power and energy generation within the criteria and operating plans established by the Secretary under Section 1804 of the Grand Canyon Protection Act[6].

IN 1.1 Continue to monitor the amount of revenues collected from the generation of electrical power at the Glen Canyon Power plant.

IN 1.2 Continue to account for the financial/economic cost of the operational changes at Glen Canyon Dam due to the ROD including rate impacts to CRSP long-term firm electrical customers.

IN 1.3 Calculate the financial costs of research flows so that these costs can be declared "non-reimbursable" (as defined by Section 1804 of the Grand Canyon Protection Act)

IN 1.4 Monitor any difficulties in operating an integrated electrical system, including regulating a load control area
(Recommendation: Dave Garrett will clarify this with Clayton Palmer)

[6] The data needed to measure and evaluate power production is already routinely collected by the USBR and WAPA (no data gathering is required of GCMRC).

PHYSICAL

WATER RESOURCES

Goal: To operate Glen Canyon Dam for water supply and water quality consistent with existing law and policy.

Definition: Water resources include all aspects of water quantity and quality. The "Law of the River" directs the operations of Glen Canyon Dam including monthly and annual release patterns and reservoir contents and elevations. Although of more recent concern, water quality as it relates to changes over time is of specific concern.

MANAGEMENT OBJECTIVES, STAKEHOLDER INFORMATION NEEDS, MANAGEMENT ACTIONS

MO 1: The Secretary shall Operate Glen Canyon Dam in a manner fully consistent with the Record of Decision and subject to the "Law of the River," including but not limited to the following: Grand Canyon Protection Act of 1992, the Colorado River Compact, the Upper Colorado River Basin Compact, the Water Treaty of 1944 with Mexico, the decree of the Supreme Court in Arizona vs. California, and the provisions of the Colorado River Storage Project Act of 1956, and the Colorado River Basin Project Act of 1968 that govern allocation, appropriation, development, and exportation of the waters of the Colorado River Basin.

IN 1.1 Annually collect and report Glen Canyon Dam flow release information.

MO 2: Maintain water quality at levels appropriate to support physical, biotic, and human resource needs of various ecosystems downstream of Glen Canyon Dam as mandated by the Grand Canyon Protection Act and incorporated into the Record of Decision.

IN 2.1 Monitor water quality, composition and temperature and compare to applicable standards.

IN 2.1a Quantify current selenium levels in water discharged from Glen Canyon Dam. Determine how selenium concentrations are affected by dam operations.

IN 2.1b Determine/quantify the dynamics of major cations, anions and nitrate/phosphate ratios resulting from dam operations.

IN 2.2 Evaluate feasibility of short term or long term changes of water temperature through selective withdrawal.

SEDIMENT RESOURCES

Goal: To maintain a range of sediment deposits over the long-term, including an annually flooded bare-sediment (unvegetated) active zone, a less frequently flooded vegetated zone, terraces (within the 45,000 cfs river stage), and backwater channels. Managing sediment resources will be on a reach-scale basis. Should significant and localized adverse impacts occur, site-specific mitigation would be considered.

Definition: Sediment resources include a broad array of material, ranging from suspended fines to coarse gravels. Primary interest relates to both material in suspension, which affects benthic capability, as well as stored sediment in beaches and channel margins, which affects recreation.

MANAGEMENT OBJECTIVES, STAKEHOLDER INFORMATION NEEDS, MANAGEMENT ACTIONS

MO 1: Maintain a long-term balance of river-stored sand to support maintenance flow (in years of low reservoir storage), beach/habitat-building flow (in years of high reservoir storage), and unscheduled flood flows. Maintain system dynamics and disturbance by annually (in years which Lake Powell water storage is low) redistributing sand stored in the river channel and eddies to areas inundated by river flows between 20,000 cfs and maximum power plant capacity.

IN 1.1 Define historical and current (character and structure) levels of river stored sediment in system and associated flow regimes

IN 1.2 Define minimal levels of river stored sediments necessary to maintain long term sandbar, backwater, instream sediment deposits

IN 1.3 Develop procedures to monitor and predict impacts of alternative operating criteria (flow regimes) on river stored sediment, and impacts in select reaches

IN 1.4 Measure and model sediment contributions from all contributing sources, including tributary and high terrace sources

IN 1.5 Evaluate the geology/geomorphology within Glen Canyon to: (1) determine historical changes in size and extent of beaches, sandbars and backwaters, (2) quantify sediment (size class and quantity) input from side channels, (3) understand bed morphology dynamics, (4) evaluate high terrace erosion and contribution to river sediment.

MO 2: As a minimum for each reach, maintain the number and average size (area and thickness) of sandbars and backwaters between the stages associated with flows of 8,000 and 45,000 cfs that existed during the 1990/91 research flows.

IN 2.1 Characterize sandbar/backwater baselines and character and structure in 1990/91

IN 2.2 Working with various resource agencies and specialists, select most appropriate flow levels/regimes under the approved operating criteria to determine baseline for comparisons for all resources

IN 2.3 Monitor future changes in sediment and define balances (channel, banks, bars) and hydraulic processes necessary to maintain 1990/91 sandbar levels

IN 2.4 Evaluation of flow regime (under the approved operating criteria) impacts on terrace and cultural resources

IN 2.5 Evaluate historical sandbar/backwater change, and develop methods for predefining beach and sandbar change under operating criteria

IN 2.6 Determine implications of dam operating criteria on beach and sandbar and backwater character and structure, including suitability of camping beaches

IN 1.7 Quantify the extent and location of existing sandbars, beaches and backwaters along the Colorado River corridor

IN 2.8 Assess the effects and use of the spillways on bed morphology in the front of the dam and its effects on power production and biota

MO 3: Periodically increase the average size of sandbars above the 20,000 cfs river stage and number and average size of backwaters to the amounts measured during the high period of 1990/91 or the 1996 test of the beach/habitat-building flow in as many years as reservoir and downstream conditions allow.

IN 3.1 Define 1996 and 1990/91 backwater ecosystems and associated flow regimes

IN 3.2 Define historical variation in backwater number and character

IN 3.3 Define changes between 1990/91 and 1996 in sediment and backwater resources character and structure associated with dam operating criteria

IN 3.4 Define all linkages, associations, interdependencies, etc., of physical sediment resource and backwater resources to biotic entities

IN 3.5 Define processes necessary to maintain backwaters at 1990/91 or 1996 levels

MO 4: Maintain system dynamics and disturbance by redistributing sand stored in the river channel and eddies to areas inundated by river flows up to 45,000 cfs in as many years as possible when BHBF hydrologic and resource criteria are met.

IN 4.1 Define character and structure of all beaches and backwaters in system after 1996 test flows

IN 4.2 Develop methodologies to define future flow regimes under approved operating criteria to maximize benefit to sediment and backwater character and structure

IN 4.3 Develop an assessment of dam operations under approved operating criteria impacts on range of variation in sediment and other resources within Colorado River ecosystem and the associated processes that created these ranges

Norm Henderson’s Comments for Sediment Information Needs:

IN 1. Quantify the available sediment in the river channel within the Glen Canyon reach to build beaches within Marble Canyon

IN 2. Determine the relative importance of high terrace erosion to beach building within the Glen Canyon reach

IN 3. Quantify the sediment inputs within the Glen Canyon reach from unregulated side channels

IN 4. Assess the impact of current and anticipated dam operations under approved operating criteria on the high terraces within Glen Canyon. Define the relative importance of natural erosion of high terraces as compared to that experienced due to current dam operations

IN 5. Develop an understanding of bed morphology dynamics within Glen Canyon

IN 6. Determine the relative importance of sediment grain size within Glen Canyon compared to downstream reaches

IN 7. Summarize the historical changes in river banks and sandbars within the Glen Canyon reach and determine long term changes in size

IN 8. Comprehensively quantify the extent and location of existing sandbars and beaches along the river corridor

GIS

MO 1: (Management Objective to be added.)

IN 1.1 Develop a comprehensive GIS base map for topography, geology and soils for the Colorado River ecosystem.

IN 1.2 Develop an integrated data/GIS structure for the storage and retrieval of all GCMRC studies.

RECREATION

Goal: To provide quality recreation experiences that do not adversely affect natural or cultural resources within the river corridor.

Definition: Recreation resources include sport fishing, white water rafting, boating, hiking, sightseeing, photography, and hunting.

MANAGEMENT OBJECTIVES, STAKEHOLDER INFORMATION NEEDS, MANAGEMENT ACTIONS

MO 1: Provide quality recreation experiences consistent with other resource objectives.

IN 1.1 Determine criteria and aspects that are important to or detract from recreational experience

IN 1.2 Determine the impacts of scientific study on recreational experience

IN 1.3 Characterize procedures to mitigate those aspects of flows that detract from quality recreational experiences

IN 1.4 Determine angler satisfaction, use and harvest

IN 1.5 Determine potential impacts of increased heavy metals on sport fishing

MA 1.1 Utilize approaches for monitoring and research that are appropriate to maintain or improve the character of the recreational experience as defined in NPS management plans for those areas.

MA 1.2 Ensure water release strategies and communications systems that support and enhance the full range of river recreation experiences allowed under NPS management plans for those areas.

MO 2: Maintain flows (under approved operating criteria) and sediment processes that create an adequate quantity, distribution and variety of beaches for camping, as long as such flows are consistent with management of natural recreation and cultural resource values (other natural resource values).

IN 2.1 Determine adequate beach quantity, quality, distribution, character and structure for camping throughout system

IN 2.2 Evaluate impacts of operating criteria on establishing and maintaining adequate beaches and distribution of other resources, quality, character and structure

IN 2.3 Develop methodology to evaluate distribution, quantity and quality changes in all campable beaches through time

IN 2.4 Develop systems models to predict flow regimes (under approved operating criteria) for building and maintaining beaches

<u>MO 3:</u> Maintain flows (under approved operating criteria) that minimize impacts to navigability by authorized water craft and for boaters, waders, and campers in the riverine corridor.

IN 3.1 Determine if operating criteria maintains safe and adequate powercraft navigability in Glen Canyon and upper Lake Mead

IN 3.2 Evaluate effects of operating criteria on recreation safety

IN 3.3 Determine if operating criteria maintains whitewater raft navigation in Grand Canyon

IN 3.4 Define ecosystem and other resource impacts of flow regimes (under approved operating criteria) required to maintain navigation

IN 3.5 Develop methodology to evaluate potential conflicts of day rafting and other resources (e.g., bank degradation, sport fishing, bird watching, etc.)

<u>MO 4:</u> Maintain flows (under approved operating criteria) and habitat suitable for quality cold water fishery opportunities in Glen Canyon.

IN 4.1 Determine flow regimes (under approved operating criteria) necessary to maintain fish populations of 100,000 adult Trout (age class II plus)

<u>MO 5:</u> Maintain flows (under approved operating criteria) and habitat suitable for waterfowl sport hunting and wildlife viewing opportunities in Glen Canyon.

IN 5.1 Define pattern of waterfowl hunting use and satisfaction and other wildlife use and conflicts to other uses

LAKE POWELL

Goal: To understand impacts of Dam operations and where possible minimize these impacts, consistent with other resource objectives.

Definition: Lake Powell includes natural, biological and cultural resources impacted by operation of Glen Canyon Dam.

MANAGEMENT OBJECTIVES, STAKEHOLDER INFORMATION NEEDS, MANAGEMENT ACTIONS

The protocol for Lake Powell Management Objectives and Information Needs are related to Upstream Effects Only. (Downstream effects are included under the specific resource sections.)

Lake Powell Water Quality

MO 1: Prevent impacts that adversely affect the water quality (physical, chemical, biological) of Lake Powell due to dam operations and ensure that fully informed AMWG decisions are possible both now and in the future.

Physical/Chemical (Limnology)

IN 1.1 Determine the effect of current dam operations (under approved operating criteria) on reservoir water quality, including but not limited to the following:

- Determine near-dam hydrogen sulfide levels (and other hazardous chemical constituents) within the hypolimnion occurring under current dam operating criteria.
- Determine the dynamics of lake stratification and advective flows and their effects on chemical constituents
- Determine/quantify the dynamics of major cations, anions, and nitrate/phosphate ratios resulting from dam operations
- Determine the effects of dam operations (under approved operating criteria) on the physical/chemical dynamics of Lake Powell side channels and embayments
- Quantify/model the heat budget for Lake Powell to determine near-term and long-term (monthly/weekly and annual summaries respectively) effects of a selective withdrawal system
- Determine the effect of current dam operations on reservoir levels of selenium.

Biological

IN 1.1 Determine the impacts of dam operations and resulting water quality on primary and secondary productivity of Lake Powell, including:

a. algae (phytoplankton, periphyton)
b. Macrophytes
c. zooplankton
d. macroinvertebrates

IN 1.2 Quantify levels of selenium and describe effects of these levels on primary and secondary productivity, fish and waterfowl, and human consumption.

Lake Powell Aquatic Ecosystem (Fishery)

Definition:

MO 2: Protect Lake Powell aquatic ecosystem from adverse impacts due to dam operations and subsequent effects, including but not limited to: temperature, reservoir surface elevations, elevated selenium levels, advective flow patterns, predator/prey relationships, and fish movements.

IN 2.1 Determine the effects of water temperature caused by dam operations

IN 2.2 Determine the effects of fluctuations in the reservoir surface elevations caused by dam operations (under approved operating criteria)

IN 2.3 Determine the effects of elevated selenium levels caused by dam operations (under approved operating criteria)

IN 2.4 Determine the effects of advective flow patterns on Lake Powell aquatic ecosystem caused by dam operations (under approved operating criteria)

IN 2.5 Determine the effects of predator/prey relationships caused by dam operations (under approved operating criteria)

IN 2.6 Determine the effects of fish movements caused by dam operations

APPENDIX

Biological Resources 1

From Aquatic Food Base Management Objective

IN 1.7 Identify and characterize the available aquatic habitat of the Colorado River and significant tributaries, such as the LCR (riffle, run, pool, backwater, etc.)

IN 1.8 Develop a comprehensive aquatic habitat map (with GIS) for the river corridor at various water levels.

IN 1.9 Quantify and evaluate changes in river habitat caused by dam operations over time

IN 1.10 Determine the effect of sediment exposure time on benthic community mortality

IN 1.11 Effects of sediment removal and transport on hyporheic communities

IN 1.12 Effects of selenium on benthic/hyporheic communities.

From Flannelmouth Sucker Management Objective

IN 1. Establish whether Flannelmouth Suckers/native fish are actually spawning in the mainstem Colorado River within Glen Canyon under current conditions. If spawning occurs, do any eggs hatch or larvae survive? Determine the current and past (before Glen Canyon Dam) importance of mainstem Glen Canyon spawning habitat (in relationship to tributary spawning).

IN 2. Determine the origin of adult Flannelmouth Suckers/native fish that are attempting to spawn in the mainstem Colorado River within Glen Canyon? Are the old pre-dam adults? Are the post-dam adults from the tributaries, i.e., Paria River, that find certain mainstem habitat factors preferable? Are they mainstem adults from the Grand Canyon?

IN 3. Determine the location of all spawning beds within Glen Canyon (related to flows) and summarize the important characteristics. Determine the relative importance of Glen Canyon habitat in relationship to other mainstem habitat within Grand Canyon.

IN 4. Specifically determine the cause(s) for mainstem spawning failure within Glen Canyon:

a. Eggs not deposited, or if deposited not viable because of low water temperature or fluctuating flows, i.e., drying of spawning beds or removal of eggs by strong currents.

b. Fertile eggs deposited and hatch but larvae can't grow because of limited or no nursery habitat for food and shelter (again, due to cold temperatures and fluctuating flows).

c. Eggs laid and hatch and some survive and move downstream to warmer water and return much later to spawn.

IN 5. Describe the specific role of flow levels and fluctuations on reproduction and survival of eggs, larvae, young-of-year, and adults. Specifically, determine the availability of moderate near-shore habitat that might be used by larvae, young-of-year, or adults.

IN 6. Describe the relative importance of various tributaries to flannelmouth survival (spawning, recruitment, predation).

IN 7. What is the food source in the mainstem now? Is there a sufficient food base for adequate growth and a healthy population in the mainstem? What was historic food source?

IN 8. Determine the optimal habitat conditions for flannelmouth sucker. reproductions, survival, recruitment, etc., i.e., temperature, flow, food, shelter. What habitat factors in the mainstem attract adult Flannelmouth suckers to spawn? What is the attraction over tributaries, i.e., Paria River?

IN 9. Determine the fidelity of Flannelmouth suckers to certain areas and spawning beds.

IN 10. Determine if possible the current and historic use of Flannelmouth sucker habitat for spawning, foraging, cover, etc., within the Colorado River and Paria Rivers as well as other tributaries.

IN 11. Develop a Flannelmouth sucker conceptual model for the Colorado River ecosystem, i.e., food, habitat, predation.

IN 12 What habitat modifications could be made to improve Flannelmouth sucker population levels and overall health, i.e., substrate modification, nursery habitat establishment (warm backwaters), flow modification, etc.

IN 13. Assess the influence of non-native fish on native fish species.

IN 14. Determine the effect of current selenium levels discharged from Glen Canyon Dam on native fish species.

APPENDIX B

Information Needs Prioritization - Overall Rankings (4/23/98)

Resource Category	Mgt Obj	Info Need	O	X
A.3 - Native Fish	MO 5:	IN 5.3	14	14
Cultural Resources	MO 1:	IN 1.1	12	13
A.3 - Native Fish	MO 3/4:	IN 3/4.2	11	8
B. Terrestrial and riparian	MO 14:	IN 14.6	11	10
A.3 - Native Fish	MO 3/4:	IN 3/4.5	10	6
A.1 - Aquatic Food Base	MO 1:	IN 1.1	10	9
A.1 - Aquatic Food Base	MO 1:	IN 1.2	10	9
A.1 - Aquatic Food Base	MO 1:	IN 1.3	10	10
A.3 - Native Fish	MO 3/4:	IN 3/4.1	10	10
A.3 - Native Fish	MO 3/4:	IN 3/4.3	10	8
A.3 - Native Fish	MO 5:	IN 5.2	10	10
Lake Powell	MO 1:	IN 1.1 (Phys)	10	14
A.3 - Native Fish	MO 6:	IN 6.1	9	8
A.3 - Native Fish	MO 6:	IN 6.2	9	7
Cultural Resources	MO 3:	IN 3.1	9	6
Cultural Resources	MO 2:	IN 2.1	9	9
A.3 - Native Fish	MO 5:	IN 5.5	9	9
B. Terrestrial and riparian	MO 11:	IN 11.1	9	9
A.3 - Native Fish	MO 8:	IN 8.1	9	8
B. Terrestrial and riparian	MO 14:	IN 14.1	9	8
Sediment Resources	MO 1:	IN 1.2	9	11
Water Resources	MO 2:	IN 2.1	9	9
A.3 - Native Fish	MO 3/4:	IN 3/4.12	9	8
A.2 - Trout	MO 2:	IN 2.1	8	9
B. Terrestrial and riparian	MO 14:	IN 14.3	8	8
A.3 - Native Fish	MO 3/4:	IN 3/4.13	8	7

Sediment Resources	MO 1:	IN 1.4	8	10

A.3 - Native Fish	MO 3/4:	IN 3/4.8	7	6
A.3 - Native Fish	MO 3/4:	IN 3/4.7	7	6
Sediment Resources	MO 1:	IN 1.3	7	10
B. Terrestrial and riparian	MO 13:	IN 13.1	7	7
A.3 - Native Fish	MO 8:	IN 8.2	7	4
B. Terrestrial and riparian	MO 14:	IN 14.2	7	7
Cultural Resources	MO 1:	IN 1.3	7	7
B. Terrestrial and riparian	MO 14:	IN 14.4	7	7
B. Terrestrial and riparian	MO 14:	IN 14.5	7	7
B. Terrestrial and riparian	MO 15:	IN 15.1	7	5
Sediment Resources	MO 3:	IN 3.4	7	8
A.3 - Native Fish	MO 5:	IN 5.4	7	2
Ecosytem Assessments	MO 1:	IN 1.1	7	14
A.3 - Native Fish	MO 9:	IN 9.3	7	3
A.3 - Native Fish	MO 8:	IN 8.6	7	4
A.3 - Native Fish	MO 8:	IN 8.5	7	4
A.3 - Native Fish	MO 7:	IN 7.1	7	5
Cultural Resources	MO 4:	IN 4.1	7	5

Cultural Resources	MO 1:	IN 1.2	6	4
Sediment Resources	MO 4:	IN 4.1	6	6
B. Terrestrial and riparian	MO 15:	IN 15.2	6	4
Sediment Resources	MO 2:	IN 2.6	6	8
Water Resources	MO 2:	IN 2.2	6	6
A.3 - Native Fish	MO 10:	IN 10.5	6	2
Cultural Resources	MO 1:	IN 1.4	6	5
A.3 - Native Fish	MO 10:	IN 10.1	6	5
A.3 - Native Fish	MO 3/4:	IN 3/4.9	6	5
A.3 - Native Fish	MO 3/4:	IN 3/4.11	6	3
A.3 - Native Fish	MO 5:	IN 5.1	6	2
Recreation	MO 2:	IN 2.2	6	8

A.3 - Native Fish	MO 9:	IN 9.4	6	1
Cultural Resources	MO 1:	IN 1.6	6	2

B. Terrestrial and riparian	MO 13:	IN 13.2	6	8
B. Terrestrial and riparian	MO 12:	IN 12.1	6	8
B. Terrestrial and riparian	MO 11:	IN 11.6	6	8
A.3 - Native Fish	MO 10:	IN 10.6	6	2
Cultural Resources	MO 2:	IN 2.2	5	2
A.2 - Trout	MO 2:	IN 2.2	5	5
Sediment Resources	MO 1:	IN 1.1	5	7
A.3 - Native Fish	MO 3/4:	IN 3/4.14	5	4
Cultural Resources	MO 1:	IN 1.5	5	2
A.3 - Native Fish	MO 8:	IN 8.4	5	2
A.3 - Native Fish	MO 9:	IN 9.2	5	1
B. Terrestrial and riparian	MO 11:	IN 11.5	5	4
B. Terrestrial and riparian	MO 14:	IN 14.7	5	6
A.3 - Native Fish	MO 10:	IN 10.4	5	2
B. Terrestrial and riparian	MO 11:	IN 11.4	5	7
B. Terrestrial and riparian	MO 16:	IN 16.1	5	6
Sediment Resources	MO 4:	IN 4.3	5	5
Sediment Resources	MO 1:	IN 1.5	5	6
Lake Powell	MO 1:	IN 1.1 (Biol)	5	12
A.3 - Native Fish	MO 10:	IN 10.2	4	3
Recreation	MO 1:	IN 1.1	4	9
A.3 - Native Fish	MO 3/4:	IN 3/4.10	4	2
Recreation	MO 1:	IN 1.3	4	10
B. Terrestrial and riparian	MO 16:	IN 16.2	4	5
B. Terrestrial and riparian	MO 11:	IN 11.2	4	6
B. Terrestrial and riparian	MO 16:	IN 16.4	4	4
B. Terrestrial and riparian	MO 16:	IN 16.6	4	5

Sediment Resources	MO 4:	IN 4.2	4	6
Sediment Resources	MO 3:	IN 3.1	4	3
A.2 - Trout	MO 2:	IN 2.5	4	0

A.2 - Trout	MO 2:	IN 2.4	4	4
A.2 - Trout	MO 2:	IN 2.6	4	3
A.3 - Native Fish	MO 9:	IN 9.1	3	2
B. Terrestrial and riparian	MO 13:	IN 13.5	3	3
Recreation	MO 3:	IN 3.2	3	3
A.3 - Native Fish	MO 8:	IN 3. (App.)	3	1
Sediment Resources	MO 2:	IN 2.2	3	2
A.3 - Native Fish	MO 8:	IN 5. (App.)	3	2
A.3 - Native Fish	MO 8:	IN 1. (App.)	3	1
Sediment Resources	MO 4:	IN NH1.	3	3
A.3 - Native Fish	MO 8:	IN 8.3	3	1
Sediment Resources	MO 2:	IN 2.3	3	5
A.2 - Trout	MO 2:	IN 2.7	3	4
Sediment Resources	MO 2:	IN 2.5	3	3
Sediment Resources	MO 3:	IN 3.3	3	4
Sediment Resources	MO 3:	IN 3.2	3	2
A.3 - Native Fish	MO 10:	IN 10.3	3	3
Recreation	MO 3:	IN 3.3	2	1
Recreation	MO 2:	IN 2.4	2	2
B. Terrestrial and riparian	MO 11:	IN 11.3	2	4
A.3 - Native Fish	MO 8:	IN 13. (App.)	2	0
A.3 - Native Fish	MO 8:	IN 11. (App.)	2	1
Recreation	MO 1:	IN 1.4	2	3
Recreation	MO 3:	IN 3.5	2	1
Recreation	MO 4:	IN 4.1	2	7
A.2 - Trout	MO 2:	IN 2.3	2	1

A.1 - Aquatic Food Base	MO 1:	IN 1.10 (App.)	2	3
A.3 - Native Fish	MO 8:	IN 2. (App.)	2	2
A.3 - Native Fish	MO 8:	IN 4. (App.)	2	1
A.3 - Native Fish	MO 8:	IN 6. (App.)	2	1

A.3 - Native Fish	MO 3/4:	IN 3/4.6	2	1
A.3 - Native Fish	MO 3/4:	IN 3/4.4	2	0
A.1 - Aquatic Food Base	MO 1:	IN 1.9 (App.)	2	4
Sediment Resources	MO 3:	IN 3.5	2	3
Sediment Resources	MO 4:	IN NH5.	2	4
Sediment Resources	MO 4:	IN NH8.	2	3
Sediment Resources	MO 4:	IN NH4.	2	1
Sediment Resources	MO 4:	IN NH3.	2	2
B. Terrestrial and riparian	MO 13:	IN 13.4	2	2
B. Terrestrial and riparian	MO 16:	IN 16.5	2	2
B. Terrestrial and riparian	MO 12:	IN 12.4	2	2
Recreation	MO 1:	IN 1.2	2	5
B. Terrestrial and riparian	MO 11:	IN 11.8	2	3
Sediment Resources	MO 2:	IN 2.7	2	5
Sediment Resources	MO 2:	IN 2.4	2	3
A.1 - Aquatic Food Base	MO 1:	IN 1.7 (App.)	1	3
Lake Powell	MO 2:	IN 2.6	1	5
A.3 - Native Fish	MO 8:	IN 9. (App.)	1	0
Sediment Resources	MO 2:	IN 2.8	1	1
A.3 - Native Fish	MO 8:	IN 8. (App.)	1	0
Sediment Resources	MO 4:	IN NH2.	1	1
A.1 - Aquatic Food Base	MO 1:	IN 1.12 (App.)	1	0
Sediment Resources	MO 2:	IN 2.1	1	1
Recreation	MO 2:	IN 2.1	1	10
A.1 - Aquatic Food Base	MO 1:	IN 1.8 (App.)	1	1
B. Terrestrial and riparian	MO 11:	IN 11.7	1	1
A.3 - Native Fish	MO 8:	IN 12. (App.)	1	0
B. Terrestrial and riparian	MO 12:	IN 12.2	1	1

Lake Powell	MO 2:	IN 2.5	1	1
Recreation	MO 3:	IN 3.4	1	0
Recreation	MO 3:	IN 3.1	1	3
B. Terrestrial and riparian	MO 13:	IN 13.3	1	1
Sediment Resources	MO 4:	IN NH6.	1	1

Recreation	MO 5:	IN 5.1	1	2
B. Terrestrial and riparian	MO 12:	IN 12.5	1	1
Recreation	MO 2:	IN 2.3	1	3
Lake Powell	MO 1:	IN 1.2	1	0
Lake Powell	MO 2:	IN 2.1	1	9
Cultural Resources	MO 1:	IN 1.7	1	0
GIS	MO 1:	IN 1.1	1	1

A.3 - Native Fish	MO 8:	IN 10. (App.)	0	0
A.3 - Native Fish	MO 8:	IN 7. (App.)	0	0
Recreation	MO 1:	IN 1.5	0	0
A.3 - Native Fish	MO 8:	IN 14. (App.)	0	0
GIS	MO 1:	IN 1.2	0	2
B. Terrestrial and riparian	MO 16:	IN 16.3	0	0
Sediment Resources	MO 4:	IN NH7.	0	2
A.1 - Aquatic Food Base	MO 1:	IN 1.11 (App.)	0	0
Lake Powell	MO 2:	IN 2.2	0	1
Lake Powell	MO 2:	IN 2.3	0	0
Lake Powell	MO 2:	IN 2.4	0	1
B. Terrestrial and riparian	MO 12:	IN 12.3	0	0

APPENDIX C

GCMRC Lake Powell Water Quality Monitoring Program

The current Lake Powell Water Quality Monitoring Program is linked closely with other water quality monitoring programs below Glen Canyon Dam, which address other downstream management objectives. The Lake Powell program consists of **monthly surveys of the forebay** above Glen Canyon Dam and **quarterly surveys of the entire reservoir**. The objective of the program is to characterize the chemical and physical parameters of the water in Lake Powell to determine the effects of Glen Canyon Dam operations and separate these effects from other natural processes affecting reservoir water quality. This program is linked to a long-term record of similar measurements collected by the Bureau of Reclamation and Glen Canyon Environmental Studies since 1965, which describes the entire history of Lake Powell since its impoundment by Glen Canyon Dam.

Pending formal approval by the Adaptive Management Work Group, this program represents an ongoing water quality monitoring effort by GCMRC that would remain in place throughout the five-year period of this work plan.

Monitoring activities are designed to meet the stated information needs of Management Objective 1 for Lake Powell Water Quality:

<u>MO 1: Lake Powell Water Quality</u> Prevent impacts that adversely affect the water quality (physical, chemical, biological) of Lake Powell due to dam operations and ensure that fully informed AMWG decisions are possible both now and in the future.

Field activities include collecting a profile of measurements throughout the water column at each station for temperature, specific conductance (an indirect measure of salinity), pH, dissolved oxygen, turbidity, and oxidation-reduction potential. This profile describes the degree of stratification, or mixing, and the range of temperature, salinity, and dissolved oxygen concentrations at a particular station. This information is used to describe the behavior and fate of inflow currents, advective and convective mixing processes, and the effect of Glen Canyon Dam withdrawal currents under different operational scenarios. It is also used to characterize the overall quality of the reservoir as well as that of the major strata within the reservoir. For example, monitoring of dissolved oxygen levels in the deepest stratum of the reservoir, or hypolimnion, can be used to predict when significant levels of hydrogen sulfide could occur.

In addition to the profile of physical and chemical characteristics, several samples may be collected at a station for further chemical analysis. Analysis of major cation and anion concentration is performed to quantify the individual components of salinity and to identify the origin of a parcel of water to further understand reservoir hydrodynamics. Analysis of nutrient compounds of phosphorus and nitrogen is also performed to determine the level of primary productivity that the reservoir can support and describe nutrient levels in reservoir releases or zones of potential release.

Quarterly lake-wide surveys include the major tributary arms of the Colorado, San Juan, and Escalante Rivers. Occasional sampling is done in mid-Navajo Canyon because of its potential for frequent hypolimnetic hypoxia. Other work on Lake Powell side channels and embayments has not been part of past programs but could be included in future work. An assessment of the potential effects of dam operations to the water quality of side channels and embayments should be conducted before establishing a long-term monitoring program for side channels and embayments. A study by the USGS for this work has been proposed by the GCNRA with external funding.

Heat budget quantification of modeling has been performed to a limited degree by the Upper Colorado Region of the Bureau of Reclamation as part of preliminary studies for selective withdrawal feasibility. The extent of this modeling has been to determine the effects over a two-year period of selective withdrawal. A more elaborate approach to reservoir modeling is needed to determine heat budget effects over a longer period and to help quantify the relative effects of dam operations and those of other hydrodynamic, hydrologic, and climatologic processes. This modeling effort would be very valuable to test the effects of various operational scenarios on short and long-term water quality conditions in Lake Powell.

Biological sampling is performed routinely as a component of the current Lake Powell Water Quality Monitoring Program. Several analyses are performed at the forebay and other selected stations on the reservoir. Chlorophyll concentrations are measured at the reservoir surface to describe the overall levels of primary productivity from photosynthesizing plankton. Discrete samples are taken near the surface for analysis of phytoplankton concentration and community structure. Composite samples are collected by vertical tows through the water column for analysis of zooplankton concentration and community structure. This information is used to describe long-term and seasonal changes in primary and secondary productivity and describe the type and amount of these organisms in Glen Canyon Dam releases. No work is currently being performed on macrophytes, periphytes, or macro-invertebrates. Evaluation of these shallow-water organisms is more appropriately addressed with a side channel and embayment water quality assessment.

No work is currently being performed by GCMRC to determine levels of selenium in reservoir water, sediment, or biota. Work is planned, however, on a Colorado River basin-wide selenium study to be performed by the Upper Colorado Region of the Bureau of Reclamation. It is expected that Lake Powell selenium issues will be addressed by BOR and that it will be linked with the existing Lake Powell Water Quality Monitoring Program.

A final component of the Lake Powell Water Quality Monitoring Program is the development of extensive science synthesis and database management systems for water quality information. This project supports the Lake Powell water quality management objective and addresses the GCMRC objective of establishing a comprehensive information technology program. These science and data assessments will be directly linked with other hydrologic and water quality databases and will be available by means of direct access and data warehousing products by various means including World Wide Web access. Its development has been ongoing and is being enhanced as other information technology programs progress.

Costs associated with this program include operating and maintenance for the sampling vessel, maintenance and repair of instrumentation and other equipment, analysis of chemical and biological samples, and travel and salary costs for personnel. The research vessels and all necessary equipment is outdated, and will need refurbishment or replacement in the next 2 to 3 years.

The vessel from which the majority of sampling is performed is a 31-foot Uniflite Sedan, which has been in use on Lake Powell for water quality sampling and other activities since 1970. The primary instrument for collecting water quality profiles is a Hydrolab H20/Surveyor 3. Chemical analyses of water samples is currently being performed by Reclamation's Water and Soil Laboratory in Denver, CO. Chlorophyll is analyzed by Reclamation's Boulder City water quality lab. A crew of 4-6 people is commonly used for quarterly reservoir surveys, comprising two GCMRC staff limnologists, an employee from Reclamation's Upper Colorado Region, an employee of the Glen Canyon National Recreation Area, and other ancillary personnel as needed.