# THE GRAND CANYON MONITORING AND RESEARCH CENTER

# LONG-TERM MONITORING AND RESEARCH STRATEGIC PLAN

by

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## 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 draft, Long-term Monitoring and Research Strategic Plan (the Plan), is designed to implement, within the center, new concepts of adaptive management and ecosystem science, called for in the Grand Canyon protection act and the Glen Canyon Dam environmental impact statement. The strategic plan is designed to be a guidance document, from which an annual monitoring and research plan will be drafted. The first five year strategic plan, and derived annual monitoring and research plans will include extensive

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synthesis of past monitoring and research, as well as in depth programs for needed future ecosystem monitoring and research. This plan presents brief historical documentation of past science, as well as more in depth discussion of planned future strategies monitoring and research programs. An appropriate starting point is discussion of part 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 biophysical and cultural resources associated with the canyon, 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 science has 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 construction of the Glen Canyon Dam in 1963, a facility that impounded over 25 million acre feet of water.

The Glen Canyon Dam was heralded as a wonderful resource for peoples of the Southwest. It was also criticized as a man-made instrument that would result in destruction of valued Colorado River resources, both above and below the Dam. Concerns over potential damage to downstream resources have been persistent since 1963, and relate mostly to operating criteria proposed 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 (Howard and Dolan 1981, Turner and Karpiscak, 1980; Laursen et al. 1976, Dolan et al. 1974). 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.

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 (USDOI 1988a, 1988b). These studies confirmed that dam operations affected downstream resources. However, 1983 through 1986 were relatively wet years and the resulting reservoir spills limited scientific understanding of effects from 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). Information from the different disciplines had not been linked, 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 (USDOI 1988b).

The NRC did conclude that the GCES Program demonstrated that impacts on Grand Canyon 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 was then launched encompassing a broader base of resources, to respond to external criticism.

Phase II 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). However, 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 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 generally understood despite considerable research efforts aimed at understanding the individual components of the river system.

Phase II studies have included research on sediment transport (e.g., Schmidt and Graf 1990, Andrews 1991, Cluer 1991, Cluer and Carpenter 1993, Schmidt 1993, Schmidt and Rubin 1995), organic drift (e.g., Angradi and Kubly 1994, Ayers and McKinney 1995), benthic ecology (e.g., Czarnecki and Blinn 1978, Blinn et al. 1994, Shannon et al. 1994), photosynthetically available radiation (e.g., Yard et al. 1993), water quality studies in Lake Powell (e.g., Stanford and Ward 1991, Ayers and McKinney 1996, Vernieu 1996), primary and secondary production in the Colorado River (e.g., Blinn and Cole 1991; Hardwick et al. 1992; Angradi and Kubly 1993; Ayers and McKinney 1995, 1996), diet of humpback chub (e.g., Carothers and Minckley 1981, Kaeding and Zimmerman 1983, Maddux et al. 1987, Kubly 1990), and overview studies (e.g., Carothers and Minckley 1981; Maddux et al. 1987; Angradi et al. 1992; Blinn et al. 1994, 1995; Angradi 1994).

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

## CHAPTER 2

## CENTER PROGRAM JUSTIFICATION AND MISSION

The rich history of research noted briefly above, primarily the Bureau of Reclamation GCES Program, has provided significant assessment of impacts of dam operations on selected resources. Yet, interested parties and agencies who are charged to protect and manage these resources have now realized that effective protection and management will only be attained through a profound understanding of the interacting components of the system, offered via ecosystem assessments using both monitoring and research efforts. Further these efforts will be greatly enhanced if accomplished within a well structured adaptive management program.

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 Glen Canyon Dam Environmental Impact Statement (GCEIS) (BOR 1995). The Act and EIS 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 "**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.

**GCMRC MISSION**

The EIS for future operation of the Glen Canyon Dam specifies the establishment of the (AMP) for assessment of Glen Canyon Dam alternative operating criteria defined in the Record of Decision (ROD) (BOR 1995), (USDOI 1996). The AMP includes the Grand Canyon Monitoring and Research Center (GCM&RC) and an Adaptive Management Work Group (AMWG).

The EIS specifies establishment of the monitoring and research center and the Adaptive Management Work Group (AMWG) within the AMP and defines it as a new approach in USDOI management direction. 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 Interior as a federal advisory committee to work cooperatively with the research center in implementing the AMP (BOR 1995). In adaptive management, the decision and management process is constantly evolving, with continuous input of new information to the Adaptive Management Work Group from the science center (Lee 1993).

The mission of the GCMRC is to determine short and long-term ecosystem resource impacts of alternative dam operation criteria[2/] and other information needs specified by the Adaptive Management Work Group (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.

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[2/]As defined in the Record of Decision of the Glen Canyon Dam EIS (USDOI 1996).

# CHAPTER 3

# SCIENCE PROGRAMING WITHIN ADAPTIVE MANAGEMENT

Figure 3.1 contains a schematic of the Adaptive Management Program (AMP) and its critical entities, including the 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 assure that operating criteria for the Glen Canyon Dam provide appropriate protection, management and use of Grand Canyon National Park and Glen Canyon Recreation Area resources, as supported by scientific assessment.

**Adaptive Management Work Group (AMWG)**: To provide to the GCMRC defined stakeholder objectives and criteria including specific information needs. To provide to the Secretary of the Interior recommendations on appropriate operating criteria for the Glen Canyon Dam.

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

**Independent Science Review Groups**: To provide independent science assessments of proposed research plans and programs, technical reports and publications and other program accomplishments.

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

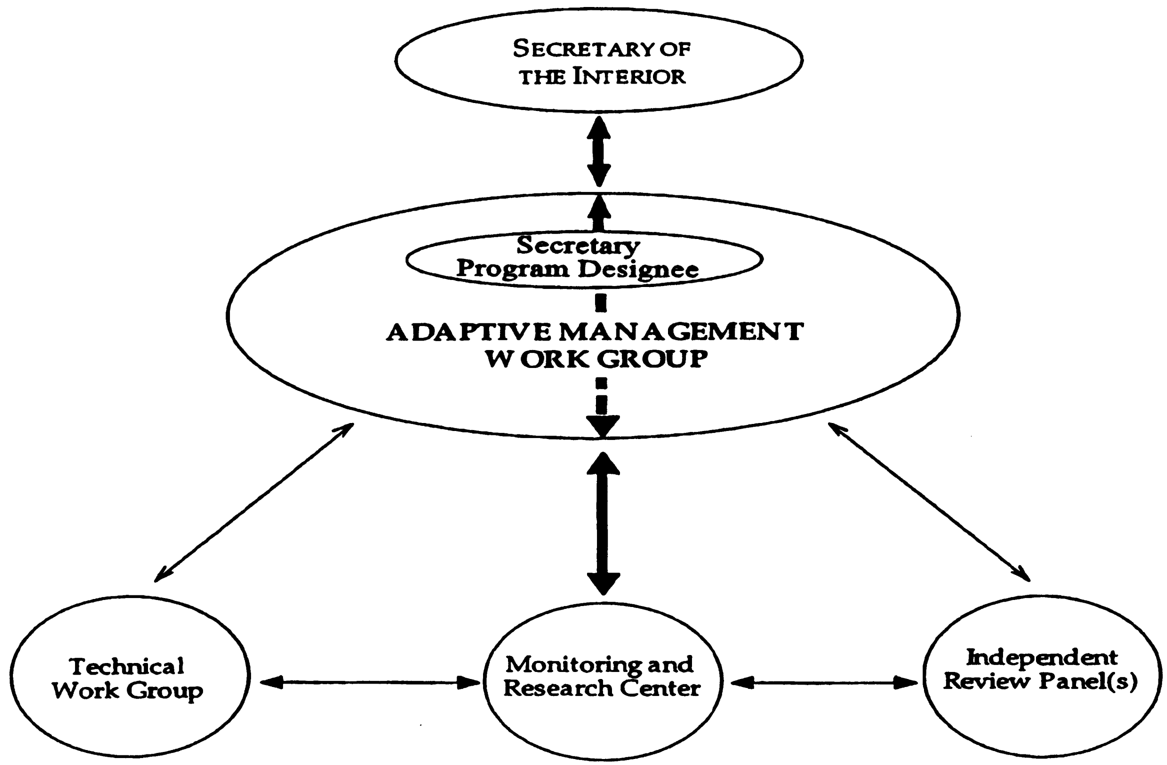


Figure 3.1. Adaptive Management Program Entities.

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

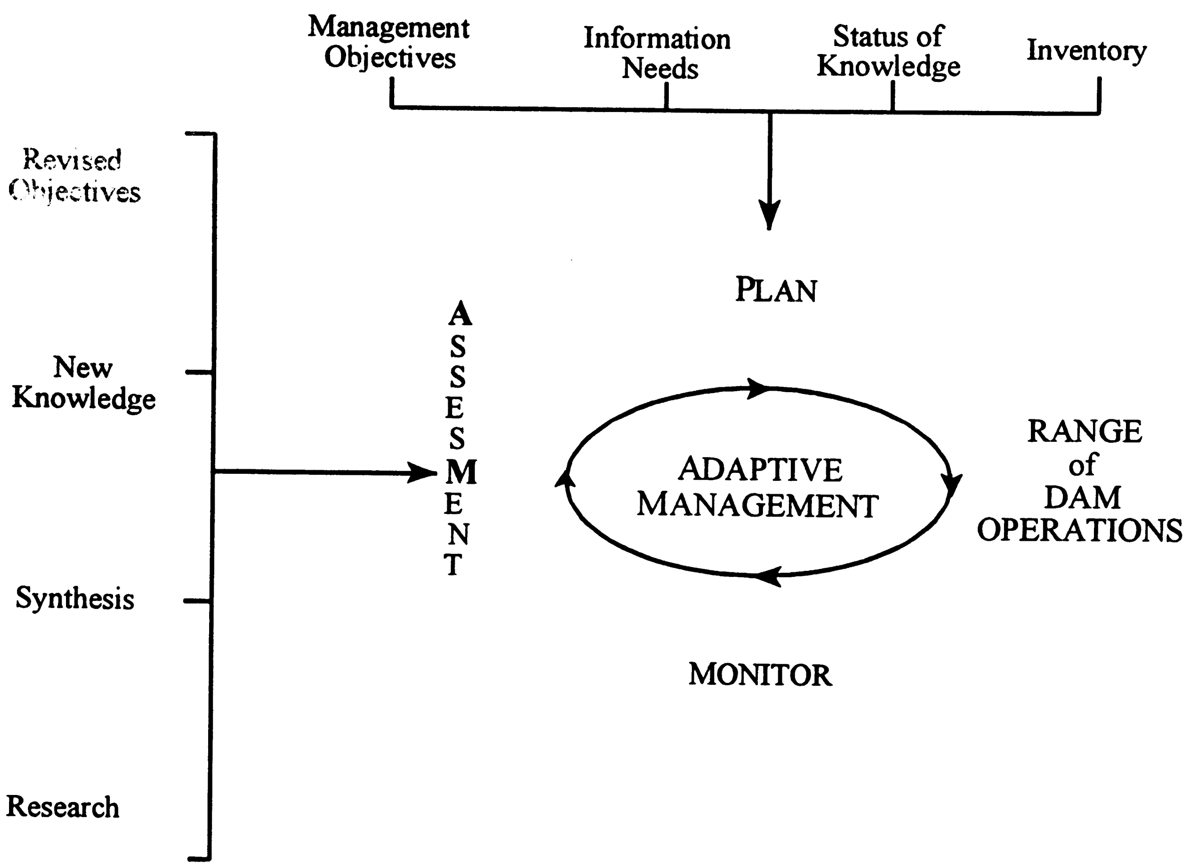


Figure 3.2: The Grand Canyon Monitoring and Research Center's approach to Adaptive Management (modified from USGS and BLM, 1994).

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 biological resources of interest will 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 to the monitoring program, is required to discern the nature of the cause and effect relationship that is indicated by the monitoring program.

Lee (1993) points out that, "Reliable knowledge comes from two procedures: controls and replication. A control matches what one is changing (the treatment), to a companion case in which that same factor is left unchanged (the control). The use of controls permits insight into whether it is the treatment that is causing the effect one sees, rather than something else such as a change in the weather. 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 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.

## THE ROLE OF SCIENCE

The GCMRC conducts 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 between the Center AMWG via the adaptive management process (Lee 1993). Science is clearly 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

The GCMRC will integrate research and monitoring information from past GCES and other programs and new GCMRC studies, into integrated 'state-of-the-science' assessments of dam operating criteria. All new GCMRC monitoring and research programs will adopt ecosystem science approaches, which will require integrated resource science assessments across space and time. These techniques are well documented in both scientific and management literature as 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) baseline 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** is the "repetition of measurements over time for the purpose of detecting change" (MacDonald et al. 1991). 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 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, especially on a longer term (decade/century) time scale, as related to defining appropriate dam operating criteria. It will also establish current baseline conditions for resources and determine the effects of differing management alternatives 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 is an essential element of the monitoring program.

Annual monitoring activities will be developed through selection processes that include an open call for proposals, open competition and cooperative agreements. 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 merit, and cost effectiveness. Monitoring priorities will be set cooperatively by the AMWG and the GCMRC.

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** 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 interaction, and development of ecosystem models. Research priorities will be assigned through cooperative assessments by the AMWG and the GCMRC. Research will be founded in the ecosystem science paradigm. However, other appropriate methods may be used to evaluate traditional and cultural values.

Research programs will be conducted through an open Call for Proposals (CFP) and cooperative programming processes, through which research projects are selected on the basis of their support of management research information needs, scientific merit, and cost effectiveness. All research study proposals will receive independent peer reviews.

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 riverene resources between Glen Canyon Dam and the inflow to Lake Mead. This mission meets the objectives of EIS, the 1992 GCPA and resource management agencies and interested stakeholders.

The Centers' mission is constrained by design. For this reason upstream monitoring in Lake Powell, and in side tributaries, i.e. Little Colorado River, is constrained to those probable impacts 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 riverine corridor and associated reaches that are explicitly related to dam operations.

**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 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 users. 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, computer tapes and disks, audio and video tapes, reports, publications, symposia, workshops, briefings, etc.

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

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 Biological Resources Program Manager is assigned by the Chief to serve as the principal assistant to the Chief in providing overall program leadership and serving as the Acting Chief in his absence.

# CHAPTER 4

## STRATEGIC RESEARCH PLANNING UNDER REVISED PARADIGM AND INSTITUTIONAL CONSTRAINTS

The Grand Canyon is a unique and complex 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 would be used in adaptive management decisions. Critical attributes are:

1. Quantity and quality of water from Lake Powell and in the Canyon.
    a. annual stream flows
    b. discharge rates and spill volume and 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 dynamics and sediment budget.
    a. stored riverbed sand
    b. elevated sandbar erosion
    c. dynamics of debris fans and rapids
    d. Side channel 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 and predator-prey interactions

4. Vegetation.

a. area and species composition of woody 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 wintering waterfowl

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

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. net economic value and regional economics

9. Power plant supply of hydropower 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 which reasonably might be affected by dam operations and for which no surrogate attributes exist. However, this program does not propose monitoring or research of those attributes clearly unrelated to dam operations or those which are adequately represented by other parameters. 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 the environment created by dam operation 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 long-term monitoring program would use methodologies that offer appropriate information about the response of the critical attributes to enable the AMWG to evaluate these changes in light of the overall management objectives for the physical, biological, cultural, recreational, and socio-economic resources of the Grand Canyon ecosystem.

## THE GEOGRAPHICAL AND INSTITUTIONAL SCOPE OF MONITORING AND RESEARCH PROGRAMS

The area to be monitored is primarily the Colorado River corridor between Glen Canyon Dam and Lake Mead reservoir (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 278), the generally accepted head of Lake Mead. 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.

Despite potential linkages that exist between the Grand Canyon and the entire upstream basin, the appropriate upstream limit for Grand Canyon monitoring and research on the effects of dam operations, is the forebay of Lake Powell, which is the intake point for water into the water release structures of the dam. Because of the critical role of reservoir-

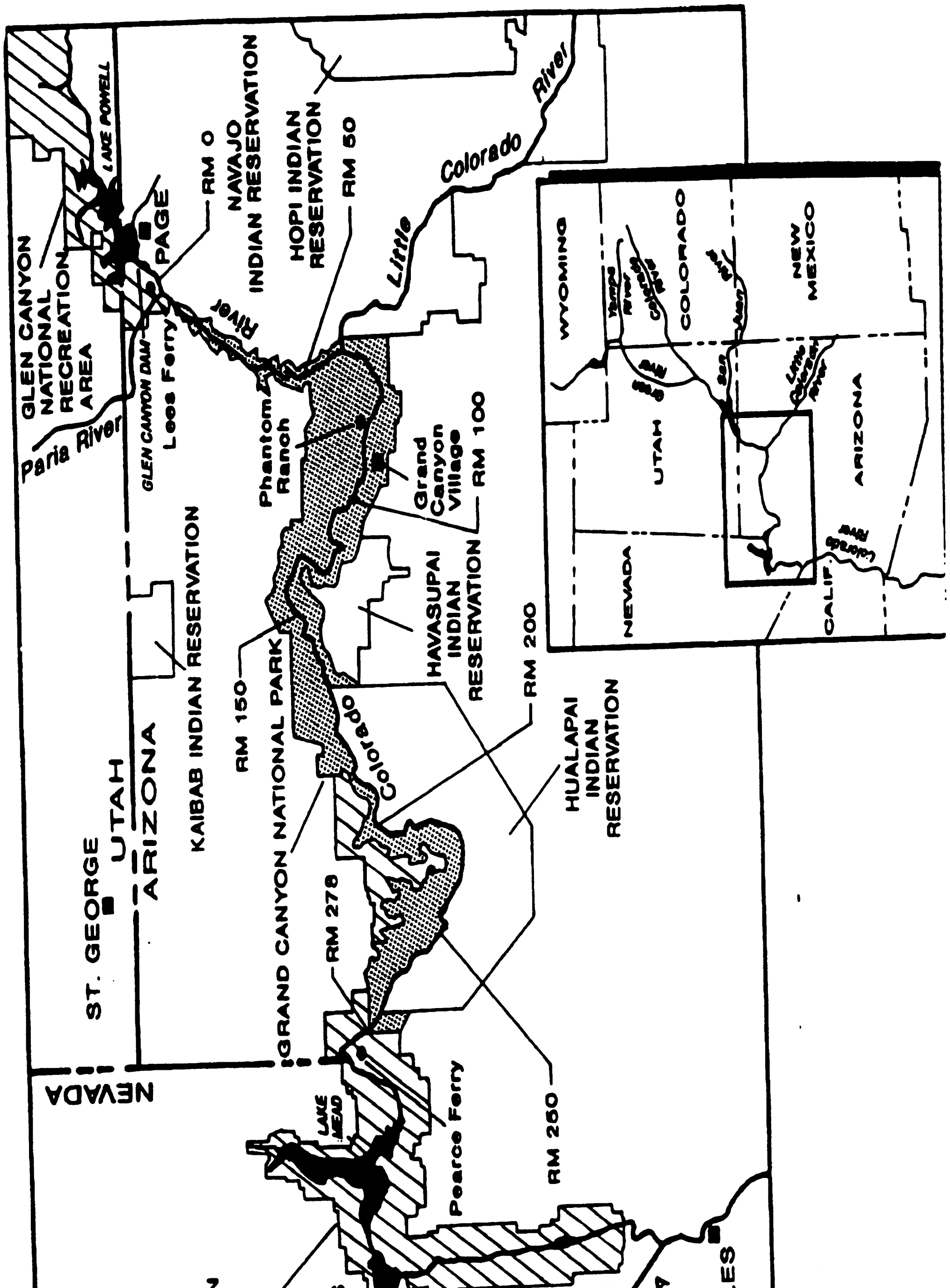


Figure 4.1. Map of the GCMRC Study Area.

scale geochemical processes in determining the quality of water at the intake sites, a separate long-term monitoring program in Lake Powell might be evaluated in the future as part of this program. However, any Lake Powell long-term monitoring program is not, at this time, being considered as part of the GCMRC long-term monitoring and research program. A one year assessment of potential impacts of past operating criteria on Lake Powell water quality is approved for fiscal year 1997. Along this same line, ongoing studies in and along the shoreline of Lake Mead within normal pool fluctuation are also not considered part of the GCMRC program at this time.

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 area for mean annual pre-dam peak flow of 100,000 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 1:24000 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. However, the scientific basis for their selection was not necessarily for the long-term monitoring and research program, since at

| 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 56 |
| 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 145 |
| 10 | LAVA FALLS | 179 to 181 |
| 11 | GRANITE PARK | 207 to 210 |
| 12 | DIAMOND CREEK | 225 to 230 |
| 13 | COLUMBINE FALLS | 273 to 276 |

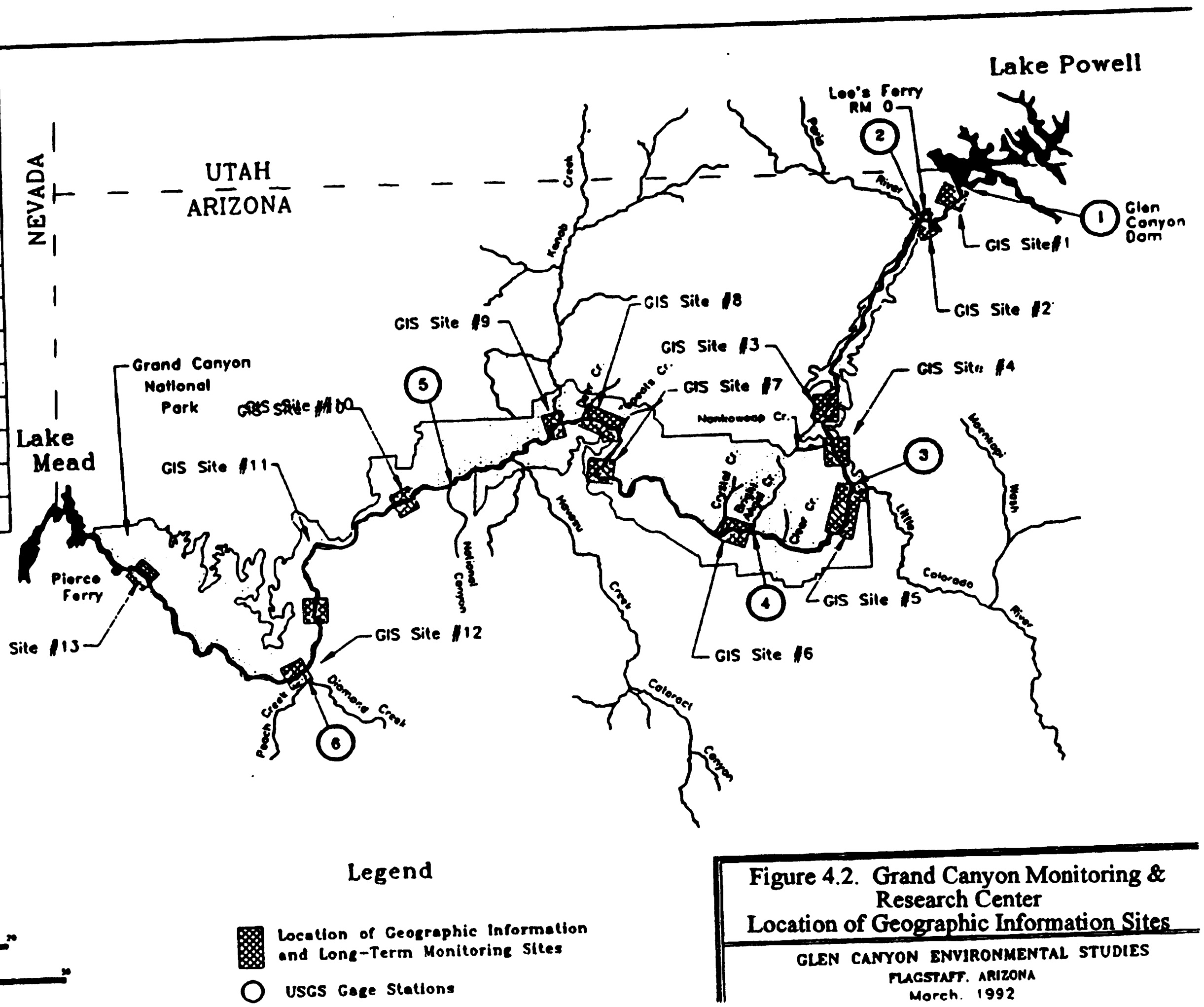


Figure 4.2. Map of the GIS-reaches established by GCE

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 of the Grand Canyon.

## CHAPTER 5

# DEFINING STAKEHOLDER OBJECTIVES AND INFORMATION NEEDS

Stakeholder, or management objectives define measurable standards which serve as targets to be achieved within the AMP. These targets serve as the basis for the identification of necessary information to be developed through the long-term monitoring and research program of the GCMRC.

Stakeholders objectives were organized within the various resource areas that had been identified during the EIS process. These broad areas were addressed and discussed within the framework of the adaptive management process to formulate stakeholder objectives and the resultant information needs. Figure 5.1 indicates the resource areas where objectives are developed as part of the EIS and long-term monitoring and research planning process.

## STAKEHOLDER OBJECTIVES

Stakeholder objectives were developed in the Spring of 1996, by a working group of stakeholders at a series of workshops organized by the Upper Colorado Regional Office of the BOR. During these workshops, the process of clarifying and consolidating the management objectives to clearly identify the management needs to the researchers and the GCMRC was begun. Objective statements were obtained from the group and condensed into specific objectives relative to each resource. The stakeholder objectives are included on the

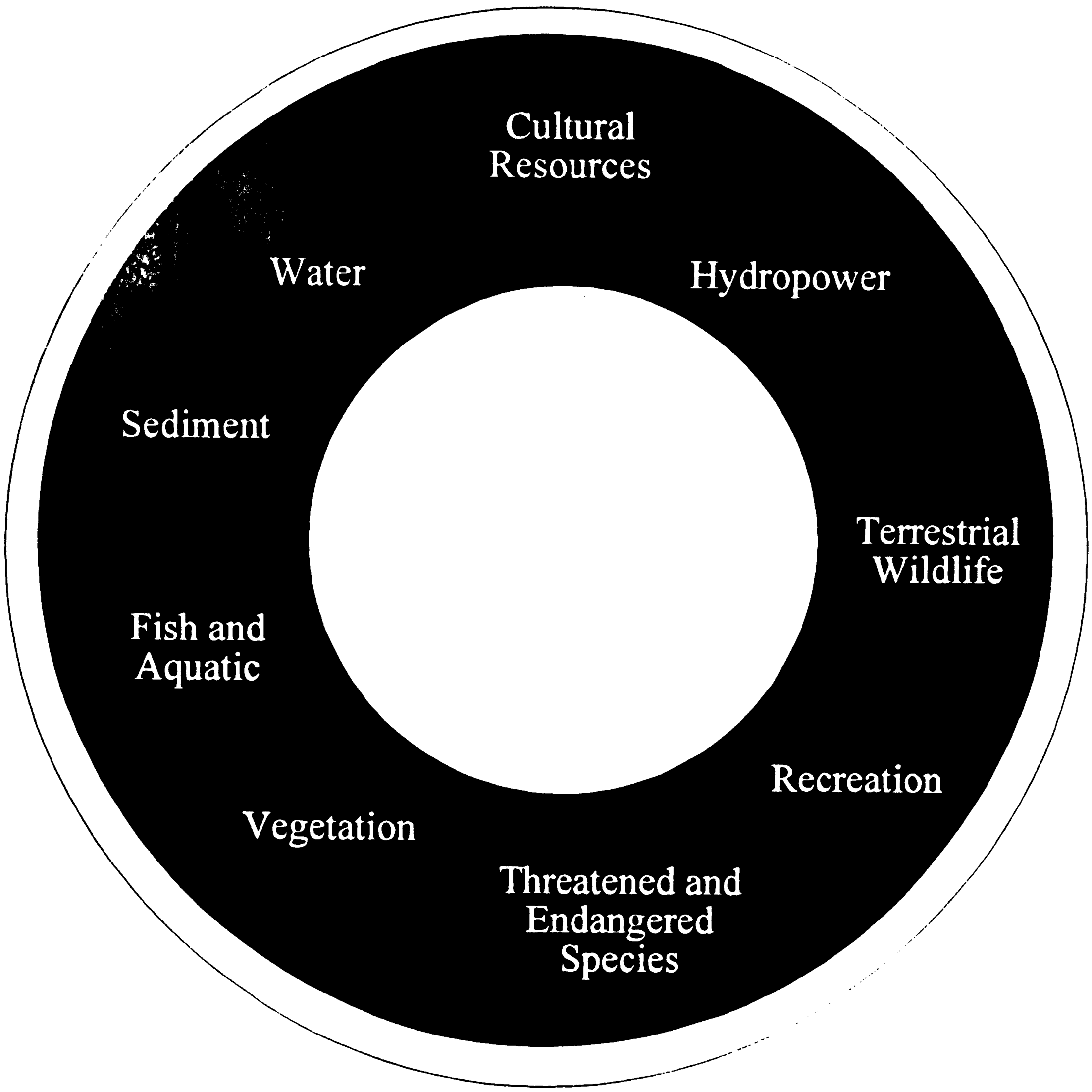


Figure 5.1. Issue Areas Proposed by the Transition work Group for Monitoring and Research.

resource sheets in Appendix A and organized by resource. Appendix B includes the objective statements of several agency stakeholders. These objectives can be identified within the content of the various resource sheets (Appendix A).

**INFORMATION NEEDS**

A series of meetings were held between May and September 1996 to gain input on information needs (research, monitoring, development) of stakeholders who are involved with protection, management, and use of resources in the riverine environment of the Grand Canyon. Interactive meetings were held with a subgroup of representatives from a larger cross section of stakeholders included in a Transition Working Group. The Transition Working Group was organized by the BOR as an interim body of stakeholders with which agencies could work until an AMWG was appointed.

The development of the information needs assessment was facilitated by the GCMRC based on the management objectives identified during BOR coordinated stakeholder meetings. The information needs assessment consisted of drafting appropriate broad data needs based on the objectives, and subject to constraints on scope of monitoring and research within the GCMRC.

The set of information needs identified by resource area and management objective are listed on the resource sheets in Appendix A. These expressed needs will become the primary basis for developing short and long term monitoring, research, and information transfer programs for the GCMRC.

# CHAPTER 6

## MONITORING AND SCIENCE PROGRAMS

This segment of the plan addresses six primary areas of the Long-Term Strategic Monitoring and Research Plan:

1. 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

## SYNTHESIS OF EXISTING KNOWLEDGE

A long standing criticism of past science in the Grand Canyon is that it lacks evaluation of existing knowledge for appropriate definition of science direction. Therefore, we intend to undertake in the first two years of implementation, an extensive synthesis of existing knowledge. A primary outcome of the synthesis is to use the increased knowledge to revise the Strategic Plan in year three. During the two year period, the Center will also continue critical monitoring programs developed during the transition from the GCES to the GCMRC programs.

The synthesis will be developed to pursue two key objectives:

1. To define a conceptual model of the riverine ecosystem, all related resource interactions, and their specific association to stakeholder objectives and information needs.
2. To define driving attributes (effectors) for all individual resources of interest, and where possible attributes that act as linkages or effectors across or among resources.

The second objective will be addressed through two separate synthesis of existing knowledge.

1. Determine, where possible, baseline conditions for critical Colorado River resources prior to dam construction, and for other river segments in the West that have not been damned.
2. Define resource attribute changes in the Colorado mainstream since dam construction and under differing operating criteria. Contrast with changes in resources in other riverine systems which have not been damned.

**A Conceptual Systems Model for Long Term Monitoring**: Following the articulation of management objectives, a conceptual systems model, based on existing knowledge of how the Grand Canyon system works, will be developed. This system model will focus on the specific goals articulated by the managers. Following the development and validation of the conceptual model, parameters to be monitored will be revised based on the known or suspected cause and effect relationships that are identified through the development at the conceptual system model.

The conceptual system model and long-term monitoring program must also be designed in recognition of the spatial and temporal characteristics of the Grand Canyon ecosystem. Given the spatial scale of the Grand Canyon, 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, thus methodologies should be selected which leave as small a "foot print" on the system as possible.

Similarly, the conceptual system model and associated long term monitoring program needs to be designed to provide information, over the long-run, on the response of the Grand Canyon ecosystem to the long-term operations of Glen Canyon Dam. This will probably require the long-term monitoring program to continue indefinitely, or as long as the dam is operable. The intensity of the monitoring program might change over time requiring a periodic review 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 management 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.

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

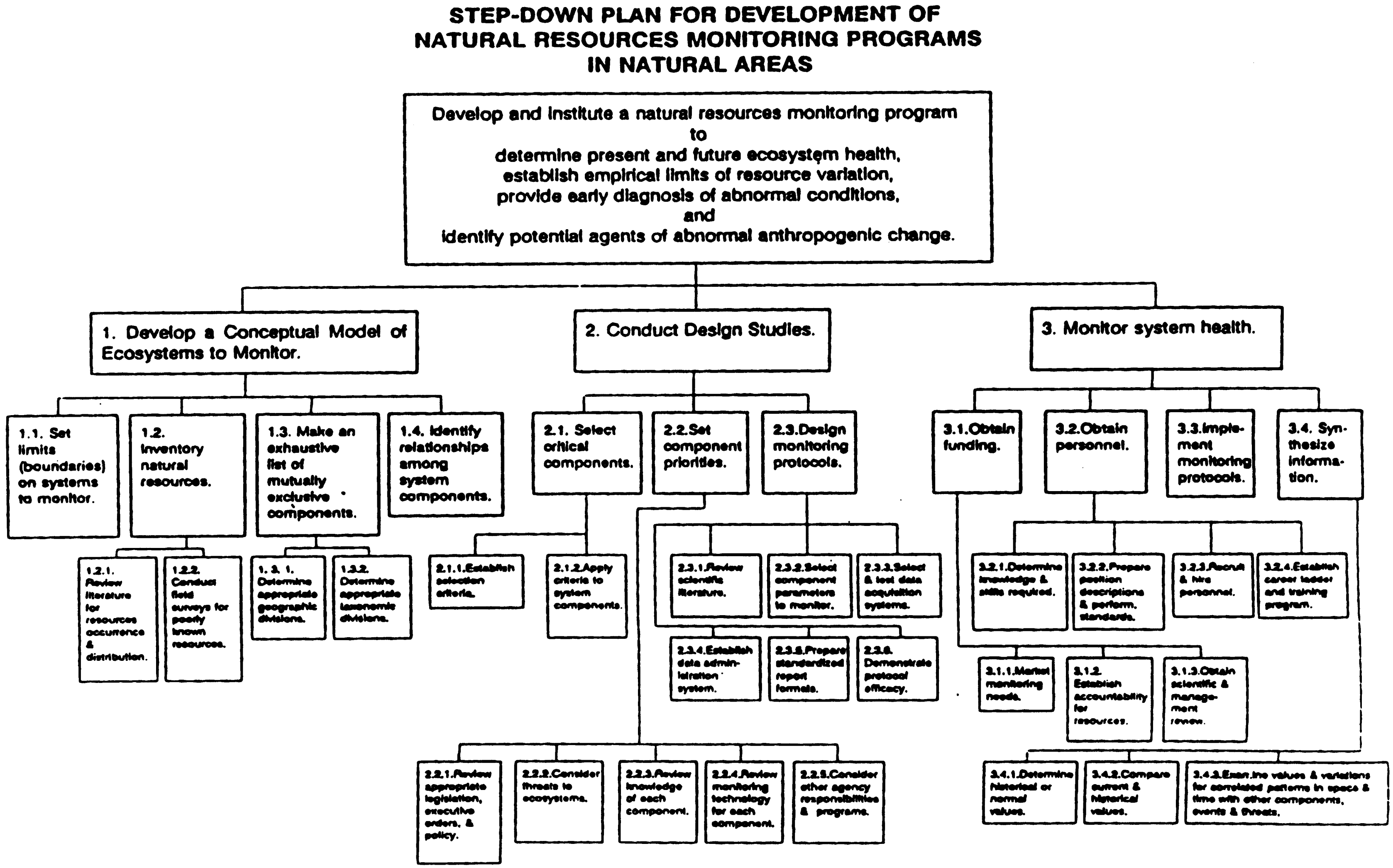


Figure 6.1. Step down Approach to the Development of a Long-term Monitoring and Research Program (Davis, 1994).

Experience with the development of long-term monitoring and research programs in an adaptive management framework suggest that it takes at least two years to develop a sound long-term monitoring program (Noon 1996). Critical to the development of a sound long-term monitoring and research program is the development, during the first year of the program, of conceptual and strategic models of the system being studied. The completion of a strategic model should provide the basis for the development of a sound long-term monitoring and research plan.

Objectives for the conceptual model exercise are threefold.

1. To specify the general system model for the Grand Canyon ecosystem with definition of critical resources, attributes, and attribute linkages.
2. To contribute to definition of information voids, and research and monitoring needs.
3. To function as an education process for scientists and stakeholders in understanding critical science and management issues.

The following approach is being proposed for use by the GCMRC in developing the needed conceptual and strategic models of the system. The GCMRC will assemble or contract with a group of modelers to work on the following activities leading to the development of the desired models. The GCMRC, together with the modeling team, will convene a scoping meeting to define the scope of the problem, design the first of two subsequent modeling workshops, identify key people (scientists and stakeholders) to participate in the modeling workshops, and begin to assemble the information that will be used at the first workshop.

The conceptual model will be designed using scientists and stakeholders currently active in Grand Canyon programs in a quasi-delphi modeling process (Garrett 1986, Hollings 1978). Scientists and stakeholders will be brought together to define resource variables/attributes that serve as linkages between/among resources. This "looking outward matrix" specification of resources, their attributes and the attribute linkages to other resources are building blocks for the conceptual system (Fight et al. 1986). Figure 6.2 provides an example of this matrix for an anadromous fisheries submodel of a conceptual systems model.

Following the scoping meeting, GCMRC will convene an initial modeling workshop to develop the conceptual model of the system. This workshop will take 5 - 10 days, and involve scientists and stakeholders knowledgeable about the Grand Canyon ecosystem. Extensive information bases including maps, databases, published reports, etc., will be made available for use during this workshop. The goal for this workshop will be to produce a conceptual model of the system, that can help identify critical relationships which structure the system, key information gaps, and the initial priorities for a long-term monitoring and research program.

A second modeling workshop of equal length will be held to refine the conceptual model and develop a strategic simulation model that can be used to begin testing major changes in management strategies. Three to six months is required between the first and second modeling workshops to validate and refine submodels, develop additional needed data and information, and where needed specify necessary subcomponents of submodels.

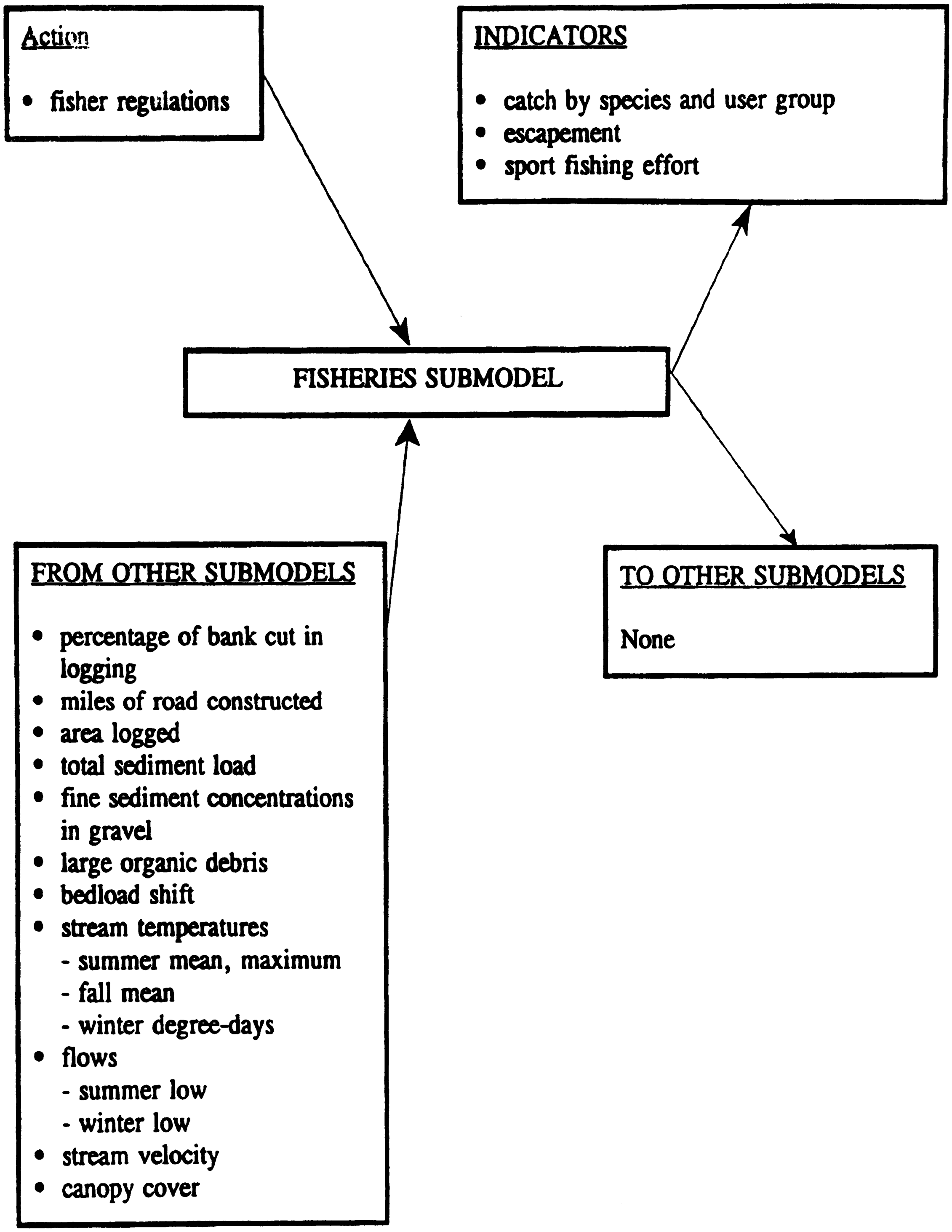


Figure 6.2. A "Looking Outward Matrix for fisheries Resources in the Southeast Alaska Multiresource Model (adapted from from Fight et al. 1986).

During the second workshop the process of assigning values to what are believed to be the key model parameters would begin, as well as, model validation and sensitivity analysis to test key assumptions embedded in the model. Analysts would begin to explore the consequences of alternative dam operations based on the assumptions and hypothesis used to construct the model. This second workshop would yield a first approximation conceptual strategic model that would provide a more sound basis for the development of a long-term monitoring and research plan.

The "working" strategic model would continue to be refined and developed over the course of the first five year strategic plan. More detailed submodels for specific elements of the system (i.e., riparian vegetation, cultural resources, etc.) would be developed through prototypes to operational stages. Merged analytically with the database management system and GIS, this modeling effort would eventually formulate a Decision Support System (DSS) for the AMWG (Covington et al. 1988).

The conceptual modeling approach described above will address objectives 1 through 3 above. The interactive workshop process for model development accommodates critical education of scientists and stakeholders regarding how the system functions.

Good simulation 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, simulation models 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 ecosystem simulation 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 computer model of the Grand Canyon 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 ones thinking. Computer models are precise and consistent (even when they are wrong), 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 provide a platform for thought experiments (Meadows et al. 1982, Fight et al. 1986).

**Development of an effective synthesis of past knowledge** will be accommodated through two steps as noted above. Both steps will be developed simultaneously.

One of the interesting quandaries in natural resource science endeavors, especially endeavors 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 make more difficult, when the western riverine ecosystem under study, has been significantly altered from its original character.

Natural systems 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 western 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 might 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 science challenge 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 analysis to another more natural western river, i.e., not impeded 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. The confounding resource impacts caused by the dam's existence can obviously overwhelm impacts due to dam operations. This is due in major part to radical changes in hydrology, sediment loads, and temperature regimes in the river, all due to dam placement.

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 western rivers without dams, is not warranted. Determining original baseline conditions for the Colorado River mainstem resources and a similar more natural riverine ecosystem in the Southwest, 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 in the lower river are presumed to be caused by existence of the dam and/or dam operations, a conclusion that removal of the dam would in fact restore these populations might not be correct. Populations in other more natural riverine settings in the western United States also appear in decline. That is, other resource attributes such as change in climatic variables or water chemistry resulting from agricultural uses upstream may be the primary contributing factor.

There has been insufficient synthesis of knowledge on both the Colorado riverine ecosystem and other western riverine ecosystems to appropriately establish baseline conditions, to which we can compare and contrast resource changes over time due to human induced 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 clearly needed 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.

**THE PHYSICAL RESOURCES PROGRAM**

The physical resource program forms the basis for understanding impacts of dam operations on other resources. Two resources, water and sediment, are scientifically linked to dam operations, and create the base dynamics found in the riverine corridor, either directly from dam operations, or indirectly from the interaction of differential discharges from dam operations with sediment and flows entering from side channels. This base dynamic of variable flow and sediment regimes in turn create the river dynamics that are related to all resources and their attributes

Variation in some physical resources seem subtle, so minor in fact that little if any visible response would be expected within or among other system resource attributes. Water temperature is an example; it is maintained in the low 40 degree Fahrenheit range from consistent dam releases at about 250+ feet below the Lake Powell surface. Yet, minor changes in these temperatures as water moves downstream result in significant changes in life forms associated with the seemingly insignificant water temperature changes.

Water and sediment are primary resources in considering relationships among resources. All other resource categories, biological, cultural, and socio-economic are directly or indirectly affected by changes in these primary resources caused by dam operations or other factors.

Within the Colorado mainstem study area, from Glen Canyon Dam to the upper reaches of Lake Mead, there are four aspects of these resources where monitoring and research efforts are important.

1. Dam discharges.
2. Water and sediment transport.
3. Interaction of mainstem water and sediment resources with side channel flows.

4. Interaction of mainstem water and sediment resources and upper Lake Mead water and sediment resources.

**Dam Discharges** Dam discharges create the physical conditions that control many of the downstream ecosystem processes, for example, sediment dynamics, habitat development, and biotic recruitment, and survival. The objectives for monitoring the outputs of Glen Canyon Dam are to determine how closely dam discharge follows the prescribed operations of the dam and the extent of the variability in discharge, should it occur. These outputs, which also include discharges or spills above dam hydropower operations, should be monitored at: 1) the dam, based on power production; 2) the U.S.G.S. gauge just downstream; and 3) within the Lake Powell forebay. Outputs to be monitored include, hourly water discharge (both flow rate and volume) and ramping rates (changes in discharge over the hour). From the above data, 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. These monitored data streams are enhanced by ongoing water quality measurements above and below the dam, including significant breadth in physical, chemical, and biological attributes. Monitoring and research of water quality attributes in the river and their relationships to dam operations are a critical part of the long term program. Changes in water quality attributes in Lake Powell, and these relationships to dam operations are the subject of intensive assessments in FY 1997 and FY 1998. Continued water quality programs in Lake Powell will need to be justified on related imports due to dam operations.

Physical attributes evaluated in the river include temperature, conductivity and inorganic compounds; chemical attributes include salts, trace elements, phosphorus and nitrogen; and biological attributes include aquatic biota assessments. Assessment of all these attributes will continue in the long term plan.

Definition of linkages and integration among attributes of physical and biological resources in the Glen Canyon reach of the river is needed to ascertain relationship of flows to primary productivity. The non-native trout fishery has become an important social and economic resource to diverse publics and it is responsive to changes in primary productivity which in turn is affected by dam operations.

The 1996 beach habitat experimental flows appeared effective in enhancing primary productivity, but also may have contributed to changes in the standing crop of biomass. A critical research need is development of a conceptual model of integrated physical and biotic attribute relationships for the Glen Canyon riverine corridor.

**Water and Sediment Transport**. The transport of water and sediment through the Canyon are interconnected (e.g., sediment transport curves). Discharge rates and changes in river state influence the amount of sediment transported and stored in the system. And, sediment is the primary substrate for many Canyon biological processes as well as camping beaches. The objectives for monitoring changes in water and sediment transport are to determine whether the flux of water and sediment through the Canyon is at the level predicted by the EIS for the prescribed operating criteria and whether the flux varies as expected within different reaches of the Canyon. Measurement objectives are: 1) continuously measure the flux of water through Grand Canyon; 2) periodically measure flux of sediment through the Canyon; and 3) measure the differences in flux in different reaches. Measurements of flux not only permit comparison of measured differences in fluxes which can be compared with measured storage changes, but the fluxes themselves are critical determinants of biological processes.

A water flow and sediment routing model is being developed by the U.S. Geological Survey, however, it is not yet time to rely solely on this model to estimate fluxes. Field measurements are still needed to provide appropriate data for model validation in differing reaches.

Gauging stations do not exist at the end points of each geomorphologically distinct reach in Grand Canyon, using the classification and research of Schmidt and Graf, 1990. The emphasis of long-term monitoring will be on maximizing the analysis of data collected at existing gauges, using models to integrate variations in inter node reaches.

Most river managers have expressed greatest 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 gauging stations on the Colorado River at Lees Ferry, above the Little Colorado River, and 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 gauging stations such as the station above Diamond Creek. It is less critical to evaluate flux differences between miles 87-225, and the gauge above National Canyon is considered the least important gauge presently existing in Grand Canyon, although it continues to be useful for bed movement studies and sediment transport modeling. If one permanent gauge is removed in the Grand Canyon, it will be the National Canyon gauge.

If one gauge were to be added in the Grand Canyon, it should be located upstream from Nankoweap Creek (perhaps upstream from Buck Farm Canyon), so that fluxes could be measured through the distinctly different reaches of upper and lower Marble Canyon. These are reaches in which impacts from upramping waves are greatly attenuated. However, the addition of a new gauge in the Grand Canyon represents a significant increase in the impact of scientific activities on the Canyon, and scientists should first explore alternative strategies to installation of permanent cableways for purposes of water and sediment gauging. Should alternatives be determined, especially cost effective alternatives affording lower impacts to Canyon resources, all gauges will be changed.

The ongoing water and sediment 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 water and sediment modeling efforts would be considered part of long-term research, such as deposit in and erosion of side channel debris, changes in existing rapids, formation and degradation of beaches, and arroya down cutting in upper river channel terrains.

Measurements of sediment fluxes will be the basis for computing annual reach-scale sediment budgets of the Grand Canyon. The sediment budget approach to river management has been endorsed by geomorphology and sediment researchers (GCES Fort Collins, 1992). Because there are insufficient gauges to compute sediment budgets for all geomorphic reaches of Grand Canyon, such budgets can only be computed currently for the following reaches: Lees Ferry to Little Colorado River, Little Colorado River to Bright Angel Creek, and Bright Angel Creek to Diamond Creek.

Calculation of the above budgets also necessitates measurement of water and sediment inflow from tributaries. Stations on the Paria River at Lees Ferry and Little Colorado River near Cameron should be continued. Sediment from Moenkopi Wash, a major sediment contributor to the Little Colorado River, is not measured and consideration will be given to developing a measurement station on this wash. Sediment measurement stations will be established on other tributaries to the mainstem only if it is determined through research that these inputs have localized reach effects to critical biological or cultural resources. This is not necessarily the case for water discharge data, and gauges for these measurements on major tributaries might still be considered.

Chemistry and temperature changes of water in the mainstem of the Colorado influences most aquatic and riparian biological processes. Changes in water chemistry and temperature may alter physiological processes of aquatic biota, potentially triggering changes in the aquatic trophic dynamics of the Canyon. Nutrient trapping by Glen Canyon Dam, changes in nutrient transport within Lake Powell resulting from changes in lake level, and in the mainstem resulting from water transport fluxes all influence the water chemistry of the mainstem below the dam. Thus, the objective of water chemistry monitoring and research is to determine the aquatic environment of the Canyon, and evaluate this in terms of maintenance of those riverine ecosystem components deemed critical by the resource management agencies and interests such as, fish, aquatic food base, and riparian vegetation.

Evaluation of chemical and biological changes in the riverine ecosystem would be dependent, in part, on river discharge, water temperature and sediment data collected at the monitored gauges on the mainstem and at the point of discharge from the dam (Tailrace). Basic data on water temperature, conductivity and pH would be measured at these gauges and the discharge point at the same time interval established for sampling discharge and/or sediment transport. Measurements of dissolved oxygen, particulate and dissolved organic matter, and nitrogen and phosphorus will be made seasonally.

Research efforts most needed are modeling of water quality changes through the canyon under differing operating criteria. Most needed are algorithms for temperature, water chemistry and biology.

**Interaction of Mainstem and Tributary water and sediment** is influenced by dam operations primarily at their confluence with the mainstem. In addition to the influence of rising and falling river levels 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, dam vs. non-dam operational causes. Tributaries of the Colorado River are relatively pristine refuge 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 where they are considered as a "control" for evaluating changes in selected attributes in the mainstem (e.g., aquatic biota), and as a source of attribute inputs.

Tributary inputs to the mainstem include hydrological, sediment and limnological attributes. Not all tributaries can be monitored, thus emphasis will be limited to those with major inputs, either abiotic or biotic. In addition to water and sediment discharges from the Paria and Little Colorado Rivers mentioned earlier, tributary discharges, water chemistry and biological attributes will be monitored at the Paria and Little Colorado Rivers, and Kanab, Bright Angel, and Havasu Creeks. Measurements will be continuous for discharge rates, seasonal for chemical and biological attributes, and they will be taken in conjunction with the measurements at the gauges in the mainstem. Discharge rate monitoring will require maintenance, reinstallation, or installation of gauging systems in the above tributaries. The necessity for this invasive technology should be evaluated against other less invasive technology. Especially with perennial flows, selected tributaries could be sampled quarterly for comparison with primary tributary and mainstem data; measurements would be limited to water chemistry and biological attributes.

Sediment dynamics in the system represent critical resource attributes to many other resources. Sediment in the Canyon is either in transport or in storage above or below the river surface. Sediment transport flux is monitored periodically at gauge sites in the Canyon. Stored sediment in the channel and eddies is the source and foundation of elevated sediment deposits.

The prescribed dam operations in the ROD consider sediment accumulation in the riverine 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. In order to determine the influence of dam operations on the integrity of these deposits, the measurement objective of the monitoring program is to determine the changes in sediment storage in different reaches of the Grand Canyon. The accomplishment of this objective will permit measurement of temporal change in the status of critical bar and bank sediment deposits and in debris fan deposits, and to place that change within the context of measurement of all sediment storage change in the Grand Canyon.

Selected campsite beaches will continue to be measured annually. Established survey techniques would be employed by trained surveyors. Measurement of short-term changes on bars, although of interest in determining sediment dynamics, are not the focus of the long-term monitoring program. Long term assessments will evaluate significant changes in bass in critical reaches and within the entire system.

Measurement of bar changes throughout the Canyon will be made using air photo interpretation and video imaging analysis strategies across multiple year periods. Such measurements permit wider ranging measurements using less invasive measurement strategies. Short-term repeat photography is not recommended as part of the long-term sediment monitoring program except perhaps at sensitive archaeological sites to determine change.

**Interaction of mainstem and Upper Lake Mead water and sediment** resources represent significant potential areas of physical resource impacts due to variable dam operations. 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 effect 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.

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 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.

> "*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.

## THE BIOLOGICAL RESOURCES PROGRAM

### Introduction

Deciding what to measure, how, where, and when to measure and 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 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. They are also affected by the difficulty in selecting appropriate parameters to measure and the appropriate approach to 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 initial monitoring program, especially regarding the effectiveness of prescribed management actions, and in light of real-world scientific, logistical, and financial constraints (NRC, 1990). This is especially true in programs which will continue to be resource limited.

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 the understanding of biological resources within the Grand Canyon ecosystem 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 Grand Canyon ecosystem and the development of a conceptual model of 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 Grand Canyon ecosystem behaves as the models predict it will, 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 lots of feedback between them (Figure 6.3, 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 Grand Canyon ecosystem, 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

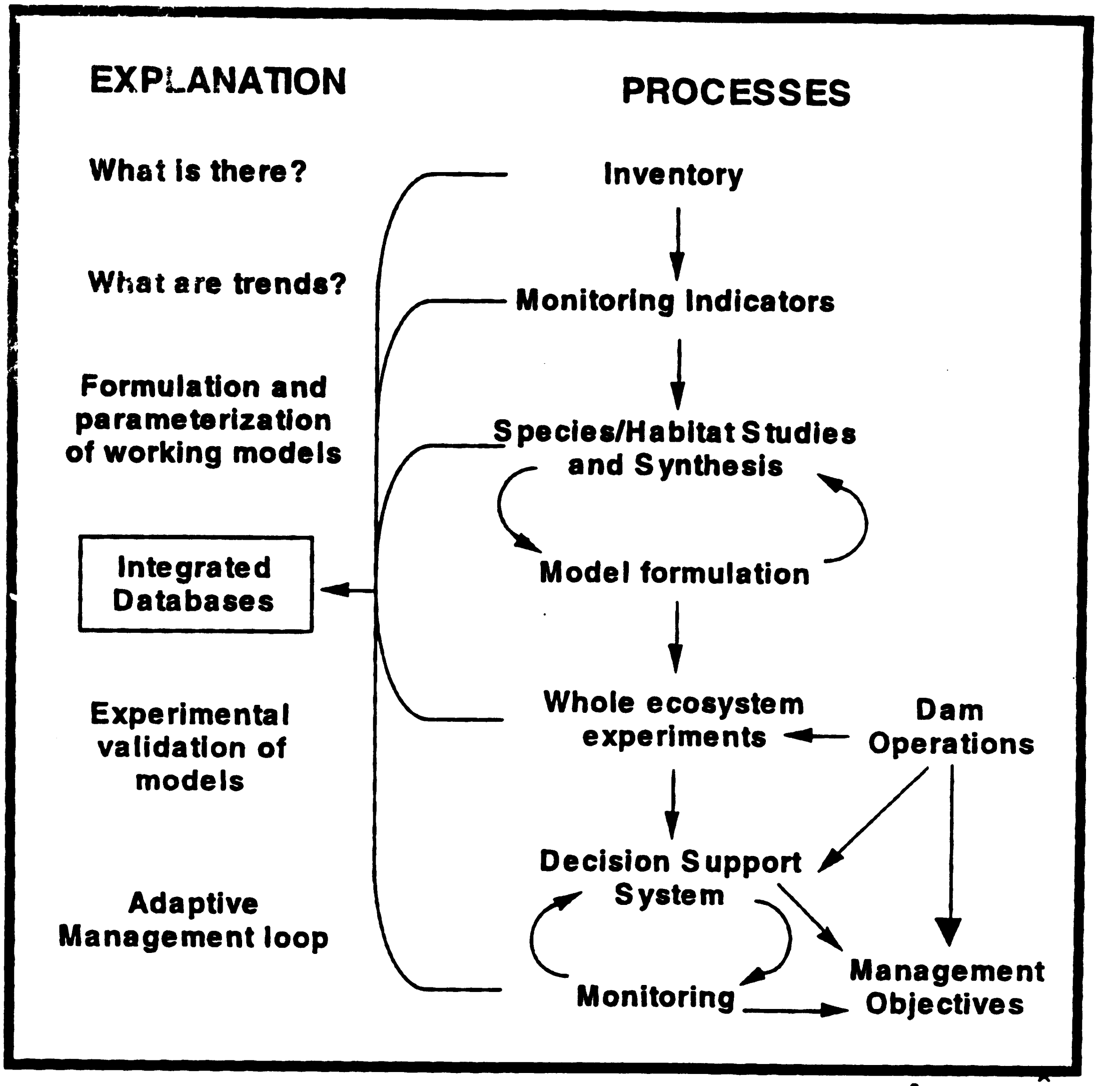


Figure 6.3. GCMRC Approach to Ecosystem and Adaptive Management (Adapted from CENR, 1995).

information base on the structure (building blocks) and function (processes) of the Grand Canyon ecosystem is a prerequisite to prediction of ecosystem effects from alternative dam operations. Information on structure and function should include knowledge of the basic building blocks of the ecosystem and an understanding of impacted and unimpacted ecological processes, both biotic and abiotic. Candidate ecosystem components for monitoring can be displayed in relation to ecosystem structure in a diagram depicting patterns of activities within an ecosystem at different levels of complexity (Figure 6.4, Likens 1992). These processes range from such things as hydrology (current flow and water temperature) to water quality (DO, salinity, nitrification) to habitat alteration, to population or community dynamics. Ecosystem building blocks include species occurrence and distribution, and abiotic components such as water, underlying hydrogeology, and nutrients. It is key that relationships between the biotic and abiotic components of the Grand Canyon ecosystem be addressed, for without an understanding of those relationships, one will not be able to predict the effects of alternative dam operations on critical biological resources and the Grand Canyon ecosystem, in general.

Alternative dam operations may impact the Grand Canyon ecosystem in ways and on scales (temporal and geographic) not generally experienced in response to natural perturbations. Knowledge regarding the impact 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.

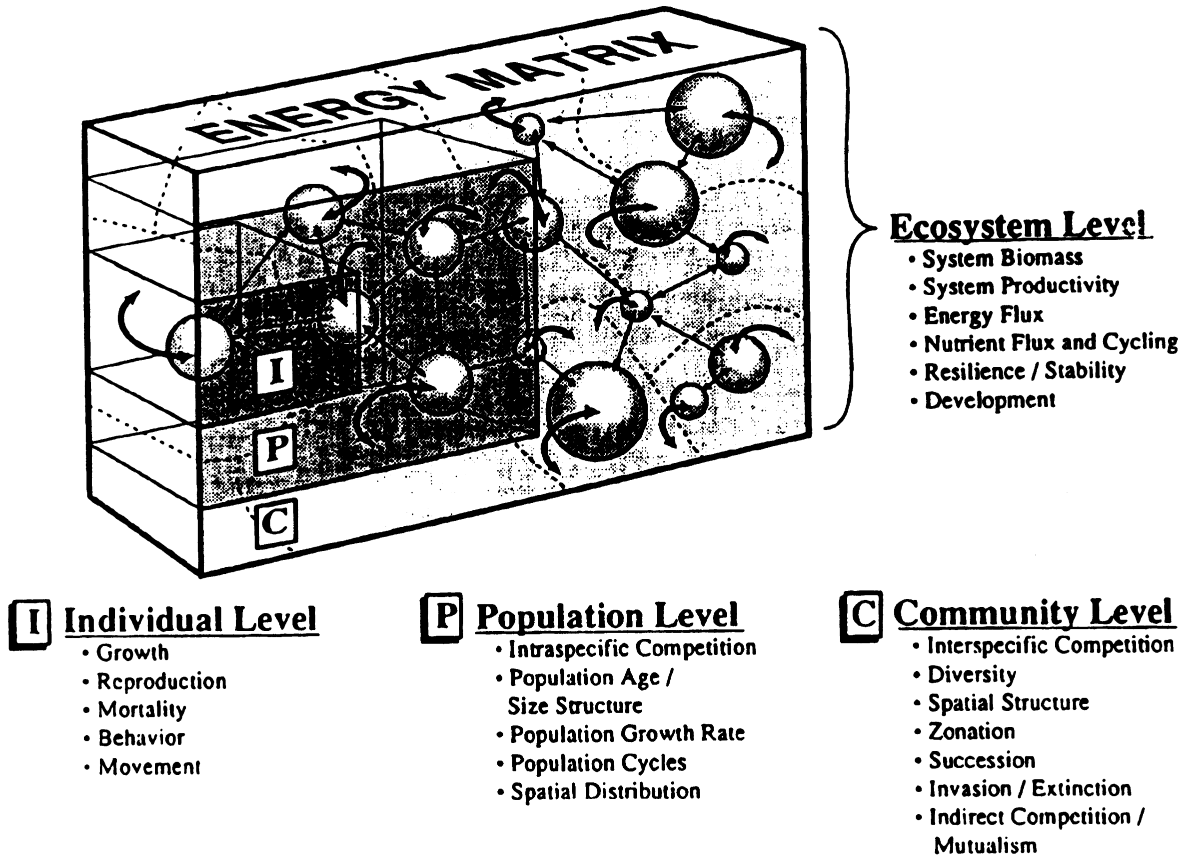


Figure 6.4. Diagrammatic conceptualization of patterns and activities at different levels of complexity. Each sphere represents an individual abiotic or biotic entity. Abiotic is defined as nonliving matter. Broad, double-headed arrows indicate feedback between entities and the energy matrix for the system. The thin arrows represent direct interactions between individual entities. Much of ecology is devoted to studying interactions between biotic and abiotic entities with a focus on the effects of such interactions on individuals (I), populations (P), or communities (C) of organisms. Ecosystem ecology studies these interactions from the viewpoint of their effect on both the biotic and abiotic entities and within the context of the system. The boundaries of the system must be established to conduct quantitative studies of flux. (From Likens 1992)

**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. An example of such a conceptual model, showing components (structure) and their linkages (process) is shown in Figure 6.5 (Noon, 1996). 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.

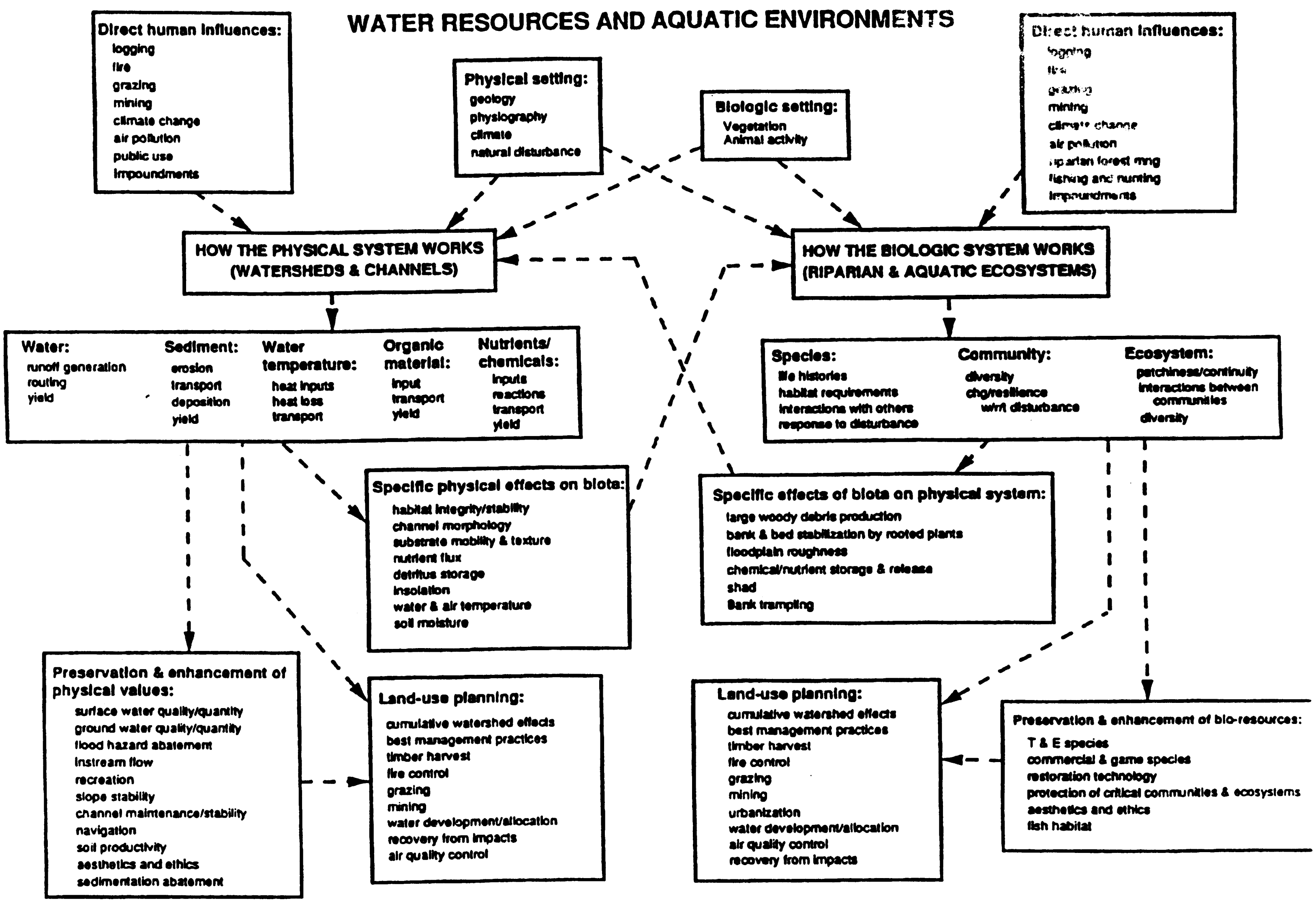


Figure 6.5. Example of a Water Resources and Aquatic Environments Conceptual Model (Noon 1996).

## PROPOSED MONITORING AND RESEARCH ACTIVITIES

### Aquatic Food Base

Many wildlife species, including fishes, depend on the aquatic food base for their survival. Fluctuations in aquatic food resulting from dam operations or other factors may trigger changes in some or all of the populations of native and non-native fish species. The long-term monitoring program should be designed to determine how the biomass, habitat, and composition of the aquatic food base will respond to alternative dam operations.

Aquatic food base monitoring should be seasonal in the mainstem, backwaters and tributaries. Quantification of changes in species survival and productivity within categories or functional group changes in the Colorado River ecosystem may be used as indicators of the lower trophic levels. Standing crop, dominance and habitat requirements of aquatic invertebrates and algae should be monitored at Glen Canyon Dam, Lees Ferry, Little Colorado River and Diamond Creek and at least two wide-reach sites and two narrow-reach sites in between. Sampling protocol should correspond with those used by Blinn et al (1992) for comparative purposes. A twice a year (early August and late October or November) (perhaps seasonally) sampling scheme should be considered. Trophic condition, should be considered for monitoring through the use of standard indicators such as chlorophyll a, nutrient concentration, and water transparency.

The sampling protocol in Blinn et al (1992) which sorts the biota into the following biotic categories: Cladophora, blue-green algae, chironomids, Gammarus, gastropods, oligochaets, simuliids, lumbricids, other invertebrates and detritus, should be modified to include a category for diatoms, an extremely important periphyton, and should be utilized.

Complementary with the biotic sampling, the following abiotic parameters should be measured for comparison with abiotic data from the gauge sites: water temperature, dissolved oxygen, pH, conductivity. Also, substratum microhabitat conditions, Secchi disc, water velocity and/or stage and depth should be measured at each site.

**Fish**

Fish are an important part of the Colorado River ecosystem because of their trophic role, their important recreational value, and because some are listed as threatened or endangered under the Endangered Species Act.

Changes in the structure and/or function of an ecosystem resulting from alternative dam operations may result in decline or failure of fish populations. Low temperature hypolimnotic releases from dams are thought to have negative effects on population dynamics and recruitment of some warm-water riverine species. The three major functions which influence successful fish recruitment are thought to be: hydrology and transport; zooplankton production; and larval fish quantity.

For a population of fish to remain viable, it must have successful recruitment. In fish, the timing of reproduction must coincide with local food production cycles, i.e.; phytoplankton and zooplankton production (match-mismatch hypothesis: Cushing 1967), and larvae must be transported to a favorable nursery habitat (member-vagrant hypothesis: Sinclair 1988). Management of river flows can affect larval transport to nursery grounds, and thereby influence recruitment. Both food production and nursery habitat quality are tied to physical factors such as temperature and nutrient supply, both of which are partially dependent on the timing of water releases upstream. Dam management practices resulting in low production of phytoplankton during normal times of fish spawning may negatively affect mean instantaneous growth rates (Pepin 1988). Slower growth rates increase the duration of high risk life stages (Shepherd and Cushing 1980, Houde 1987, Anderson 1988), 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, spawning, larval transport, trophic dynamics, and recruitment.

The Colorado River's native and endangered fishes have been effected by environmental changes resulting from the construction of Glen Canyon Dam and subsequent power plant operations, the introduction of exotic fishes, plants, and invertebrates.

Abiotic changes in the environment are thought by most researchers to be responsible for the present day status and condition of the native ichthyofauna. These changes -- which have resulted primarily from the operations of Glen Canyon Dam -- include reduced sediment transport, altered flow regimes, and reduced water temperatures. In addition, the altered flow regimes have lead to a change in channel morphology, including the loss and degradation of backwaters thought to be important nursery habitat.

Recently a contract has been awarded to develop an integrated state-of-the-science review and assessment of existing information on native and endangered fishes in Glen and Grand Canyons. The intent of this effort is to identify factors that limit reproduction, development, recruitment or survival of native fishes in the Little Colorado River and its associated tributaries in Glen and Grand Canyons. This activity should lead to the development of information critical to the development of a conceptual model linking abiotic and biotic components of the system, as well as to identify key parameters for long-term monitoring and related research activities.

The interim long-term monitoring plan will evaluate the status and trends of native fish populations in the Grand Canyon ecosystem and seek to collect data that can be used to assess the response of native and non-native fish communities to alternative operation of Glen Canyon Dam. These native fish species include: humpback chub (Gila cypha), razorback sucker (Zyrauchen texanus), flannelmouth sucker (Catostomus latipinnis), bluehead sucker (Catostomus discobolus), and speckled dace (Rhinichthys osculus). The plan will emphasize the endangered humpback chub and will seek to address concerns raised by the U.S. Fish and Wildlife Service in the Biological Opinion.

Data to be collected during this interim monitoring effort will include appropriate estimates of abundance, species composition, age structure, and reproductive condition. The sampling time frame should recognize the long- or short-lived nature of the species being monitored. Annual sampling should be conducted to coincide with appropriate seasonal activity and, if possible, correspond with sites selected for aquatic food base monitoring.

**Humpback Chub**

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. This population is concentrated in the mainstem Colorado River near the mouth of the Little

Colorado River (LCR), as well as in the lower 13 km of the LCR. The mouth of the LCR is 99 km downstream of Lees Ferry (RM 61.3), or 124 km below Glen Canyon Dam. Humpback chub are also found in low numbers in five locations downstream of the LCR reach, including upper Middle Granite Gorge (RM 127), Bright Angel Creek inflow (RM 87.7), Shinumo Creek inflow (RM 108.8), Havasu Creek inflow (RM 156.9), and Pumpkin Springs (RM 212.9).

**Other Native Species**

Flannelmouth suckers and bluehead suckers have apparently 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) in March and April. The adults spend up to two months in the tributaries during spawning, but relatively little is known of the larvae and young following hatching. Flannelmouth and bluehead suckers are found throughout the Grand Canyon, although large pre-spawning aggregations have been seen at the mouth of Kanab Creek.

The razorback sucker is very rare in Grand Canyon. It is thought that only a few old and senile adults remain in such low numbers that the species can be considered biological extinct 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 one may wish to consider monitoring the area from Diamond Creek to Pearce Ferry for presence of these fish.

Little is known about the speckled dace in Grand Canyon. The species is ubiquitous throughout the western US, but little is known of its status and trends in Grand Canyon.

Speckled dace are most common in riffles and rocky shorelines, but are also found in silt-substrate backwaters and shorelines.

**Possible Monitoring Objectives**

The hydrograph of the LCR should be monitored to examine the relationship between flow timing, magnitude, sediment load and strength of the year class. Maintenance of the LCR stream gauge may provide the data needed to examine the relationship linking river flow with reproductive success.

Young humpback chub are commonly found in backwaters and are thought to use them as nursery habitats if these habitats are warm, turbid, and sheltered from mainstream inundation or desiccation. Humpback chub do not use these habitats exclusively; they also use adjacent sheltered talus shorelines. Nevertheless, backwaters are usually permanent features that can be sampled as indices of year class strength, survival, and individual growth.

Survival of cohorts 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 of adult age (3 to 4 years) probably greatly enhances the chances for survival of individuals. Understanding the survival of cohorts (year classes) is important to monitoring in order to identify factors that may limit that survival, particularly if they are flow-related.

Monitoring the relative abundance of adult humpback chub provides an index of the long-term trend of the population. This trend is usually determined by biotic factors such as year class strength, food availability, and diseases and parasites; as well as abiotic factors such as water quality and habitat stability. Most factors that affect adult population size are not manifest for several years, and so assessment of year class strength, survival, etc., is important to understanding causative factors leading to long-term population trends.

Habitat quality, selection, and use by many species of native as well as non-native fish should be examined. Backwater habitats are thought to be particularly important as nursery areas for young native fishes, but are also used extensively by many non-native fishes. 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.

Similarly, shorelines with talus, tapeats ledges, or vegetation are frequently occupied by native fish since these offer shelter from predators, provide immediate sources of food, and protect the fish from the rigors of the mainstream. 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). Like backwaters, shoreline habitats can also be *monitored to determine the flow releases most suitable for maximum* habitat development.

Finally, 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 effects. Monitoring should be conducted to determine how alternative dam operating scenarios could effect non-native species and may prevent further intrusion by these fishes into the Grand Canyon ecosystem.

**Trout**

Trout were first introduced into spring-fed tributaries of the Colorado River in Grand Canyon during the early 1900s. 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 occurs but has been insufficient to sustain desired trout numbers.

The 25 km Lees Ferry reach below Glen Canyon Dam is managed as a blue-ribbon fishery with emphasis on production of trophy-sized trout. Although trout occur in the Colorado River and many of its tributaries throughout 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 affect trout found in the dam tailwater. Indirect effects involve ecosystem processes and lower trophic levels which provide the food base for the fish. Direct effects include stranding of all life stages in isolated pools, dewatering of spawning and rearing habitats, and displacement of individuals from preferred habitats. 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.

Monitoring of trout should concentrate on growth, survivorship, and changes in population structure, including the contribution from natural reproduction, over time. Emphasis should be placed on the trout population above Lees Ferry. Downstream sampling may be accomplished in conjunction with monitoring activities for native fish.

It has been recommended that the minimum frequency of sampling for trout should be twice yearly in the fall and spring. Unusual flow events may suggest additional sampling periods. Creel data and regular surveying of fish guides may be used to supplement trout monitoring data gathered above Lees Ferry.

**Riparian Vegetation**

The riparian vegetation communities along the Colorado River and its tributaries are important for stream bank stability, fish and wildlife habitat, and aesthetic and recreational values. Those along the mainstem of the Colorado River are composed of three nearly distinct communities, the old high water zone (OHWZ) and the new high water zone (NHWZ) riparian communities, and the near shoreline wetland communities. For long-term monitoring purposes, all three of these community types should be included; however, because of the different response rates of these communities to changes in the river dynamics, monitoring procedures (especially timing) should differ.

Management of species responding to strong environmental signals will be enhanced by improving the understanding of the physical or biological factors forcing biological changes, so that options can be explored for implementing adaptive management strategies.

The National Park Service (NPS) has established permanent quadrats along the mainstem and in perennial and ephemeral tributaries for the purpose of evaluating long-term responses of the riparian and wetland communities to natural and anthropogenic influences in the Grand Canyon. Twenty four sets of these quadrats (5m x 10m with each subdivided into eight sub-plots) are distributed throughout Schmidt and Graf's (1990) geomorphic reach designations between Paria and Diamond, and stage-to-discharge relationships are being developed for each study area. The geomorphic settings examined at each study area include: (1) marsh (<550 m3/sec stage elevation), (2) low bar (550 to 850 m3/sec stage), (3) general beach (850 to 1,300 m3/sec stage), (4) channel margin (850 to 1,300 m3/sec stage), (5) debris fan (ca. 1,400 m3/sec stage), (6) old high water zone (2,800 to 7,000 m3/sec stage) and (7) xeric zone (>7,000 m3/sec stage). Tributary quadrats have been located in comparable channel margin, debris flow terrace and xeric settings.

Monitoring of these quadrats should be in three time frames. Marsh and low bar settings should be sampled twice a year for the first five years and annually thereafter, except when there are unusual hydrological events, and then immediately after and then twice a year again for three years. General beach, channel margin and debris fan settings should be sampled once a year, while OHWZ and xeric settings should be sampled every five years. The equivalent settings along tributaries should follow the same sampling schedule.

Annual video photography (or perhaps aerial photography) of the Grand Canyon has been suggested for mapping riparian vegetation in the GIS reaches established by the GCES program (subject to appropriate scientific review) in order to quantify changes in cover area. This is proposed to be linked with equivalent monitoring of sediment (and beach) changes.

**Riparian Fauna**

Riparian faunal habitat relations have not been well established in the Grand Canyon. Determination of faunal response to dam operations is extremely difficult and is dependent on knowing faunal response to changing ambient conditions. Thus monitoring of faunal assemblages should be aligned to sampling of riparian vegetation habitat changes.

**Invertebrates**

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 far from complete, with numerous undescribed endemic taxa still likely to be discovered.

Monitoring of selected key taxa would permit evaluation of changes that may be a response to dam operations. Inventorying of the invertebrate fauna should continue along with other inventory programs of the NPS, but an extensive and intensive monitoring program of invertebrates as part of the long-term monitoring program probably won't allow an estimation of invertebrate response to variations in river flows. As part of a long-term research program, it is essential to establish the invertebrate assemblages (e.g., using selected taxa) that are associated with different riverine and shoreline vegetational communities. In this way, long-term monitoring of these vegetation communities can be used as a surrogate for determining response of invertebrates to operational changes in the Grand Canyon.

**Vertebrates**

Terrestrial riparian vertebrate populations in the Colorado River corridor in Grand Canyon are trophically significant secondary consumers, integrating habitat conditions to invertebrate and other primary consumer populations. The Colorado River corridor supports high densities of terrestrial/riparian vertebrates and populations of many species are changing. More than a dozen native vertebrate taxa have recently been lost, or are of unknown status in this system, and several native and non-native species populations have increased in recent years. Terrestrial vertebrates are relatively easily monitored, exert significant trophic influences on ecosystem structure, and are recognized as priority resources by the NPS. Avifauna are especially conspicuous and are trophically significant secondary consumers, integrating habitat structure, food resource production and predator populations. The Grand Canyon serves as an important flyway and stopover location for migratory waterfowl, raptors and passerine species; however, monitoring has been inconsistent. Several avian species are federally listed as rare and endangered, or are considered for listing, including bald eagle peregrine flacon and willow flycatcher. Therefore, vertebrate species deserve monitoring attention.

The intensity of effort required for vertebrate (herpetofauna, mammals and birds) population sampling precludes sampling at all long-term vegetation study areas and requires a focus on the habitat relations of selected assemblages of vertebrates, especially herpetofauna and birds.

Monitoring of these vertebrates will require large study sites at which full descriptions of vegetation, soils and topography must be determined. Spot sampling at other locations might also be required to expand the monitoring data base.

Most herpetofaunal species in this system are so rare that they require baseline inventory level study; however, ecological stability conferred by construction of Glen Canyon Dam probably permitted two amphibian and four lizard populations to increase. These species can be used to monitor population dynamics and establish trophic interactions.

Most mammal species in this system are nocturnal and require baseline population study. The ecological stability conferred by construction of Glen Canyon Dam permitted habitat conditions to improve for some species, but population dynamics remain largely unstudied. Mammal species can be used to monitor trophic dynamics, response to human use levels and interactions with other herbivores.

For herpetofauna, mammals, and birds a seasonal sampling schedule (3x/year for first 5 years) and following exceptional flows at large and small sites recommended by Stevens (1992) will help establish the baseline needed for evaluation of population changes over time.

For herpetofauna, sex, age class and density, air and soil temperature should be recorded on 10m X 100m transects in the xeric zone, NHWZ and OHWZ. Spot observations can be used to document distributional data during routine travel between study sites.

For mammals, species, sex reproductive and body condition, body mass, and site conditions be recorded on all trapping runs. Determination of home range size and population dynamics should be made using standard toe-clipping and/or ink-dying methods to detect retrapped animals. Analyses should include species composition, biomass considerations, habitat preference and population dynamics components.

Scat and spot observations can be used to document distributional data for larger mammals during routine travel between study sites. Beaver dens and activity should be tabulated by reach at low water, and should be monitored annually. Desert bighorn sheep and mule deer presence and habitat use patterns should also be recorded. Additional mammal studies may be required for large/rare predators, such as bobcat, mountain lion and coyote.

Birds

Avifauna inventory and monitoring should emphasize listed species (e.g., bald eagle, southwestern willow flycatcher, peregrine falcon), wintering and breeding waterfowl, riparian obligate species, resident non-obligate species, and migrant species in a biogeographic/ geomorphic/seasonal context. New, dam-created riparian habitats (e.g., tamarisk stands and marshes) are being colonized for nesting, while the status of avian use in the relictual old high water zone is unknown.

Common taxa can be readily monitored on plots, while waterfowl, shorebirds, migrating raptors and wading species can be monitored while floating through the river corridor. These data, in concert with regional populational data, will permit systematic evaluation of changing populations sizes.

Migrant and breeding avifauna are proposed to be monitored during up to seven river trips per year (February, April, May, June, August, October and December). Location of birds (and nests) observed along the river should be mapped on the GIS system within the Schmidt and Graf canyon reach determination, while intensive sampling should occur at the large sample sites. Nest locations should be mapped and habitat described.

Wintering bald eagle and spawning trout population should be monitored using the techniques suggested by Brown and Stevens (1991). April, May and June research trips should be used to locate willow flycatcher pairs and active nest sites. Additional July trips may be required as nesting is reported to continue through that month. If nests are located, an observation team should be established to monitor nesting success. This team may also be responsible for reduction of brown-headed cowbird populations by mist-netting if that management action is deemed necessary.

## THE CULTURAL RESOURCES PROGRAM

**Introduction**

The cultural resource program is charged with designing and implementing monitoring and research activities that assess cultural resource impacts related to dam operations. Once these impacts are identified and understood, the GCMRC is required to provide this information to the AMG to assist them in formulating their recommendations.

Based on the GCMRC's authority and responsibility to obtain information, the 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 part of the larger cultural resource program that includes tribal participation in resource assessments and research, data management and information dissemination.

The cultural resource program activities integrate well with other agency responsibilities to assess resource impacts, although the purposes for the assessments are different. The NPS and the BOR have specific responsibilities to ensure the protection of cultural resources within the 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, the Archaeological Resources Protection Act 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 of the water releases associated with dam operations. The NPS responsibilities include the management and administration of Historic Properties through cultural resources 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 specifys the compliance process for these agencies relative to 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 PA represents a landmark process involving closely coordinated activities among eight tribal nations, the NPS and the BOR.

As stated in the GCEIS [pg 36], the cultural resource activities of the GCMRC will be conducted in accordance with the PA stipulations to ensure integration and compatibility between the PA program and the GCMRC's long-term monitoring and research program. These activities will serve dual purposes in that the GCMRC's programs and projects will provide information necessary for the GCMRC's larger cultural resource program and its reports to the AMG and these activities will provide valuable information for the NPS and BOR to incorporate within their management and legal responsibilities.

Projects and activities included within the GCMRC's cultural program will be funded through its funding allocations from power revenues from Western Area Power Authority subject to budgetary recommendations by the AMG and approval by the Secretary. Program activities will be formulated at the GCMRC based on stakeholder objectives and the information needs that wree developed in consultation with the members of the AMWG. The tribal, bureau, and NPS PA signatories are members of the AMWG. As members of the AMWG they should discuss and prepare recommendations to the GCMRC for needed projects that are consistent witht he identified objectives and information needs. These projects may coincide with PA activities, but they need to be formulated as activities that are channelled through the AMWG. These projects will be reviewed by the Cultural Program Manager who will act as a liaison in conveying program information from the GCMRC and assisting in recommendations to the GCMRC. Consequently, to the extent that the required PA activities coincide with the activities of the cultural program of the GCMRC, they may be fundable by the GCMRC, subject to 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. The GCMRC strongly encourages the cultural subgroup of the AMWG to work collaboratively with GCMRC staff in project development relative to the cultural program. It is the intention of the GCMRC to administer all of its programs in the general spirit of the process utilized to develop the PA.

The cultural resources program will also integrate with the other GCMRC programs. The Program Manager will function as a liaison with the other programs to assess project proposals that may have cultural content. Because the GCMRC definition of cultural resources includes biological and physical elements of traditional cultural importance to the tribes, the Program Manager will serve as an initial reviewer for proposals that may have sensitive content. If these are identified, the proposals will be referred to the appropriate parties for assessment. The Program Manager will work to coordinate this review and work with all parties to facilitate project evaluation. In this sense, the Program Manager will serve both liaison and coordination roles.

**Program Description**

The cultural resource program consists of three primary components that include 1) a core program, 2) a tribal projects element and, 3) a cooperative programming aspect (Figure 6.6). The program manager is responsible for the implementation of these elements to the Center's chief.

A) Core Program. The Core Program represents the largest program area.. The core program consists of monitoring and research activities designed to address the stakeholder objectives and information needs identified through discussions with the AMWG. The proposed activities represent investigative strategies to address monitoring and research issues that derive from the stakeholder objectives. These activities build on information from monitoring and research activities related to past archaeological inventories as well as tribal monitoring programs. Examples of existing sources of information include, site recordation using mapping techniques and photography, and remedial actions such as stabilization

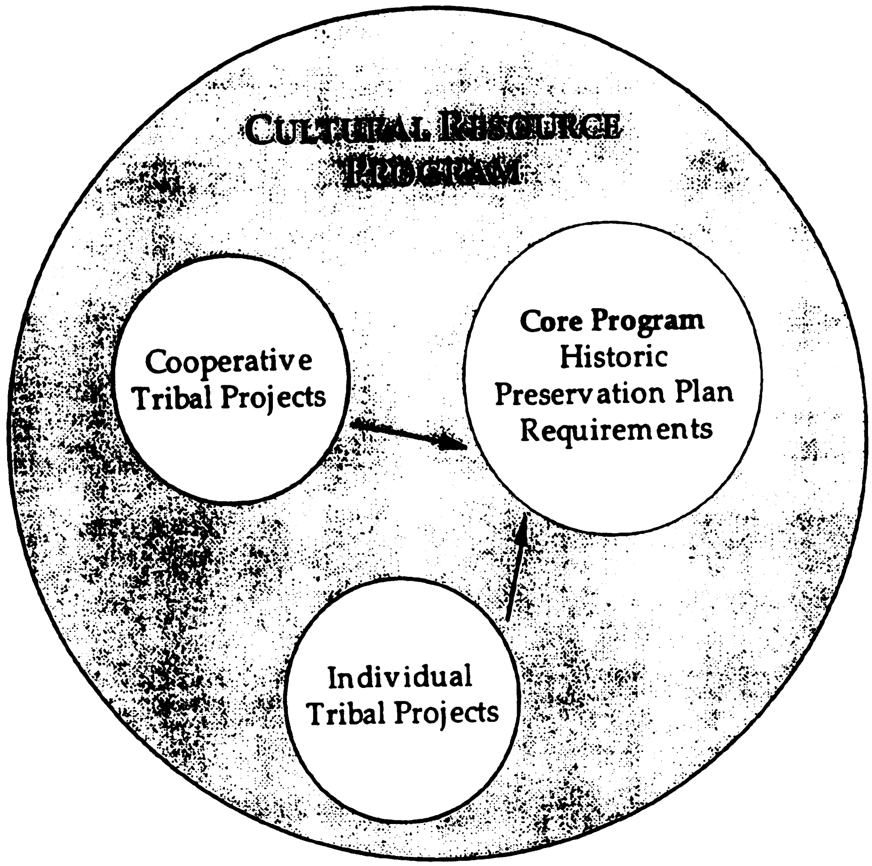


Figure 6.6. Primary Components of the Cultural Resources Program.

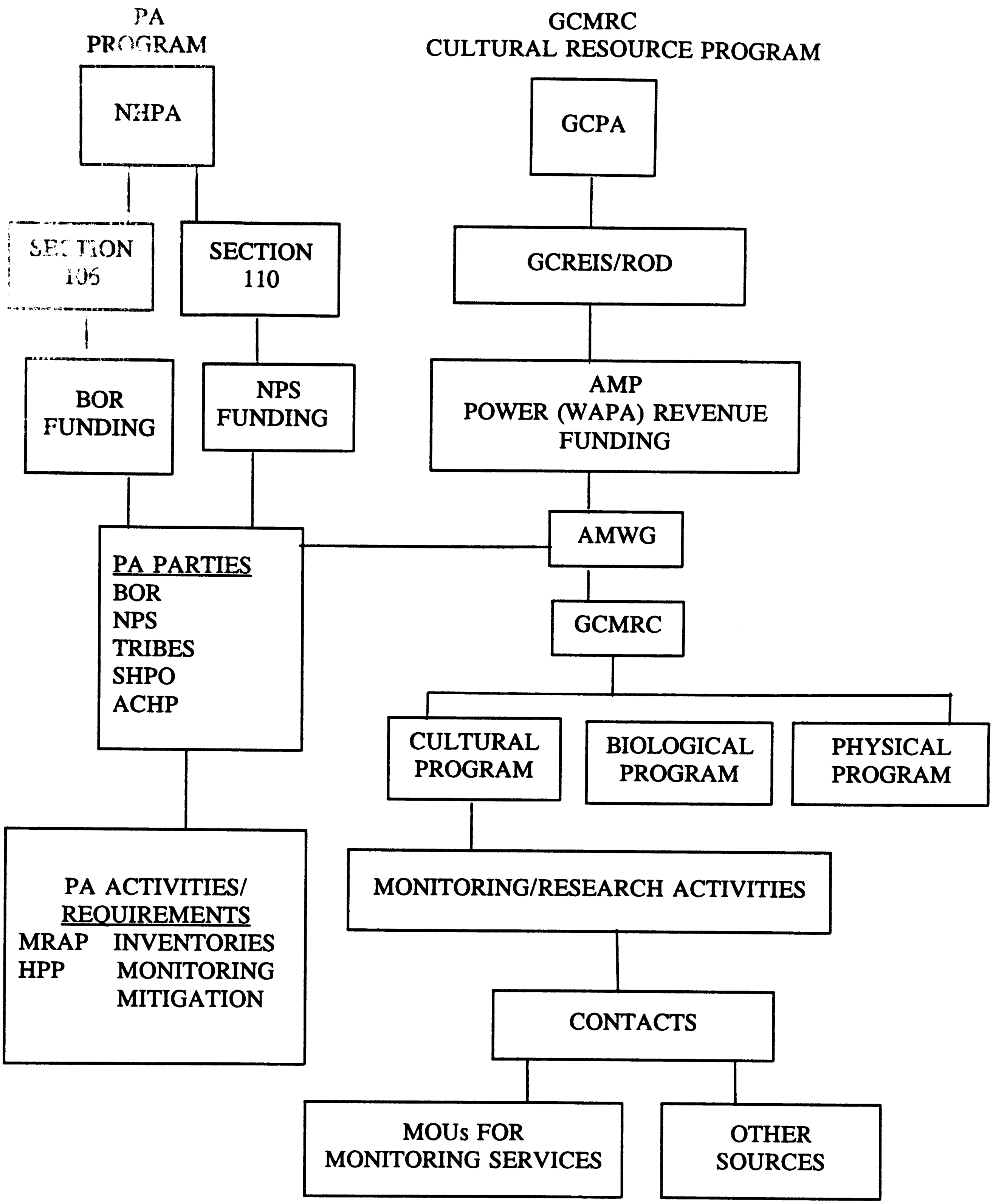


Figure 6.7. Program Tracking

techniques. Data generated from the proposed activities will be used to formulate future annual plans as well as modification to the long-term plan.shall be incorporated into the long term monitoring plans.

Research measures may need to be formulated when monitoring activities have detected impacts to resources that are thought to be related to dam operations. These activities may include the full range of investigative strategies including testing, sampling, and full data recovery. Monitoring and research activities will be developed in consultation with the cultural resource component of the AMWG.

New resources may be encountered during activities conducted under this program.These resources must be characterized when they are encountered and some research studies may be necessary to determine their important qualities that may be impacted by dam operations. The Native American tribes will be involved in these efforts. These research studies, although less extensive than the monitoring program, are an important part of the program.

The second part of the Core Program is implemented by tribal members of the AMWG. Tribal groups shall design and implement their monitoring programs to evaluate the condition of their traditional cultural places and resources within the riverine corridor based on dam operations. These programs will conform to the long-term and annual plans developed by the GCMRC.. Because the values associated with these places are known and understood by tribal individuals, the GCMRC recognizes that Native Americans are the most appropriate authorities to formulate programs that address their concerns about dam related impacts to these resources. Because of the sensitive nature of these places, information about the sites may be restricted both within and outside the Native American tribe. As such, these portions of the monitoring program and the information related to these monitoring and research projects with these segments are known only by the tribal nations, and in some cases only specific members within the group. Specific procedures will be developed between the tribes and the GCMRC where information about resource significance and locations can be protected.

The on-going monitoring and research efforts and the tribal activities associated with assessments of traditional cultural places may coincide with the NPS and BOR's requirements under the PA to address resource impacts from dam operations. Information derived from these activities will assist the GCMRC in meeting its requirements to provide the AMG with information to formulate recommendations to the Secretary. These activities may also provide assistance to the NPS and the BOR in meeting their legal responsibilities.

The core program will be managed by the GCMRC Program Manager. Based on identified stakeholder objectives and information needs, annual work plans will be developed by the GCMRC. These work plans will be tranformed into work contracts. The project proposal responses will be assessed for monitoring and research activities will be conducted by a team. The team will include representatives from the AMWG and the cultural resource program manager. Team evaluations will be forwarded to the Program Manager and the Chief where final approvals will be made. A team approach is critical to the continued development and enhancement of this core program. The leadership and knowledge represented by individuals in the tribal nations, NPS and the BOR is vital to the success of this aspect of the program. This mechanism will provide a collaborative approach for assessments of proposed actions under this program. Due to the GCMRC's funding allocations and the associated authorized technical reporting (ATR) responsibilities, the GCMRC must take final responsibility for proposal review and approval. However, proposal review and approval will involve full participation and input of team members.

B) Individual Tribal Programs. A second major element of the cultural program includes individual tribal programs that may enhance monitoring and research activities. Opportunities exist for the tribes to enhance and enrich their monitoring and research programs through projects that focus on additional monitoring technologies, indirect impacts to resources, or alternative investigative paradigms. Some examples of monitoring technologies include GIS mapping projects and locational studies, historical documentation and research, and traditional histories. Studies of resources that may be indirectly impacted may be included in this portion of the cultural program. For example, resources that are impacted by dam operations may have unknown contextual relations with other nearby sites and/or resources that are not directly impacted by dam operations. Studies of the context of the resource that is suffering degradation may include other resources that are believed to be related but indirectly impacted. These more comprehensive studies will contribute to the full understanding of the significance of the impacted resource.

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.

Although this element of the cultural program may be less prominent in the total program, it is considered an important part of the overall cultural program. In addition, this element helps to implement an important goal of the cultural program; that participating tribal groups are full partners in the development and implementation of strategies to assess, evaluate, and protect cultural resources in the river corridor.

C) Cooperative Programming. Although the core program incorporates cooperative planning and programming for monitoring activities, most of the elements of the monitoring and research programs are individualized to specific tribes. This is also true of project proposals initiated by tribal groups to enhance their individual monitoring and research projects.

There are potential areas of interest to the tribes wherein the community of tribes may have common interests in both developing and participating in research planning and programming. These efforts could enhance monitoring and research capabilities, as well as, provide additional information regarding tribal associations with the Glen Canyon National Recreational Area and Grand Canyon National Park areas.

One example of an potential area of common programming 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 resources subject to monitoring and science activity in the canyon.

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.

In conclusion, the 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 issues, such as education opportunities and public outreach. Following the ecosystem paradigm, the cultural program maintains an integrative and inclusive definition of cultural resources as defined by tribal participants in the adaptive management program. As such, the cultural 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.

The cultural resource Program Manager has an additional responsibility that requires increased cooperation with the Chief and other Program Managers. The cultural resource program has a requirement to function 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 the physical and biological Program Managers and the Chief. 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.

**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 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 GCEIS 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. 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 Navajo Nation, the Hopi Tribe, the Hualapai Tribe, the Southern San Juan 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. 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 traditional cultural resources.

Current monitoring procedures include site visits, photographs, study units to observe artifact movement, 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 run off 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.

Recommendations from monitoring efforts include changes in monitoring scheduling, site or feature testing, surface collection of artifacts from sites for analysis and curation purposes, development of defined trails and obliteration of others, site patrols, and measures to educate the public.

**PROPOSED MONITORING AND RESEARCH ACTIVITIES**

The past work provides a knowledge base to formulate a long-term monitoring and research plan that addresses the AMG 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) Preserve *in situ* all the downstream cultural resources and take into account Native American cultural resource concerns in Glen and Grand Canyons.

2) If *in situ* preservation 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 provide physical access to and use of traditional cultural properties and other cultural resources used for religious purposes, by the participating Native American Tribes and traditional practitioners.

4) Develop, maintain, and integrate available cultural resources data recovered from monitoring, remedial and mitigative actions into evolving research designs for understanding human use and occupation in the canyon.

The above objectives were developed in consultation with a technical subgroup of the AMG composed of individuals with cultural 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 to assess risk of damage and loss from varying flow regimes, 3) develop tribal monitoring programs for the 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 for sites with documented impacts from dam operations, 6) characterize resource values through directed study.

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

<u>1) Develop data and monitoring systems to assess impacts</u>.

Monitoring data has been collected on cultural resources by the NPS and the tribal groups for approximately four years. In part, this information has been partitioned into areas where different entities have jurisdiction. The existing information needs to be complied into the GCMRC's study area and synthesized. Baseline information needs to be reviewed to ensure that data exist for all sites having the potential of being impacted by dam operations. The existing monitoring data need to be synthesized and evaluated against baseline information. Some of the possible elements of the data organization include site location and physical context, site types (structures, features, scatters, prehistoric, historic, Traditional Cultural Properties (TCPs)), rock art sites, monitoring frequency, monitoring techniques, monitoring history, etc.

In addition, data on Isolated Occurrences (IOs) need to be included in this synthesis. IOs may represent the last remains of site materials, or they may constitute the first exposures of buried sites. All of these data on sites and IOs should be summarized in qualitative and quantitative formats to provide basic information on the resource base.

Following data synthesis, the data base must be evaluated relative to the classes of impacts identified in the monitoring assessments. At present, the major categories of impacts appear to be physical (with several sub categories) and visitor-related impacts as previously defined. Resources need to be evaluated to determine if they are experiencing impacts. If so, they need to be assigned to impact classes using information to date. Based on these initial assignments, a determination must be made if the existing data base is adequate to conduct analysis of probable site impacts. If the data appear adequate, resources should be assigned to the appropriate class. If not, it is necessary to determine what additional information may be necessary. Explicit criteria to be used in site monitoring must be developed to provide additional data and/or the basic information for future research endeavors.

<u>2) Develop data to assess risk of damage and loss from varying flow regimes</u>

Once resources experiencing impacts have been identified and they have been assigned to an impact class, a determination needs to be made if these impacts are related to dam operations. For example, resources may experience erosion that is related to river flows while other resources experience similar erosional patterns that are not associated with river flows.

In order to make assessments, additional information may be necessary. Information may be obtained from additional monitoring observations that are designed to inform on specific questions to determine if impacts are related to dam operations. Schedule for monitoring cultural sites would be dependent on the baseline condition of the site and severity of impacts and ambiguity of determining if resource impacts result from dam operations. At this point, determinations of impacts related to dam operations may be sufficient, and the relationship between operations and impacts will be addressed through research activities.

Additional sources of information to determine possible source of impacts include modeling flow regimes at various stages and mapping the model results in combination with resource locations and other descriptive parameters. This information would help in determining the likelihood of resource inundations at particular stages.

3) Develop tribal monitoring programs for the evaluation of impacts to cultural resources.

Tribal programs to monitor and assess cultural resources are an important component of resource assessments. These programs supply different but complementary information on resource impacts. Resources may embody a full range of important qualities. These may include data concerning past occupations as well as tribal histories for descendants of the prehistoric occupants. While archaeological monitors can evaluate the physical impactst of data loss on resources, others may view the resource impacts in other ways. Because of these varying perspectives on resource qualities, resource impacts are viewed differently. These impacts may be related to integrity of the resource, information loss of the resource, and vandalization. For 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 assessments and it helps to provide assessments on the full range of important qualities of the resource. The ongoing tribal monitoring programs continue to assess resources for impacts that result from dam operations. In addition, consultation with these groups provides information that is important for additional monitoring and research activities that investigate dam related impacts to other resource qualities. It is recommended that tribes should develop and implement field visits to monitor resources. Monitoring activities should be structured so that they inform tribal values and concerns as well as monitoring and research activities included in the GCMRC cultural program. Also, resource locations and areas of possible impacts from flooding, research activities need to be mapped. These maps will assist in consultation with the tribes and for their monitoring activities. Together, these activities would be an integral part of the long-term monitoring program supported by the GCMRC.

4) Develop a predictive model of geomorphic processes that are related to archaeological site erosion.

The existing work on geomorphic process and archaeological site erosion (Hereford et al. 1991) needs to be assessed for the status of knowledge relative to site impacts resulting from dam operations. This assessment should evaluate the baseline and monitoring data base developed above against the information available in current models. In addition, sediments recently deposited from the beach/habitat building flow need to be mapped and compared to past deposits and resource locations. This information should provide a basis to determine the possible extent of resources that may be impacted by these large flood episodes. Together, this information should provide data to formulate hypotheses to test the geomorphic model for predictive benefits to both locate additional sites and develop site mitigation strategies to conserve resources.

All of the assessments and activities suggested above provide basic data for describing the existing data on 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.

<u>5) Develop mitigation strategies related to documented dam impacts to sites by monitoring assessments,</u> and <u>6) Characterize resource values through scientific study</u>

Monitoring activities can indicate that change in resource conditions is occurring. The research activities are formulated to explain the sources of that change. It is proposed that research activities be initiated to determine relationships between resource impacts and dam operations when these are suggested from monitoring observations. 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. Resource significance includes scientific value such as the ability of the resource to inform on others (site redundancy) or as a unique resource. Traditional values are also a component of resource significance. These values will depend on the resource and the tribal group that identifies the importance of the resource. In this area, tribal participation in providing monitoring information, devising treatment options, evaluating proposed activities, and conducting appropriate field activities is critical. Data recovery will be structured to answer research questions related to the source of resource impacts. To the maximum extent feasible these activities will be compatible with the research domains listed within the Historic Preservation Plan and developed under the PA programs and new domains yet to be discovered, as these organize inquiry and inform on past human use and occupancy of the river corridor.

Without the benefit of results of the above monitoring assessments, 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 preliminary information that is currently available.

Following the above 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 recreationists via beaches and trails.

In the area of physical impacts to resources, possible research questions include investigations to determine the relationship between bank slumpage and lateral 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.

**PROGRAM IMPLEMENTATION**

The methods for implementing activities included in the cultural program will follow the established protocols for the GCMRC's work that have been discussed elsewhere. The general process of the GCMRC includes the participatory approach developed within the framework of the AMP, and this approach will be emphasized within this program. The specific methods employed within this program will emphasize collaboratory efforts and Native American involvement. The three program elements (core program, tribal projects, and cooperative programming) emphasize Native American involvement and this will be reflected in the ways in which the program activities are implemented.

A methods criteria will be developed with a team of agency cultural representatives and tribal participants (the team). These criteria will include evaluations based on relatedness to AMG objectives, degree of tribal involvement at various project levels, cost considerations, work priority within the cultural program, and the ability of the information to relate to other GCMRC programs. The team will assist in the review and recommendations of proposals that are proposed within the cultural program. Because Native Americans often view other resources (e.g., plants, fishes, landforms) as traditionally cultural, proposals from other GCMRC programs will be screened by the program manager to determine if there may be cultural content. Proposals with cultural content will be referred to team members for comment. Specific methods and approaches for proposed projects will not be specified within the methods criteria, but will be defined within the competitive process.

## SUMMARY

The monitoring and research activities proposed in this plan are general, given the available data at this time. It is anticipated that this plan will undergo substantial revision as information is assessed and evaluated and there is collaborative participation in defining program objectives.

The program can be summarized to include three elements. These include: 1) the core program that emphasizes the monitoring and research activities necessary to address the objectives and information needs identified with the AMWG; 2) individual tribal projects; 3) and cooperative programming. The 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 cultural 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. Cooperative programming involves 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.

The monitoring and research proposals included within this plan are formulated in a step-wise fashion. First, the existing data must be synthesized. Following this the data base will be evaluated relative to impacts to resources. Geomorphic information, resource mapping, and flow regime modeling will be prepared and analyzed to provide additional descriptive data. Data retrieval may be proposed following a complete assessment of the status of the resources and impacts to address research questions. Specific details will be developed after data assessment and in consultation with the cultural program team.

There are several issues that can and will amend this preliminary 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 cultural program. However, the method of program implementation will not change. The program will continue to function in a collaborative and participatory manner.

## THE SOCIO-ECONOMIC RESOURCES PROGRAM

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, and all of the resources in the Canyon are considered to be significant to the public.

**Recreation** use of the Grand Canyon is of economic and environmental importance. As a major public use within the Canyon, recreation creates jobs and financial support within the region, but also is a significant component of impact analysis. The preferred alternative in the EIS has considered impacts on recreation and has attempted to enhance the recreational experience in the Canyon and increase safety. Also of importance are the possible impacts of recreation on Canyon resources. The objectives of the long-term monitoring and research program, therefore, are to determine whether recreation is enhanced and safety improved over impacts resulting from historical dam operations, and whether changes in recreational patterns resulting from the selected dam operational alternative have any effect on the Canyon's downstream resources.

To determine whether dam operations are affecting the pattern and amount of use in the Canyon, data on use and changes resulting from recreation would be compiled on two year intervals. 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 qualities, 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 uses. Data for whitewater 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, birdwatching, 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. Survey results would be summarized and evaluated every two years.

Beach area data would be monitored using aerial video- or photography at the same discharge levels every other year. Changes in beach camping area, above 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.

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. This information would be gathered via user surveys of appropriate groups. Value evaluation is separate from values determined using non-use value methodologies. The former deals directly with use and experiences in the Canyon while the latter are based on no direct contact with the Canyon.

**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 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 tied to 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.

**Water resource** has associated value with both its quantity and quality. It is in the best interest of water marketers to hold quantities of water from the market to realize maximum returns. 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. Although operating criteria can effect water quality and therefore realized values, it is less likely to impact water quality.

A comprehensive assessment of both market and non-market costs and values was conducted in Phase II of 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 or 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 this system should be in year four or five of the first 5 year plan, and year one and two of the second 5 year plan.

## INFORMATION TECHNOLOGIES

Extensive data and information currently exists in the GCMRC relating to resource levels, quality, relationship to other resources, etc. Further, potentially equal amounts of data and information exist within museums, universities, agencies, etc. This information represents a valuable resource to researchers, managers and interested stakeholders. Its potential utility for problem solving, formulating improved management guidelines, modeling relationships, or increasing understanding of the various resources and system under study, justify an aggressive program in information technologies.

Prior to conducting the extensive synthesis of these data and information, planning is required to properly enter the information into a computerized Database Management System (DBMS) and Geographical Information System (GIS). Software systems utilized need to have the following general capabilities.

- Accommodate large relational databases.
    - Be time and cost efficient and maintained through R&D programs.
    - Be compatible with software utilized by stakeholders and scientist groups.
- Be user friendly.

__Protocols for Data Collection, Processing and Use__. Each component of the long-term monitoring and research program must have an explicit, detailed protocol which spells out: 1) objectives; 2) experimental design; 3) procedures for data collection, QA/QC, data analysis, data storage, and reporting. This allows anyone to replicate measurements and to evaluate them in a consistent statistical manner. Where appropriate, each experimental design will be evaluated for statistical integrity. The protocol for each component will specify the level of knowledge and training required for those collecting field data, analyzing samples, entering data, and interpreting the data. There will be a comparable protocol for managing the database.

Scientists collecting the data will be involved with data interpretation. Although the time frame of the GCMRC program extends well beyond the participation period of any one scientist, it is anticipated that those who collect the data will be familiar with Grand Canyon data management protocols and may use the data as part of ongoing research programs. This connection of data collection and interpretation will result in data being collected appropriately and efficiently.

Releasing and sharing data must be a requirement for every project. Those collecting original information, however, should be allowed a reasonable time for analysis and publication before releasing the data to the public. Trust must be established among data collectors and managers to ensure transfer and integration of information. Each monitoring and research project will prepare an annual report using a consistent and defined format, including reports from data base managers.

**Database Management**. A general principle is that all data will be freely available. However, in some cases, such as archaeological-site data, data that Indian Tribes define as sensitive, or information on localized endangered species, a level of confidentiality will be necessary. Explicit protocols will be developed to ensure confidentiality.

A centralized, integrated database is necessary to avoid duplication of effort and facilitate exchanges of information among projects. This includes incorporation of information from past monitoring, inventories and research. Each file in the database must be cross-referenced to files which document data-collection procedures, variability, and uncertainties. All data would be copied and stored in at least two locations to maximize security.

**GIS and Remote Sensing**. The use of Geographic Information Systems (GIS) for data storage is an important component of the data management process; however, not all data can be put into GIS format. GIS can be an important analytical tool for integrating and comparing spatially based data, but the applicability of this technique will depend upon the particular objectives of each monitoring project. Each project will specify which GIS data layers are required.

The validity of the existing GIS reaches in the Canyon will be tested for representativeness or designation as critical reaches. Usefulness of these reaches for the GCMRC program will be evaluated once the objectives and priorities for long-term monitoring are established. The use of satellite and remote sensing (e.g., aerial video- and photography) data will also be evaluated relative to the level of detail needed for each monitoring project (satellite data will probably be too coarse for use in many area of monitoring in the Canyon).

**Increasing Stakeholder Direct Access to Data and Information**. The hardware and software systems of GCMRC, and the analysts operating these systems are necessary for two primary information technology thrusts planned by the GCMRC. These are:

1. Develop and implement programs for direct access and use of GCMRC data and information.
2. Develop and implement an outreach program for stakeholders and analysts to maximize utilization of developed science information.

Developing direct access to GCMRC databases can be accommodated in several ways, and all methods, as appropriate, will be used. Opportunities exist to utilize the Internet in information dissemination. In like manner, interested parties can enter program files directly, assuming electives are established. Some access will of course be limited, including unpublished data, the location of endangered species and cultural resource information. Protocols will be established to assure that only authorized access is permitted.

**Developed Outreach Programs**. To also accommodate greater use of GCMRC information will involve significant interaction between GCMRC information technologists and stakeholders. Several programs are planned to insure increased use of GCMRC information as follows.

1. Development of workshops to minimize difficulties in using important GIS software.
2. Involvement of stakeholders and scientists in conceptual modeling workshops to increase knowledge of resource information systems.
3. Training of stakeholders and scientists in use of software such as ARC-VIEW and SAS to enhance utility of archived data.

# CHAPTER 7

# SCHEDULE AND BUDGET

## SCHEDULE

The strategic plan outlined in this document addresses monitoring and research for a five year period: Fiscal Year 1998 - 2002, i.e., October 1997 - October 2002. Each year, in May, an annual operating 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.

This strategic plan is designed to guide specified monitoring and research in the Grand Canyon National Park and Glen Canyon National Recreational Area through three fundamental science phases.

1) Synthesis of existing knowledge and determination of key factors affecting differing resources and their related change.

2) Definition of integrated impacts of key factors within a resource set and across all resources (ecosystems).

3) Development of decision support guidelines and models to assist managers and interested stakeholders to better understand resource interactions, impacts of dam operations on resources, and procedures for mitigating impacts.

Figure 7.1 graphically provides general targets for the scheduled completion of the three phases of the five year Strategic Plan.

**Phase 1** is critical in realizing two major outcomes. First, a conceptual model of the riverine system is needed to define most critical intra and inter resource linkages and interactions. Development of this conceptual system model will rely on existing knowledge of current and past science investigators, using a quasi-delphi process and simulation modeling exercises after Hollings (1978), and Walters (1986). Development of the conceptual model will occur in the first year of Phase 1.

Second, extensive data and science have been completed on Grand Canyon resource change since dam construction. A complete synthesis of these data and studies will be completed in years one and two. Included in these assessments will be a synthesis of all past research on Lake Powell, especially data collected from 1989-1996, to determine if operating criteria under the ROD are likely to effect physical, chemical, or biological resources in Lake Powell.

In addition to the above synthesis, there will be a more limited assessment of research and data on Grand Canyon resources prior to dam construction. These syntheses of baseline conditions are critical in understanding resource impacts due to current dam operations.

The primary goal of all the above syntheses will be to identify key driving resource variables or attributes associated with change in individual resources that are directly related to dam operations. Where possible, linkages of key driving attributes across resources will also be determined.

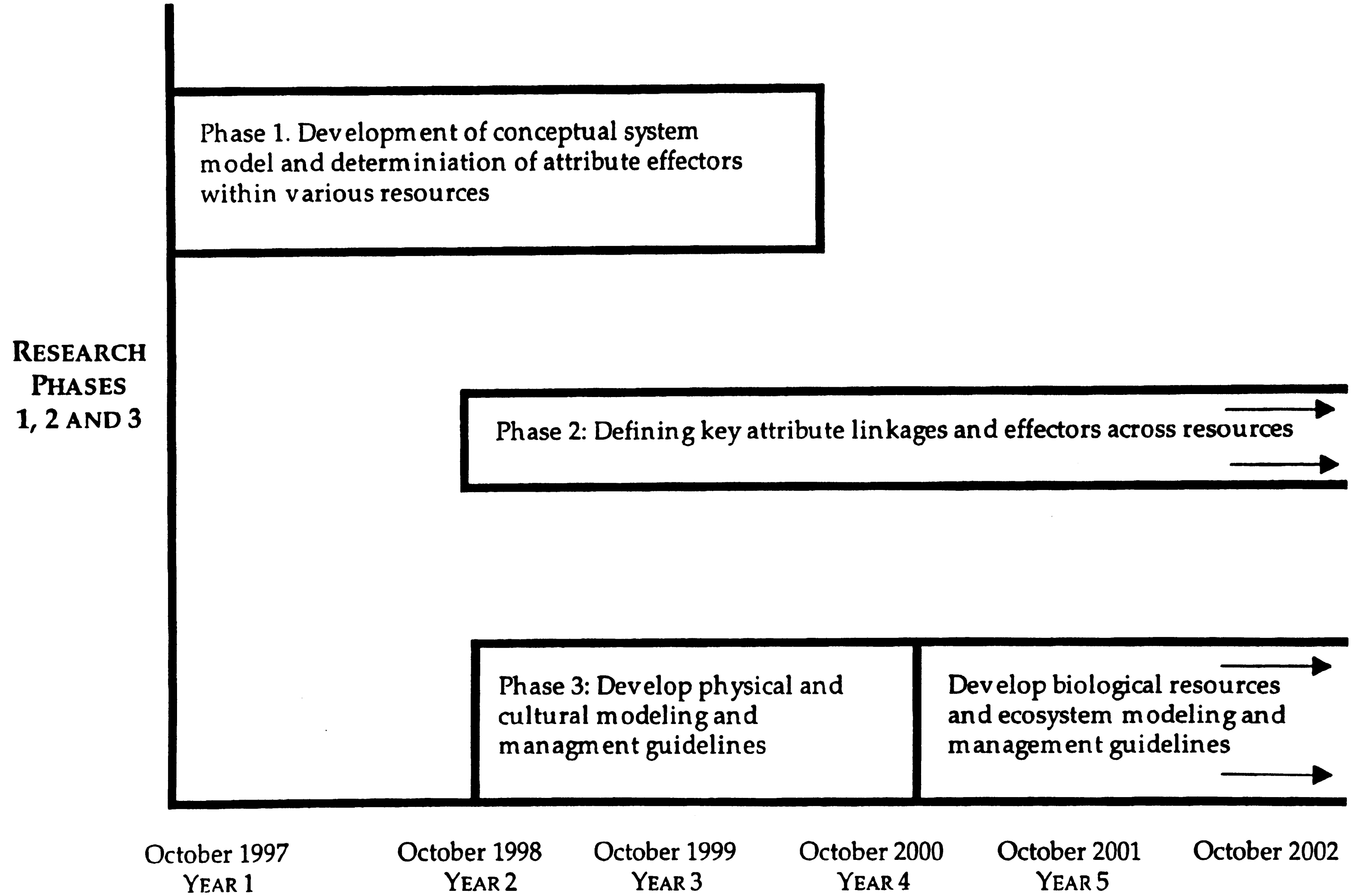


Figure 7.1 Timelines for completion of major phase years in Strategic Plan

This Strategic Plan, which is based on best available knowledge, can be greatly improved over the next two years as information is gleaned from these synthesis analysis. An intensive review of the Strategic Plan will be conducted after Phase 1 is completed to enhance the plan.

**Phase 2** will be used to monitor driving attributes determined for individual resources, but will be primarily focused on defining driving attributes that operate across resources. Selected research programs will be necessary where suitable data is insufficient to define relationships.

Phase 2 is open-ended at year 5, because all programs will not be completed in the first 5 year Strategic Plan. The resource area of greatest complexity and likely to have the longest cycle for defining attribute interdependence is biological resources. These relationships are not anticipated to be defined to a satisfactory level until the second 5 year plan.

**Phase 3** is the most critical phase for realizing maximum benefit to managers/stakeholders. In this phase, established science relationships within resources can be used to develop decision rules, management guidelines, and decision support models and systems. Sufficient information exists to begin Phase 3 in FY 1999 in physical resources. Cultural resource modeling will likely begin in FY1999 or 2000. This phase, by necessity, will extend into the second 5 year plan, due to the inability to effectively model many biological resource interactions. Phase 2 analysis of these resources will not have progressed sufficiently to develop all significant biological relationships into algorithmic form.

**BUDGET**

The budget process for funding the Grand Canyon Monitoring and Research Center involved a transfer of funds from the Western Area Power Authority (WAPA), a federal government entity, to the GCMRC, an administrative unit of the Office of the Secretary, USDOI. This budget is for the entire 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, administers the Adaptive Management Program and is the budget office for the Center.

The budget for the original Bureau of Reclamation GCES program increased from less than $1 million per year in 1981 to over $10 million per year in the early 1990's. The 1996 budget was approximately $6.9 million.

The fiscal year 1997 budget for the Adaptive Management Program is approximately $7.0 million. It is anticipated that this FY 1998 and FY 1999 budgets for the program, already in planning, will also approximate $7.0 million

Although some opportunity does exist for budget enhancement during the five year planning period (1996 - 2001), the Adaptive Management Program and research center are planned around an average annual budget of $7.0 million. The first budget that can be significantly influenced by the new research team is Fiscal Year 2000. A proposal for an increased allocation in FY 2000. A proposal for an increased allocation in FY 2000 will center around equipment for implementation of more automated monitoring systems for the Grand Canyon and Glen Canyon research areas.

Of the total $7.0 million per year budget allocation approximately $5.3 million is placed into on-the-ground research programs. Approximately $0.5 million is required by the Upper Colorado Region, BOR to administer the Adaptive Management Program, and $1.2 million is required to operate all of the center's administration and service programming.

The Adaptive Management Program is comprised of four entities (Figure 7.2) all funded out of the $7.0 million annual allocation. 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 research center.

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 a bid price competitive with similar services available from other agencies.

The center staff provides administrative, management, technical, scientific and other support to the research program under its direction. In general the monitoring and research program involved servicing approximately 20-30 separate research contracts and/or cooperative agreements. Approximately $1.2 million is required to service these programs. These involve other federal and state agencies, Native American Tribes, consulting firms, etc. Within and/or external to these contracts the Center provides logistics, surveying, GIS

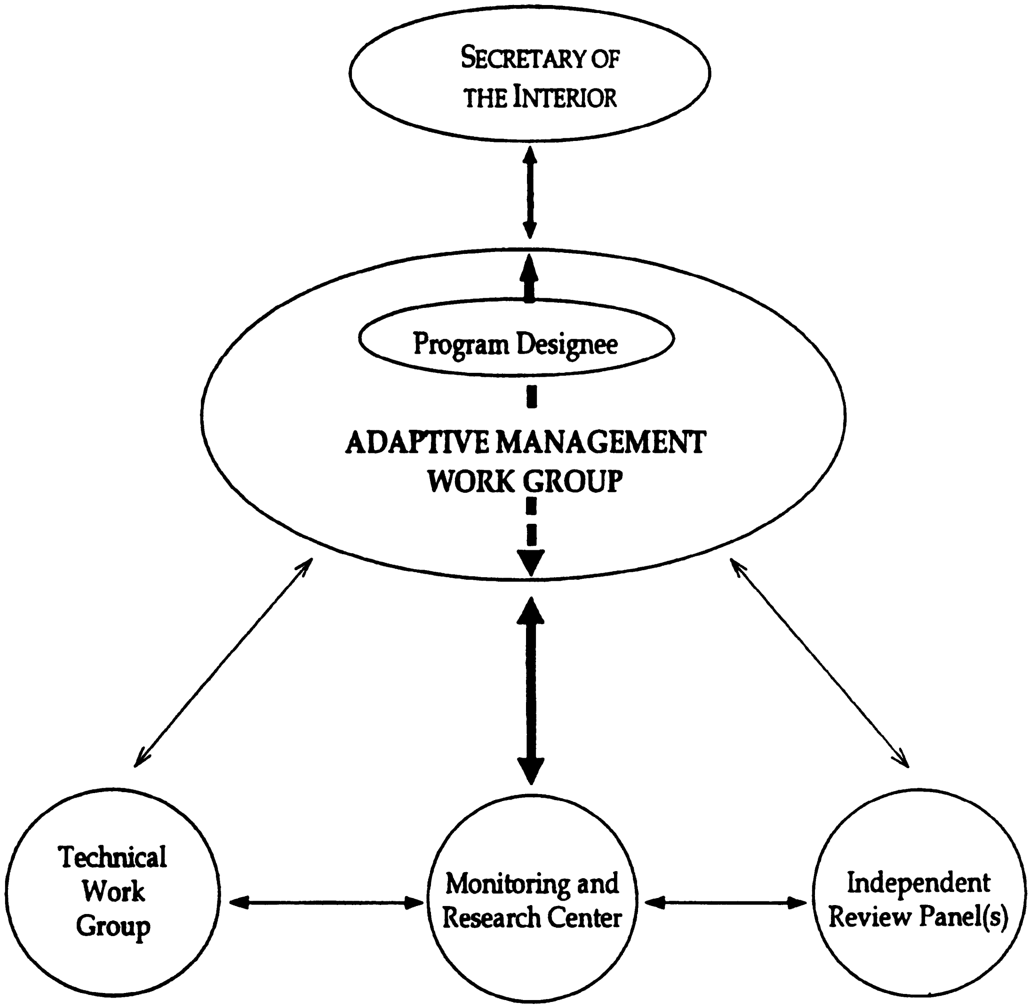


Figure 7.2. Adaptive Management Program for the Grand Canyon Monitoring and Research Center.

and data management support. For example, logistics support for all research trips through the Grand Canyon each year costs approximately $600,000.

The above budget levels noted for the center's five year Strategic Plan is only for program requirements in which the center is currently active and for which the center is currently responsible. Although this does include activities on the biological opinion (T&E species) and programmatic agreement (cultural resources), it does not incorporate other potential program areas currently in development. For example, long-term monitoring and research programs for Lake Powell are not incorporated in the plan or budget. In like manner, monitoring and research programs required to evaluate impacts of flash boards or operation of selective withdrawal structures on Glen Canyon Dam are not programmed into the budget specified.

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# APPENDIX A

# RESOURCE SHEETS

Note: The resource sheets do not reflect changes resulting from the GCMRC memo of 12/3/96 which requested that suggestions for final revisions be submitted to GCMRC by 1/3/97.

## AQUATIC FOOD BASE

| Stakeholders' Objectives | Stakeholders' Information Needs | Scientists' Knowledge | Scientists' need to know | Scientists' Monitoring Statements | Scientists' Research Questions |
|---|---|---|---|---|---|
| Maintain and enhance the aquatic food base in Glen Canyon. Maintain continuously inundated areas to Cladophora and aquatic invertebrates at or above 5,000 cfs discharge. | 1. Define current and historic food base character and structure.<br>2. Define food base character, structure & requirements for maintaining target populations.<br>3. Determine system changes to maintain/ enhance food base.<br>4. Define impacts of alternative operating criteria on ecosystem (food base).<br>5. Monitor the species composition & the distribution of aquatic algae & macrophytes in Glen & Grand Canyons.<br>6. Monitor the species composition and density of macroinvertebrates in Glen and Grand Canyons. | • Food web energetics model.<br>• Conceptual "diagrams" of ecosystem.<br>• Mainstem algae & macroinvert community structure, biomass, & seasonal variability; limited similar information for LCR & other tributaries.<br>• Linkages between algae and primary consumers & detrital links; diatoms are key organic drift.<br>• Physical (structural) habitat requirements for Cladophora.<br>• Cladophora is best substrate for diatoms; diatoms are rainbow trout food base.<br>• Relationship between flow and data.<br>• Models e.g.; Yard Model (discharge sediment/Cladophora).<br>• Structures known through corridor by seasons. | • Water velocity & discharge limits for diatoms/Cladophora.<br>• How does stage relate to proportion of algae exposed?<br>• How does stage relate to primary productivity (light, etc.)?<br>• The interactions among algal species?<br>• How changes in nutrient regimes in Lake Powell change macrophyte communities?<br>• Phosphorus availability/limitations.<br>• Nutrient linkages (including ground water & tributary inputs) to primary producers.<br>• What are links between benthic biomass /productivity & how does temperature affect benthic communities & primary production.<br>• How stage affects diatom abundance distribution. | Monitor fish food habits via drift assessments.<br>Monitor tributaries to determine if changes in the CR are due to dam operations or to landscape changes in the watershed. | Complete CR energetics model to determine if the system is food limited.<br>Determine, in association with specific water releases (defined flows), the effects of flow rate (velocities) on primary producers in the Glen Canyon reach.<br>Determine potential for invasion of other aquatic species, especially under low steady flows or selected temperature withdrawals; zebra mussels, fish parasites, etc. |

| Stakeholder's Objectives | Stakeholders' Information Needs | Scientists' Knowledge | Scientists' need to know | Scientists' Monitoring Statements | Scientists' Research Questions |
|---|---|---|---|---|---|
| | | • Aquatic conversion to energy levels in main-stem.<br>• Know diet linkages of primary and secondary consumers.<br>• Know thresholds (temperature/water) of exposure for diatoms, Cladophora.<br>• Know recovery rates of diatom and Cladophora. | • What warmwater tolerant macrophytes exist in the regions that might replace Cladophora.<br>• Aquatic food base data needed for Grand Canyon beyond Glen Canyon.<br>• What factors affect sexual reproduction of Cladophora?<br>• What is the microbial contribution to organic processing?<br>• Inventory needs - Oligochaetes, flatworms, chironomids.<br>• Fonlanalis & Chara contributions to ecosystems.<br>• Linkages between discharge/aquatic invertebrates/fish.<br>• Nutrient levels inside channels needed.<br>• The potential productivity (food base) loss at differing flows. | | |

| Stakeholder's Objectives | Stakeholders' Information Needs | Scientists' Knowledge | Scientists' need to know | Scientists' Monitoring Statements | Scientists' Research Questions |
|---|---|---|---|---|---|
| General: Protect and enhance native fish populations in Glen and Grand Canyons, recreationally important cold-water sport fish populations in Glen Canyon, and the aquatic food base upon which they depend. | | | | | |
| Maintain or enhance the existing population of humpback chub at or above 1987 levels. Maintain levels of recruitment of humpback chub in the mainstem and Little Colorado River. Verify the status of and manage for healthy, self sustaining populations of native fish in Glen Canyon based upon the capability of the habitat to support those fishes. | 1. Monitor adult humpback chub populations and evaluate population level trends.<br><br>2. Monitor levels of recruitment of humpback chub in the mainstem and the LCR.<br><br>3. Monitor quantity & quality of chub backwater habitat in mainstem.<br><br>4. Determine and identify surrogate native or non-native fishes for evaluation of health factors for humpback chub.<br><br>5. Develop a backwater quality index, using existing data for humpback chub. | • Have some conceptual "diagrams" of ecosystems requirement.<br><br>• Some fish populations sizes, especially T&E species.<br><br>• Some fish habitat requirements, i.e.; trout, humpback chub.<br><br>• Structure and location of nine existing aggregations of humpback chub in mainstem.<br><br>• Glen Canyon is one of six populations of humpback chub nationally; it is largest, centered at Little Colorado River with successful reproduction possible.<br><br>• Site fidelity in humpback chub. | • Structural and functional linkages of aquatic ecosystems, threatened and endangered and sensitive fishes.<br><br>• Validate all data on fish assemblages.<br><br>• Native versus non-native fish interactions must be defined by positive and negative linkages.<br><br>• Recruitment of humpback chub into Little Colorado River aggregations.<br><br>• Genetics of humpback chub aggregations.<br><br>• Ecology information (diet, cycles, requirements) for flannelmouth suckers, blue headed sucker, speckled dace. | Monitor humpback chubs in the LCR, mainstem CR, especially where population of insterest are located.<br><br>Monitor flannelmouth sucker aggregations at tributary locations (primarily Paria River).<br><br>Monitor physical occurrence of backwaters and shallow channel side waters suitable for young fish, including HBC.<br><br>Hourly hydrograph of lower LCR.<br><br>Use event recorders (e.g., daily camera) monitor flows at the mouths of the four large tributaries (Paria, LCR, Kanab Creek, Havasu). | Evalute food habits (gut contents) of flannelmouth sucker over time using non-lethal methods.<br><br>Genetically characterize HBC and other native fish aggregations in the LCR, 30 mile, & Middle Granite Reach.<br><br>Collect HBC tissue samples throughout canyon, extract DNA and bank for future studies.<br><br>Test alternative methods for tagging HBC smaller than 150 mm.<br><br>Test efficacy of experimental non-native fish control) i.e.; the removal of non-native fishes and the response in the native fish population). |

| Stakeholder's Objectives | Stakeholders' Information Needs | Scientists' Knowledge | Scientists' need to know | Scientists' Monitoring Statements | Scientists' Research Questions |
|---|---|---|---|---|---|
| Verify the status of and manage for healthy, self sustaining populations of flannelmouth sucker, bluehead sucker, and speckled dace in the mainstem Colorado River in Grand Canyon and its tributaries.<br>Verify the status of and manage for healthy, self sustaining populations of native fish in Glen Canyon based upon the capability of the habitat to support those fishes. | 1. Determine historic and current character and structure of species populations.<br><br>2. Determine historic & current ecosystem requirements of species.<br><br>3. Monitor and define impacts of alternative flow regimes on species population character and structure.<br><br>4. Determine requirements to maintain/enhance self sustaining populations of species. | • Spawning and rearing temperature, salinity, DO requires of humpback chub.<br><br>• Possible downward trend in LCR adult numbers over last 10 years derived from mark-recapture data; similar downward trend in mainstem not noted.<br><br>• What native fish are eaten by rainbow trout, brown trout, catfish. | • Ecology information (diet, habitat requirements, predation, etc.) for humpback chub in Little Colorado River.<br><br>• PIT tag data repository at the Center for all of river system.<br><br>• Energetics of T&E sensitive species.<br><br>• Parasite, disease, life history and related interactions of native and non-native fish. | Monitor [illegible] of Lake Powell if selective withdrawal is implemented.<br><br>Monitor all fish species native and non native, in all habitat types (numbers caught, location, length, weight, oparasites) for effects of flows, reproductive condition, etc.<br><br>Monitor rainbow trout above Lees Ferry; reproduction, percent of population that is native spawned, downstream movement. | Study native and non-native species interactions through controlled research ( especially the impacts of various temperature regimes).<br><br>Test experimental enhancement of flannel mouth populations and other species through Paria River rearing ponds, including imprinting in Paria water. |
| Establish a second, self sustaining population of humpback chub by 2005 contingent on feasibility. Monitor for and determine the contribution of other existing spawning aggregations as one component of assessing feasibility. | 1. Develop criteria for self sustaining populations of humpback chubs.<br><br>2. Assess feasibility of second population including other current aggregations. | • Swimming ability of juvenile humpback chub and flannelmouth sucker.<br><br>• Which springs they feed near.<br><br>• Humpback chub and rainbow trout use significant drift feed.<br><br>• Humpback chub seem to feed more on terrestrial than benthic components. | • How does stage relates to drying of trout redds?<br><br>• Food web energetics; re: how does algal mass related to trout production?<br><br>• How does trout management in Glen Canyon affect native species?<br><br>• Interactions of native fish and food base. | Establish and maintain a PIT tag data repository. | Establish experimental populations of special status fishes for physiological studies, including temperature effects on larval fish, for forecasting broad stock.<br><br>Evaluate the establishment of an experimental program for mainstem reestablishment.<br><br>Determine cumulative effect of handling (research) on fish (stress, trap avoidance, etc.). |

| Stakeholder's Objectives | Stakeholders' Information Needs | Scientists' Knowledge | Scientists' need to know | Scientists' Monitoring Statements | Scientists' Research Questions |
|---|---|---|---|---|---|
| In Colorado River corridor below Glen Canyon Dam to the confluence with the Paria River, natural reproduced fish should compose at least 50% of the Age III rainbow trout. Sufficient suitable spawning habitat should be maintained to reach this objective. The total populations of rainbow trout (age II⁺) in this reach should be maintained at approximately 100,000 fish. Rainbow trout should achieve 18 inches in length by Age III with a mean relative weight (Wr) of at least 0.80. | 1. Determine ecosystem requirements, population character and structure to maximize reproduced populations of Age II⁺ population levels.<br><br>2. Monitor changes in population character & structure.<br><br>3. Monitor harvested & field sampled rainbow trout to determine contribution of naturally reproduced fish to the population.<br><br>4. Monitor availability and quality of spawning substrates in Glen Canyon reach.<br><br>5. Monitor size of the population of Age II⁺ rainbow trout in Glen Canyon reach.<br><br>6. Monitor growth and condition of rainbow trout in Glen Canyon.<br><br>7. Define criteria for healthy trout population. | | • Stomach contents analysis of pre-dam humpback chub from existing collections.<br><br>• Food availability for humpback chub throughout Little Colorado River.<br><br>• Temperatures regimes in river's ecosystems?<br><br>• What proportion of adult humpback chub in the LCR are resident?<br><br>• Effects of sampling efforts on fish populations.<br><br>• Non-lethal disease assessment procedures; or assessment procedures for surrogate species. | | Determine the extent of food limitation on distribution and condition of native fish.<br><br>Review potential diseases, parasites and other factors affecting fish lenght in the future.<br><br>Determine the inter relationships between mainstem flow/backwater geochemistry, warming and fisheries diet, habitats in backwaters. |

| Stakeholder's Objectives | Stakeholders' Information Needs | Scientists' Knowledge | Scientists' need to know | [illegible] Statement | Scientists' Research Questions |
|---|---|---|---|---|---|
| Minimize, to the extent possible, interactions between native and non-native fishes. | 1. Define areas & conditions of current & future existing & potential native and non-native fish interactions.<br>2. Monitor key attributes associated with interaction.<br>3. Determine methods for minimizing interactions through isolation.<br>4. Determine methods for minimizing interactions without isolation.<br>5. Monitor species composition, relative abundance & size class structure of non-native fish in Grand Canyon & important tributaries.<br>6. Identify existing & potential resources of interaction (predatory, competitive) between extant non-native and native fish of Grand Canyon.<br>7. Evaluate effects of beach habitat building and habitat maintenance flows on the distribution & abundance of non native fish in Grand Canyon.<br>8. Identify potential alternative strategies to suppress problematic non-native species in Grand Canyon. | | | | |

## Fish and Aquatic Resources

| Stakeholder's Objectives | Stakeholders' Information Needs | Scientists' Knowledge | Scientists' need to know | Scientists' Monitoring Statements | Scientists' Research Questions |
|---|---|---|---|---|---|
| Evaluate through monitoring and research the reasonable and prudent alternatives specified by the US Fish and Wildlife Service. | 1. Using monitoring & research programs evaluate all test flows in RPA and potential impacts to threatened and endangered fisheries.<br><br>2. Determine the benefits and impacts of installing selective withdrawal for thermal modification in the mainstem of the Colorado River downstream of Glen Canyon Dam. | | | | |

**Proposed Science Program**

1. Determine whether biomass, habitat and composition of the aquatic food base is responding to dam operations.
2. Aquatic food base monitoring would include both the mainstem, and tributaries.
3. Monitor the condition and population fluxes of native and non-native fish species to evaluate their response, as predicted, to dam operations.

**NRC Concerns**

1. Support a monitoring program to evaluate future operations in the context of a Colorado River ecosystem model with priority on sediments and aquatic biota components.
2. Include algal and invertebrate productivity in future aquatic studies.
3. Produce a sound set of monitoring data on trout populations.

**Needs Proposed in Biological Opinion**

Attainment of riverine conditions that support all life stages of endangered and native fish species is essential to the Colorado River ecosystem.
The service believes that actions for one native species should be supportive of other native species in the ecosystem.
Reclamation and the Service will meet at least annually to coordinate reasonable and prudent alternative activities.
Determine humpback chub life history schedule for populations downstream of Glen Canyon.
Establish a second spawning aggregation of humpback chub downstream of Glen Canyon Dam.
Protect humpback chub spawning population and habitat in LCR by being instrumental in developing a management plan for this river.
Develop actions that will help ensure the continued existence of the razorback sucker.
Develop a management plan for the species in the Grand Canyon.

| Stakeholders' Objectives | Stakeholders' Information Needs | Scientists Knowledge | Scientists' need to know | Scientists' Monitoring Statements | Scientists' Research Questions |
|---|---|---|---|---|---|
| Protect, restore and enhance survival of special status species. Ensure that the required habitat for these species is preserved. Maintain native faunal components of the ecosystems for the benefit of T&E species. | 1. Define and specify ecology of native faunal components, especially T&E species; including evolutionary & environmental changes, natural range of variation, linkages, interdependencies & requirements.<br><br>2. Monitor departures of species population from natural range of variation.<br><br>3. Monitoring changes (declines in special status species) & characterize ecosystem changes to benefit species. | | | Distribution and abundance of large mammals should be determined at 5-year intervals.<br><br>Distribution and abundance of reptiles should be determined at 5-year intervals. Monitor abundance of RM 9 leopard frogs.<br><br>Monitor endangered birds, number, and habitat. | |

## Monitoring and Research Planning
### NATIVE TERRESTRIAL WILDLIFE RESOURCES

| Stakeholder's Objectives | Stakeholders' Information Needs | Scientists' Knowledge | Scientists' need to know | Scientists' Monitoring Statements | Scientists' Research Questions |
|---|---|---|---|---|---|
| Maintain a natural age-class distribution throughout the majority of natural range in Glen and Grand Canyons, emphasizing the need to recruit into breeding age classes. | 1. Determine species natural ranges (pre-post dam).<br>2. Determine historic age class distribution (pre-post dam).<br>3. Assess natural range & age class disruption, changes, constraints, probable long term viability implications to species; assess alternative habitat, ecology associations (specifically age class); and ecosystem associations.<br>4. Monitor impacts of alternative operating criteria on ecosystem & ecology requirements of species. | | Ecology in these settings not fully known. | | Assessment of current knowledge on distribution abundance, and life history of riparian reptiles and mammals.<br>Determine significance of post-dam vegetated corridors to range extensions and interbreeding among previously isolated populations of amphibians and reptiles. |
| Evaluate the viability of food chain for native fauna, including the Peregrine Falcon, Willow Flycatcher, and other special status species. | 1. Define food chain associations, interdependencies, requirements, etc.; for native species population targets.<br>2. Monitor impacts of alternative operating criteria on food chain associations. | | | | |

| Stakeholder's Objectives | Stakeholders' Information Needs | Scientists' Knowledge | Scientists' need to know | Scientists' Monitoring Statements | Scientists' Research Questions |
|---|---|---|---|---|---|
| Consider & mitigate impacts to special status species that may use the river corridor opportunistically. Maintain self-sustaining fish populations as forage to provide opportunities for bald eagles. Monitor for nesting. | 1. Characterize historic and current use or expected use of area by species.<br><br>2. Determine habitat, forage, nesting, etc.; requirements based on current or future use. | | | General avian community monitoring Determine what species are breeding, relative abundance, etc. Monitor bat populations and habitats. | |
| The population Kanab Ambersnail should be inventoried and maintained near current levels. Efforts to establish additional population center should be guided by the recovery plan for the species. | 1. Characterize historical and current populations of snail & locations.<br><br>2. Determine ecology & ecosystem related requirements for snail to maintain 1996 levels.<br><br>3. Monitor changes in populations, health, & character of Ambersnail. | Kanab Ambersnail populations.<br><br>Amphibian distribution is roughly known, not densities. | Need second population of Kanab Ambersnail established.<br><br>Reptile ecologies, densities, and diversity. | Monitor Kanab Ambersnail for compliance.<br><br>Monitor Kanab Ambersnail populations above 60,000 cfs.<br><br>Monitor occurrence of Kanab Ambersnail trematode parasite.<br><br>Monitor abundance and food habits of Peromyscus predator at Vaseys Paradise. | Determine definitive host of Kanab Ambersnail trematode parasite. |

## Monitoring and Research Planning
### NATIVE TERRESTRIAL WILDLIFE RESOURCES

| Stakeholder's Objectives | Stakeholders' Information Needs | Scientists' Knowledge | Scientists' need to know | Scientists' Monitoring Statements | Scientists' Research Questions |
|---|---|---|---|---|---|
| Maintain a diversity of wildlife species associated with ongoing natural evolutionary and ecological processes, giving priority to native species. | 1. Determine the historical and current wildlife occupying or using habitats in the Canyon.<br><br>2. Determine range of natural variability, ecology and ecosystem requirements of species.<br><br>3. Monitor impacts of operating criteria on wildlife with emphasis on special status species. | GIS map of upper Lake Mead, physical areas not delineated.<br><br>Upper Lake Powell regarding riparian vegetation, neo-tropical migrant birds, native and non-native fish.<br><br>Know location and vegetation requirements of some mammals. | | | |

**NRC Concerns**

1. Link biotic studies with each other, and integrate with hydrological and geomorphic studies that would make the essential connection to operations.

| Stakeholders' Objectives | Stakeholders' Information Needs | Scientists' Knowledge | Scientists' need to know | Scientists' Monitoring Statements | Scientists' Research Questions |
|---|---|---|---|---|---|
| General: Maintain dynamic vegetative communities made up of diverse groups of native riparian & upland species (where affected by dam operations) at different stages of succession and at different elevations above the water line. | | | | | |
| Preserve or restore (where possible) natural species composition & abundance within riparian and upland communities affected by dam operations. | 1. Determine historical natural composition of riparian and upland communities.<br>2. Characterize normal range of variation and ecology of species.<br>3. Monitor impacts of operating criteria to natural vegetation communities. | • Terrestrial vegetation divided into three zones: marsh, new high water, old high water.<br>• Inundation levels and grain size control riparian vegetation in still water.<br>• Know all vegetation volumes and types. | • Information on vegetation composition and changes.<br>• Nutrient dynamics in the inundation zone.<br>• Use of shoreline marshes by vertebrates (waterfowl, other birds, bighorns, deer, etc.). | Monitor riparian habitat between Glen Canyon Dam and Lake Mead, as it is important to the Grand Canyon ecosystem.<br>Monitor spread or contraction of vegetative communities below the dam. | Explore by GIS modeling the impacts of alternative flow regimes on riparian vegtation.<br>Conduct basic life history studies of non-native vegetation: camelthorn, tree of heaven, Lepium lattifolium, Eragnostis cerrula. |
| Emphasize the preservation of unique plant communities and any special status species (federal, tribal, & state designations) to ensure their perpetuation within system. | 1. Determine historic & current distributions, range of variation and ecology of T&E and special status species.<br>2. Establish ecosystem requirements of special status species & determine probable impacts of proposed flow regimes.<br>3. Monitor population changes in special status species. | • Conceptual successional model of marsh and sandbar vegetation.<br>• GIS of some reaches; vegetation maps for reaches.<br>• Old high water zone vegetation is not reproducing. | • Match shoreline fish sites with shoreline vegetation.<br>• Quantitative successional vegetation models.<br>• To evaluate changes in vertebrate species densities as a result of increase in riparian vegetation (e.g.; neotropical migrants). | Monitor fate of old high water species (e.g., mesquite) in new riparian areas, under different flow regimes.<br>Monitor areal extent of marshes.<br>Monitor Willow flycatcher in relation to vegetation community structure. | Determine effects of management alternatives on riparian vegetation: steady summer flows, habitat building flows.<br>Determine food habits of terrestrial vertebrates and effects of and on changing vegetative communities: bighorn sheep and rushes, beaver & cottonwood, etc. |

## Riparian And Terrestrial Vegetation

| Stakeholder's Objectives | Stakeholders' Information Needs | Scientists' Knowledge | Scientists' need to know | Scientists' Monitoring Statements | Scientists' Research Questions |
|---|---|---|---|---|---|
| | | • Preferred alternative will reduce vegetation levels below current levels (elevation).<br><br>• Cottonwoods are establishing.<br><br>• 13% of riparian plant species in canyon are exotic; accounts for 40% of area coverage.<br><br>• Some exotics have become important to target species for conservation (e.g.; Tamarisk/Southwest Willow Flycatcher).<br><br>• There are no sensitive or endangered plant species listed along the river that are at risk. | • Linkage of terrestrial vegetation and aquatic food base for important species.<br><br>• Groundwater/nutrients flows - how they relate to riparian vegetation.<br><br>• Invertebrate productivity and relationships to vegetation and vegetation change.<br><br>• Invertebrate inventory of GCNRA and GCNP. | Monitor changes in extent and relative abundance of Willow and Tamarisk.<br><br>Monitor Kanab Ambersnail habitat.<br><br>Monitor spread of non-native vegetation, camelthorn, Lepium latifolium, Eragnostis cerrula, Tamarisk, Russian olive. | |

**NRC Concerns**

1. Establish links to river productivity in future terrestrial studies.
2. Plan for heterogeneity and match methods to the temporal and spatial scales of the phenomena.

| Stakeholders' Objectives | Stakeholders' Information Needs | Scientists' Knowledge | Scientists' need to know | Scientists' Monitoring Statements | Scientists' Research Questions |
|---|---|---|---|---|---|
| Preserve in situ all the downstream cultural resources and take into account Native American cultural resource concerns in Glen and Grand Canyon. | 1. Develop data and monitoring systems to assess impacts to cultural resources.<br><br>2. Develop predictive model of geomorphic processes related to archaeological site erosion including:<br>• Types of degradation; threats<br>• Rates of degradation<br>• Define immediacy of threats to resources<br>• Protection methodologies<br>• Protection, monitoring and research costs.<br><br>3. Develop tribal monitoring programs for the evaluation of impacts to cultural resources. | 1. Locations of cultural resource sites identified in resource inventories.<br><br>2. Conditions of sites within various impact zones based on annual monitoring activities. | 1. Area assessments, and probability model for location of additional sites is needed. | 1. Assess existing data on I.O.s to determine adequacy of monitoring information. | 1. Study I.O.s to determine their relationship to site formation or degradation processes. |

| Stakeholder's Objectives | Stakeholders' Information Needs | Scientists' Knowledge | Scientists' need to know | Scientists' Monitoring Statements | Scientists' Research Questions |
|---|---|---|---|---|---|
| If in situ preservation is not possible, design mitigative strategies that integrate the full consideration of the values of all concerned tribes with a scientific approach. | 1. Characterize through scientific study & data development all assumed historical & current values of resources to Tribal Nations and to general public.<br>2. Develop data systems to assess variable risk of damage/loss of differing resources/ sites from dam operating criteria.<br>3. Develop mitigation strategies related to documented site impacts monitoring assessments, evaluation of the affectiveness of monitoring procedures.<br>4. Develop mitigation costs. | 1. Geomorphology processes that promote erosion. | 1. Factors governing rates of erosion need to be determined. | | 1. Define long term impacts of flows on streamside bank degradation (lateral bank retreat), arroyo headwall damage and model impacts to cultural resources and opportunities for restoration. |
| Protect and provide physical access to and use of traditional cultural properties and other cultural resources, used for religious purposes, by the participating Native American Tribes and traditional practitioners. | 1. Characterize historic & current religious associations of all sites associated with impacts of dam operations.<br>2. Develop tribal programs to maintain traditional use of cultural resources including sacred sites. | Location of some traditional cultural sites is known; some are not yet discovered. | 1. Location of tribe-identified traditional cultural sites needed if individuals will divulge locations.<br>2. Develop baseline cultural resource maps to facilitate tribal consultation for:<br>• resource locations<br>• risk of loss<br>• resource study locations (including other resource studies)<br>• plant & biological resource locations<br>• sensitive physical/land-form locations | 1. Revise GIS resource maps as needed. | |

# CULTURAL RESOURCES

| Stakeholder's Objectives | Stakeholders' Information Needs | Scientists' Knowledge | Scientists' need to know | Scientists' Monitoring Statements | Scientists' Research Questions |
|---|---|---|---|---|---|
| Develop, maintain and integrate available cultural resources data recovered from monitoring, remedial and mitigative actions into evolving research designs for understanding human use and occupation in the canyons. | 1. Characterize all cultural resource sites as to the specific associated management/research needs, i.e.; preservation stabilization, documentation, etc.; under alternate operating criteria.<br><br>2. Preserve, stabilize and/or documentation of cultural resources as impacted by sediment resources associated with alternative operating criteria.<br><br>3. Evaluate flood terrace stability necessary to maintain cultural resources and terraces at pre-dam conditions.<br><br>4. Design and develop integrated relational data systems to support research program goals/designs.<br><br>5. Develop technology /procedures for providing relevant/protected data to appropriate groups/tribes. | 1. Some site stabilization techniques are known. | 1. Site formation processes of deposits not known.<br><br>2. Additional site stabilization techniques needed. | 1. Monitor existing stabilization techniques affected by high flow regimes. | 1. Formulate a research design to study the relationship of I.O.s to site formation or degradation processes and dam operations.<br><br>2. Evaluate specific locations to obtain site formation data for differing temporal occupation/activity periods.<br><br>3. Design investigations to determine if certain temporal activity/occupation periods are obscured from archaeological record due to dam operations.<br><br>4. Formulate pilot assessment of geologic history of terrace formations and their relation to past human occupations. |

**NRC Concerns**

1. Tribal studies should not be considered academic studies but rather applied studies focused toward specific objectives, that is, the protection of specific tribal cultural resources.

2. Develop a clear outline of criteria to be used in the selection of sites to be monitored.

**Requirements of Programmatic Agreement**

1. Within three months of the execution of the Programmatic Agreement, BOR and the NPS, in consultation with the SHPO and Tribes, shall develop a plan for monitoring the effects of the Glen Canyon Dam operations on historic properties with the APE and for carrying out remedial actions to address the effects of ongoing damage to historic properties. Reclamation shall submit a draft of the Plan to the parties in this agreement for review and comment. Each party shall have 60 days from receipt of the Plan to comment.

2. Remedial measures shall be implemented to mitigate ongoing adverse effects and may include, but not be limited necessarily to, bank stabilization, check dam construction and data recovery, as appropriate.

3. Reclamation and the NPS shall incorporate the results of the identification, evaluation, and monitoring and remedial action efforts into a Historic Preservation Plan (HPP) for the long-term management of the Grand Canyon River Corridor District and any other historic properties within the APE.

4. The HPP shall establish consultation and coordination procedures, long term monitoring and mitigation strategies, management mechanisms and goals for long term management of historic properties with the APE.

5. Reclamation and the NPS shall take into consideration all comments received in their development of a final draft HPP, and submit the final draft HPP to the reviewing parties for a second review opportunity.

## Monitoring and Research Planning
## HYDROPOWER RESOURCES

| Stakeholders' Objectives | Stakeholders' Information Needs | Scientists' Knowledge | Scientists' need to know | Scientists' Monitoring Statements | Scientists' Research Questions |
|---|---|---|---|---|---|
| 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. | None specified. | 1. Past daily average discharge are known for:<br>1. Lees Ferry<br>2. Grand Canyon<br>3. Paria<br>4. LCR-Cameron<br><br>2. Discharge routing model exists that predicts discharges to 45,000 cfs in all canyon reaches.<br><br>3. Hourly dam releases completed from power generation data are available.<br><br>4. Reach average water particle velocity at steady 15,000 and 45,000 cfs and unsteady releases with daily mean of 15,000 cfs.<br><br>5. Know average water particle velocity in Glen Canyon reach at steady 5,000 cfs.<br><br>6. Past stage at 30-50 sites for various releases regimes.<br><br>7. Some information on flow from ungaged springs. | 1. Unit values (15 min. values) of discharge at:<br>Lees Ferry, above LCR, Grand Canyon, Diamond Creek, lower LCR reach, Paria<br><br>2. Reach average water velocity at low flows. | 1. Monitor unit values of stage and maintain stage discharge relations at:<br>- Lees Ferry<br>- above LCR<br>- Grand Canyon<br>- Diamond Creek<br>- Paria<br><br>2. Monitor stage and discharge at base flow below Blue Springs area for temperature, discharge, and chemical, physical characteristics to mainstem T&E species.<br><br>3. Monitor unit values of stage and discharge in LCR near Cameron.<br><br>4. Monitor base flow discharge on<br>- Diamond Creek<br>- above Kanab Creek<br>- Havasu Creek<br>- possibly Spencer Creek for T&E species.<br><br>5. Monitoring side canyon debris flows. | 1. How do reach average water velocity at very low flows affect the accuracy of the discharge routine model? |

**NRC Concerns**

1. Study possible changes in dam operations and non-operations alternatives for protecting downstream resources.

## Monitoring and Research Planning
## RECREATION

| Stakeholders' Objectives | Stakeholders' Information Needs | Scientists' Knowledge | Scientists' need to know | Scientists' Monitoring Statements | Scientists' Research Questions |
|---|---|---|---|---|---|
| Provide quality recreation experiences that do not adversely affect natural or cultural resources.<br><br>Maintain or improve wilderness character of the recreational experience. | 1. Determine criteria and aspects that are im-portant to or detract from wilderness experience.<br><br>2. Characterize procedures to mitigate those aspects of flows that detract from wilderness character of river. | 1. Accident data on boating/fishing. | 1. Evolution of rapids in waterway and effects on navigation. | | 1. Determine relationship of impacts through time of debris flows on sites of recreation campsites through models. |
| Maintain flows and sediment processes that create adequate beach character and structure for camping. | 1. Determine adequate beach quality character and structure for camping throughout system.<br><br>2. Evaluate impacts of operating criteria on establishing and maintaining adequate beaches and distribution of other resource, quality, character and structure.<br><br>3. Monitor beach character and structure changes.<br><br>4. Develop systems models to predict flow regimes for building & maintaining beaches. | 1. Discharge levels and related satisfaction of boaters. | 1. Effects of temperature variation and effects on fisheries in Lake Powell and river. | 1. Monitor temperature regimes and their effect on recreational use of fishery. | |

## Monitoring and Research Planning
## RECREATION (continued)

| Stakeholder's Objectives | Stakeholders' Information Needs | Scientists' Knowledge | Scientists' need to know | Scientists' Monitoring Statements | Scientists' Research Questions |
|---|---|---|---|---|---|
| Maintain flow regimes that do not preclude white water and power craft navigation. | 1. Determine if operating criteria maintain adequate power craft navigability in Glen Canyon and upper Lake Mead.<br><br>2. Determine if operating criteria maintain white water raft navigation in Grand Canyon.<br><br>3. Define ecosystem & other resource impacts of flow regimes to maintain navigation. | 1. Glen Canyon discharge and related "accident" data such as boats and motors striking bottom. | 1. Effects of rapid lake level drop on fisheries and endangered fish in Lake Powell. | 1. Compile and use aerial photography, videos, etc.; to evaluate flow regimes on camp size, quality and number. | 1. Conduct study to relate probable changing temperature regimes to fisheries and water fowl.<br><br>2. Study of probable impacts of rapid drops in Lake Powell to biotic communities and the effects on recreational uses. |
| Maintain cold water fisheries opportunity (100,000 age adult II⁺) in Glen Canyon. | 1. Determine flow regimes necessary to maintain fish populations of 100,000 adult Trout (age call II⁺).<br><br>2. Determine impacts of operating criteria on other resources and ecosystems. | 1. Beach areas as related to interim flows, floods below Paria. | 1. Recreational expectations of Glen and Grand Canyon visitors. | 1. Establish cooperative monitoring with boatman and fishermen on resource change. | 1. Using recreation study assessments completed, determine probable impacts to recreation expectations under different flow regimes. |

| Stakeholder's Objectives | Stakeholders' Information Needs | Scientists' Knowledge | Scientists' need to know | Scientists' Monitoring Statements | Scientists' Research Questions |
|---|---|---|---|---|---|
| Maintain sport hunting opportunities for water-fowl in Glen Canyon. | 1. Define pattern of waterfowl use and conflicts to other uses. | 1. Adequate flows for white water rapids.<br><br>2. Angler satisfaction and use at various flow levels. | 1. Visitor/boat carrying capacity of river corridor by reach.<br><br>2. Improved "accident" data (rates, locations).<br><br>3. Trout production/ bioengergetics model.<br><br>4. Beach area from interim flows and floods in Glen Canyon reach.<br><br>5. Usefulness of recreational fishing to control exotic fish.<br><br>6. Effects of dam operation on bird populations and sports hunting.<br><br>7. Monitoring of angler use and satisfaction. | | 1. Using flight data, assess impacts of flow regimes on boating capacity in reaches with critical resources. |

**NRC Concerns**

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

## Monitoring and Research Planning
## SEDIMENT RESOURCES

| Stakeholders' Objectives | Stakeholders' Information Needs | Scientists' Knowledge | Scientists' need to know | Scientists' Monitoring Statements | Scientists' Research Questions |
|---|---|---|---|---|---|
| The overall resource management target is to maintain a range of sediment deposits over the long term. The dam would operate with the goal managing sediment resources on a reach-scale basis. | | 1. Enough sediment exists in the system under current regime to match sandbar formation under interim flows, but insufficient sediment exists for regimes of the 1880s. | | 1. Monitor flow and sediment input from the Paria and LCR tributaries. Establish observer system to monitor occurrence and size of debris flows. | 1. Analyze historic debris flows and their effect on the ecology of the riverine system under low flow regimes.<br>2. Estimate sediment contributions from ungaged tributaries by debris flows.<br>3.Complete the development of debris flow prediction techniques. |
| As a minimum for each, maintain the number and average size of sandbars between the stages associated with flows of 8,000 and 45,000 cfs and the number and average size of backwaters at 8,000 cfs that existed during baseline conditions. | 1. Characterize sandbar, backwaters, and return channels target structures.<br>2. Monitor changes in sediment storage and define balances and hydraulic processes necessary to maintain target sandbar levels.<br>3. Evaluate historical sandbar change.<br>4. Develop methods for predefining change in sandbar character structure under alternative dam operating criteria.<br>5. Determine baseline conditions. | 2. Data base exists for sandbar changes during post dam operations.<br>3. Can predict amount and area distribution of sand deposition from tributaries in mainstem channel and sandbars.<br>4. Sand channel monitoring sediment transportation modeling accurately monitor sand in channel. | 1. Where sand in the Glen Canyon reach comes from.<br>2. Monitor number, size and morphology of sandbars and backwaters at various flow regimes.<br>3. Synthesize and evaluate sand bar data from mid-1970s to present. | 2. Monitor sand stored in the channel bed and sandbars in the Glen Canyon, Marble Canyon, and Grand Canyon reaches.<br>3. Monitor sand in sand pools below main side streams (i.e., LCR). | 4. Determine if current monitoring methods & networks for sandbars and channel bed sand should be modified to provide better correspondence between channel stored sand and sandbars.<br>5. Investigate methods for determination of depth to non-erodible material in the channel.<br>6. Map the channel geometry in any reaches for bed evolution predictions are needed.<br>7. If needed to improve accuracy of the discharge & sediment routing models, measure reach averaged flow velocity at low flow. |

| Stakeholder's Objectives | Stakeholders' Information Needs | Scientists' Knowledge | Scientists' need to know | Scientists' Management Statements | Scientists' Research Questions |
|---|---|---|---|---|---|
| | | | | | 8. Test models currently being developed with data from the spring 1996 high releases and other available data to verify predictions of rates and amount and areal distribution of bed evolution.<br><br>9. Investigate the significance of rapid erosion events and, if significant, develop methods for their perdition.<br><br>10. Use well tested multidimensional bed evolution models to investigate the relation between the amount of sand available and size, duration of habitat-building releases required to rebuild sandbars and backwaters of given size and character. |

| Stakeholder's Objectives | Stakeholders' Information Needs | Scientists' Knowledge | Scientists' need to know | Scientists' Monitoring Statements | Scientists' Research Questions |
|---|---|---|---|---|---|
| Increase the average size of sandbars above the 20,000 cfs river stage and number of backwaters at 8,000 cfs to the amount measured after the 1996 test of the beach/habitat building flow in as many years as reservoir and downstream conditions allow. | 1. Define target backwater ecosystems and associated flow regimes.<br><br>2. Define historical variation in backwater number and character.<br><br>3. Monitor and define changes in backwater character & structure associated with dam operating criteria.<br><br>4. Define all linkages, associations, interdependencies, etc.; of physical backwater resources to biotic entities.<br><br>5. Define processes necessary to maintain backwaters at target levels. | 1. Know long-term changes in sand storage at Lees Ferry near Grand Canyon. Shorter term changes known at several locations. | 1. Long-term trends in variability in sand storage.<br><br>2. Accuracy of model predicted rates of erosion and sand deposition. | 1. Monitor sediment movement through system with model verified by cross sections. | |
| 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 downstream resources warrant and when Lake Powell water storage is high. | 1. Define character and structure of all sandbars and backwaters in system after 1996 test flows.<br><br>2. Develop methodologies to define future operating alternatives to maximize benefit to sandbar and backwater character and structure. | | 1. Continued monitoring required to know changes & status of system.<br>2. Rate of change of sandbars & backwaters during major deposition events.<br>3. Optimum size & duration of releases to rebuild sandbars & reform recirculation zones for mainstem storage. | 1. Measure and monitor sediments at Lees Ferry at peak flow events. | |

| Stakeholder's Objectives | Stakeholders' Information Needs | Scientists' Knowledge | Scientists' need to know | Scientists' Monitoring Statements | Scientists' Research Questions |
|---|---|---|---|---|---|
| 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. | 1. Define historical and current levels of bottom sediment deposits in system.<br>2. Define minimal levels of bottom sediments necessary to maintain long-term sandbar, backwater, channel sediment deposits.<br>3. Develop procedures to monitor and predict impacts of alternative operating criteria on channel sediment deposits, and implication to sandbars and backwaters in selected reaches. | 1. Sediment transport relationships are known. | 1. Amounts of stored sediments in river bottom.<br>2. Minimum levels of stored sand required to maintain sand resources at target levels.<br>3. Accuracy of bed evolution models to predict sand transport bed evolution.<br>4. Ability to predict rapid erosion during high releases.<br>5. Depth of river bed and channel geometry at various locations. | | |
| 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 and 30,000 cfs. | | 1. Geomorphic/sandbar indicators and cross-section indicators can be used to determine when there is enough sand for a flood.<br>2. Have tools to "predict" backwater formation re: discharge events | 1. Do low flow velocities affect accuracy of discharge sediment routing models.<br>2. Sediment balance for entire system or parts of system.<br>3. Modeling approach to predict sediment balance, distribution, etc.; by reach. | | |

**NRC Concerns**

1. Development of alternative sampling methods within the National Park.
2. More emphasis on sediment quality.

## Monitoring and Research Planning
### WATER RESOURCES

| Stakeholder's Objectives | Stakeholders' Information Needs | Scientists' Knowledge | Scientists' need to know | Scientists' Monitoring Statements | Scientists' Research Questions |
|---|---|---|---|---|---|
| Maintain chemical and physical characteristics of water at levels appropriate to support physical, biotic, and human resource needs of various ecosystems. | 1. Monitor changes in the physical and chemical characteristics over time.<br><br>2. Monitor concentrations of chemical constituents with established EPA/state standards. | 1. Canyon water characteristics are a function of Lake Powell water.<br><br>2. Lake Powell water release characteristics are a function of dam operations and they are variable over time.<br><br>3. Conductance at several sites in the Canyon is known. | 1. Ability to predict downstream water temperatures in mainstem and backwater from dam releases.<br><br>2. Influence of flow variables on aquatic biota, especially temperature and sediment.<br><br>3. Long-term phosphorus changes are not known and not predictable.<br><br>4. Levels of phosphorus, nitrogen and salinity for comparisons to standards.<br><br>5. Interactive relationship between tributaries and springs and mainstem water temperature.<br><br>6. Physical and chemical water trends, such as salinity, relative to dam operations.<br><br>7. Relationship of dam operations to bacterial levels, especially MLIS.<br><br>8. Effects of variability in water quality in Lake Powell to forebay /discharge quality. | 1. Monitoring temperature through canyon corridor.<br><br>2. Monitor temperature to determine aquatic productivity.<br><br>3. Monitor nutrient changes from dam to Lees Ferry.<br><br>4. Monitor nitrogen and phosphorus levels in stored sediment and sediment being deposited.<br><br>5. Determine appropriate water quality standards & evaluate water quality against established standards. | 1. Determine effect of dam discharge on temperature.<br><br>2. Determine rate of water temperatures increases throughout the canyon.<br><br>3. Determine the relationship between flow and temperature.<br><br>4. Determine temperature variation in the backwaters.<br><br>5. Determine changes in phosphorus salinity levels and are their association to dam operations.<br><br>6. Determine bacteria levels.<br><br>7. Determine Lake Powell water quality changes due to dam operations. |

# APPENDIX B

## OBJECTIVE STATEMENT OF STAKEHOLDERS

### National Park Service

The NPS objectives are to attempt to maintain the essential dynamic elements and processes that existed pre-dam through restoration, maintenance and protection. The NPS is committed to managing the Colorado River ecosystem and its attendant cultural resources as a coherent whole that, to the extent possible, simulates the ecosystem that existed prior to the construction of the dam.

### Bureau of Reclamation

As manager of the Colorado River, the Bureau of Reclamation's management objectives are to strike a balance among water releases established under the "Law of the River" and the Annual Operating Plan for Glen Canyon Dam, the hydroelectric power requirements of Western Area Power Administration, and "protection" of the downstream ecosystem under the 1992 Grand Canyon Protection Act. The priorities given to each of these components under the EIS and long-term monitoring program are dependent on potential risk for change in Canyon resources or attributes of concern, and laws and regulations that direct the Bureau's operations.

### Fish and Wildlife Service

The management objectives of the Fish and Wildlife Service in the Grand Canyon, as elsewhere, are to conserve, protect, and enhance fish and wildlife and their habitat for the continuing benefit of the public In the Canyon emphasis is placed on threatened and endangered species, migratory birds, and native fish and sports fisheries.

**Western Area Power Administration**

Management objectives of Western Area Power Administration (Western) are the marketing and transmission of electricity generated at Federal water power projects.

**Bureau of Indian Affairs**

The Bureau of Indian Affairs has no management role in the proposed action. However, it has management goals, among which is fostering of self-determination of Indian Tribes. Its goal is to assure that the interests of Indian Tribes are coordinated with other Federal agencies and to supply advice and assistance to Tribes when requested to do so.

**Hualapai Tribe**

Management objectives of the Hualapai Tribe are long-term sustainable and balanced multiple uses of its resources through natural integrated resource management. These resources include natural and cultural resources including sacred ceremonial and burial sites within the Canyon located outside the boundaries of the Reservation Lands.

## Other Indian Tribes

The management objectives of other Indian Tribes with interest in Glen and Grand Canyons, but whose lands do not border the mainstem of the Colorado River, are the preservation of the natural and cultural resources of the Canyon to maintain their values to the tribes. This includes spiritual and ancestral stewardship and management responsibilities to the Grand Canyon and specific places contained therein.

## Arizona Game and Fish Department

The management objectives of the Arizona Game and Fish Department are to conserve, enhance and restore Arizona's wildlife and habitats, and to provide wildlife and safe watercraft recreation for the enjoyment, appreciation and use of the public.