General Core Monitoring Plan for the Glen Canyon Dam Adaptive Management Program

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Chapter 1. Introduction to the Core Monitoring Plan

Establishment and implementation of a long-term monitoring program has been identified by the Canyon Dam Adaptive Management Program (GCDAMP) as a critical program need since the inception of the program in 1996. Since then, the focus has been on the development of a “core” monitoring program to meet the environmental and monitoring commitments of the Glen Canyon Dam Environmental Impact Statement and Record of Decision (ROD) and comply with the Grand Canyon Protection Act of 1992. The GCDAMP Strategic Plan (GCDAMP, 2003) defines core monitoring as follows:

> *Consistent, long-term, repeated measurements using scientifically accepted protocols to measure status and trends of key resources to answer specific questions. Core monitoring is implemented on a fixed schedule regardless of budget or other circumstances (for example, water year, experimental flows, temperature control, stocking strategy, nonnative control, etc.) affecting target resources.*

This document describes a general plan and framework for the development of a core monitoring program for the GCDAMP during federal fiscal years 2010 through 2015. Detailed core monitoring plans with explicit methodologies for each resource category will be developed as outlined in this plan over the next several years. The proposed process is consistent with the strategies and objectives described in the Grand Canyon Monitoring and Research Center’s (GCMRC) Monitoring and Research Plan (U.S. Geological Survey, 2007), and the GCDAMP Strategic Plan as amended by the Adaptive Management Work Group at their August 2003 meeting (AMWG written comm., 2003, hereafter cited as GCDAMP, 2003).

Monitoring is a fundamental requirement of the adaptive management process (Walters, 1986; Walters and Holling, 1990). The Department of the Interior (DOI) Adaptive Management Technical Guide (Williams and others, 2007) identifies four primary purposes for monitoring within an adaptive management program:

1. To evaluate progress towards achieving management objectives
2. To determine resource status in order to identify appropriate management action
3. To increase understanding of resource dynamics via the comparison of predictions against field observations
4. To enhance and develop models of resource dynamics as needed

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In 1995, the Grand Canyon Monitoring and Research Center (GCMRC) was created to fulfill the mandate in the 1992 Grand Canyon Protection Act for the

> *establishment and implementation of a long-term monitoring and research program to ensure that Glen Canyon Dam is operated in a manner that protects the values for which*

> *the Grand Canyon National Park and the Glen Canyon National Recreation Area were created.*

Since its inception, many of the GCMRC activities have focused on continuing certain monitoring tasks previously established under the Glen Canyon Environmental Studies program (termed here as "Legacy" monitoring), conducting field experiments, and developing technologies in support of development of a core monitoring program. Implementation of a long-term core monitoring program will require a significant commitment of qualified personnel to ensure that the program is implemented in a sustainable and timely manner. With a few exceptions, much of the data collection is proposed to be performed by cooperating agencies and contractors as discussed below; however, some monitoring, such as quality of water and sediment monitoring that has historically been part of the USGS mission, is proposed to continue internal to the GCMRC and the Water Resources Discipline within USGS.

1.1 Purpose and Scope of the General Core Monitoring Plan

The Monitoring and Research Plan (MRP) describes a four-step process for defining and refining core monitoring projects associated with various GCDAMP goals and key resources based on the best currently available information. As described in the MRP, the four steps are (1) develop a general core monitoring plan (this document), (2) conduct information needs workshops with the Technical Work Group (TWG) in advance of convening independent protocol evaluation panel (PEP) reviews, (3) conduct PEPs for each resource goal, and (4) prepare final core monitoring program reports for each resource goal. This is then followed by review and approval by TWG and AMWG (see Appendix B).

This general Core Monitoring Plan (CMP) is the first step in this four-step process of implementing the Core Monitoring Program for the GCDAMP. The CMP identifies the general goals, objectives, scope, schedule, and funding level for each proposed core monitoring project as well as the program as a whole. The scope of the CMP is based on the core monitoring ~~currently identified~~ information needs (CMINS) defined by AMWG in the 2003 Strategic Plan, as modified and prioritized by the 2005 Science Planning Group (SPG). -The CMP~~is~~ ~~Plan~~ takes into account the feasibility of developing monitoring protocols to meet those needs while ~~and~~ includ~~es~~ing a flexible approach for incorporating risk assessments and trade-off analyses to support decision making related to the scope and elements of the monitoring programs. The CMP also identifies the process and strategies which will be used to develop and finalize individual core monitoring program plans.

The CMP has been responsive to most of the higher priority CMINS, however given the scope of the information needs and funding limitations to develop monitoring programs, it does not currently account for all of them. Development and implementation of the core monitoring program for the GCDAMP ~~will~~ would consume a large percentage of the current GCDAMP science budget based on the ~~information needs~~CMINS. ~~identified by the GCDAMP.~~ The CMP includes initial estimates for costs and timeframes for program implementation but recognizes that a practical decision-making process will be needed by TWG to decide on a core monitoring program that meets stakeholder needs within available budget constraints. Those budget constraints cannot be articulated here as needs for management actions and other compliance needs are changing, but appear to be taking a larger percentage of the budget than in recent years. Without specific policy guidance on cost, TWG will be using a review and approval process to evaluate and make recommendations on individual plans to AMWG, that process is described in Appendix B.

In general, TWG is requesting that each individual plan contain 3 levels of funding commitment within a trade-off analysis framwork:

“High” – would implement the CMINs for that goal to the extent practicable and represent as close to full implementation as can be obtained with current resources.

“Medium” – would implement modest reductions in spending (about 10-30%) to implement the higher priority CMINs.

“Low” – would implement substantial reductions in spending (about 40-50%) to implement only the highest priority CMINs.

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The analysis would not only show the reductions in cost, but the ability of the program to respond to CMINs (i.e., the ability to answer critical questions), and the rationale for those choices. These tradeoffs will be considered by TWG and a recommendation made to AMWG to consider the policy implications of those choices and to approve a plan that is both technically sound and well considered within our long-term financial limitations. This process would allow for a scientifically driven review of different funding scenarios and provide the decision-makers with the information necessary to make difficult policy decisions. It is inevitable that at current funding levels we cannot support robust monitoring capable of responding to all of the CMINs during the next 10 years, thus we understand that a serious review of our core monitoring program is critical in supporting the long-term funding needs of the GCDAMP. Given future funding needs by many competing activities, we expect that the monitoring program will be reduced to some extent, that process should include a structured review process (Appendix TWG) and include a clear understanding of the abilities which will be lost and which resources they would affect. In previous core monitoring discussion scope of the program was considered and from 2004 the Core Monitoring Team indicated that an appropriate size would be 40-60% of the GCDAMP budget. The current program is about 60% of the overall budget and about 75% of the current GCMRC expenditures.

1.2 Legislation, Statutes, Policy, and Strategic Planning

The Colorado River is managed and operated under numerous compacts, federal and state laws, court decisions and decrees, contracts, treaties, and regulatory guidelines, collectively known as the Law of the River. This collection of documents apportions the water among the seven Colorado River basin states and Mexico, and regulates the flows of the Colorado River (Adler, 2007)

The Glen Canyon Dam Adaptive Management Program and Grand Canyon Monitoring and Research Center were established in 1996–97 to meet the environmental and monitoring commitments identified in the Glen Canyon Dam Final Environmental Impact Statement (EIS; U.S. Department of Interior, 1995) and Record of Decision (ROD) (Department of the Interior, 1996), and to comply with the Grand Canyon Protection Act (GCPA) of 1992. Specifically, the GCMRC was created to fulfill the GCPA mandate for the “establishment and implementation of a long-term monitoring and research program to ensure that Glen Canyon Dam (GCD) is operated in a manner that protects the values for which Grand Canyon National Park (GRCA) and the Glen Canyon National Recreation Area (GLCA) were created.” This program includes necessary research and monitoring to determine the effects of dam management on the natural, recreational, and cultural resources downstream of Glen Canyon Dam.

As mandated by the GCPA and described in the 1995 EIS, the Secretary consults with stakeholders through their participation in the Adaptive Management Work Group (AMWG), a Federal Advisory Committee Act (FACA) group comprising representatives of the seven Colorado River basin states

(Arizona, California, Colorado, Nevada, New Mexico, Utah, and Wyoming), six Native American tribes (Hopi, Hualapai, Navajo, Kaibab Southern Paiutes, Southern Piute Tribes of Utah, and Pueblo of Zuni), two power user groups, two environmental groups, two recreation groups, and five federal agencies (Bureau of Reclamation, Bureau of Indian Affairs, National Park Service, U.S. Fish and Wildlife Service, and Western Area Power Administration. These same entities participate at a technical level in the TWG, which formulates recommendations about research and monitoring for consideration by the AMWG.

The GCPA allows for management actions, in addition to dam operations, to accomplish the intent of protecting the values for which Grand Canyon National Park and Glen Canyon National Recreation Area were established. Examples of management actions may include water temperature modification, nonnative fish control, stabilization of historic properties, and removal of nonnative vegetation. When such actions are taken, research and monitoring are necessary to assess the effectiveness of these actions in achieving the intent of the GCPA.

Establishment and implementation of a long-term monitoring program has been identified by the GCDAMP as a critical program need since the inception of the program in 1996. Since then, the focus has been on the development of a "core" monitoring program, *"to measure status and trends of* ***key resources*** *to answer specific questions"* (GCDAMP 2003).

In a broad sense, the GCPA identifies *key resources* as the "natural, recreational, and cultural resources of Grand Canyon National Park and the Glen Canyon National Recreation Area" that are affected by GCD operations. This general mandate has been further refined by the GCDAMP (2003) to include 11 resource goals and 1 programmatic goal, as listed in Table 1 below:

Table 1. The goals of the Glen Canyon Dam Adaptive Management Program.

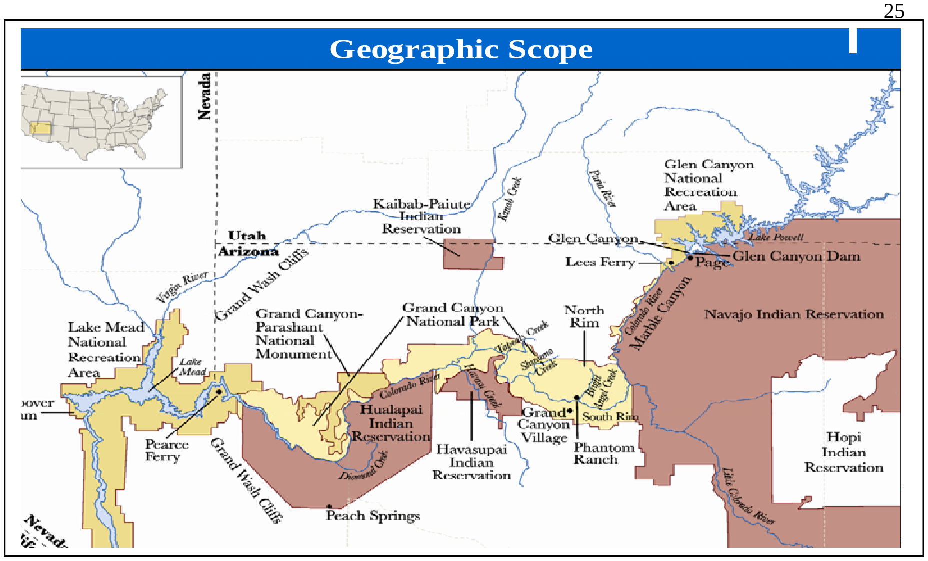
	RESOURCE GOALS
1.	Protect or improve the aquatic food base so that it will support viable populations of desired species at higher trophic levels.
2.	Maintain or attain viable populations of existing native fish, remove jeopardy from humpback chub (*Gila cypha*) and razorback sucker (*Xyrauchen texanus*), and prevent adverse modification to their critical habitat.
3.	Restore populations of extirpated species, as feasible and advisable.
4..	Maintain a naturally reproducing population of rainbow trout (*Oncorhynchus mykiss*) above the Paria River, to the extent practicable and consistent with the maintenance of viable populations of native fish.
5.	Maintain or attain viable populations of the Kanab ambersnail (*Oxyloma haydeni kanabensis*).
6.	Protect or improve the biotic riparian and spring communities, including threatened and endangered species and their critical habitat.
7.	Establish water temperature, quality, and flow dynamics to achieve the Adaptive Management Program ecosystem goals.
8.	Maintain or attain levels of sediment storage within the main channel and along shorelines to achieve the Adaptive Management Program ecosystem goals.
9.	Maintain or improve the quality of recreational experiences for users of the Colorado River ecosystem, within the framework of the Adaptive Management Program ecosystem goals.
10.	Maintain power production capacity and energy generation, and increase where feasible

	RESOURCE GOALS
	and advisable, within the framework of the Adaptive Management Program ecosystem goals.
11.	Preserve, protect, manage, and treat cultural resources for the inspiration and benefit of past, present, and future generations.
	PROGRAMMATIC GOAL
12.	Maintain a high-quality monitoring, research, and adaptive management program.

This general core monitoring plan assumes that the "core" purpose of the GCDAMP monitoring program is to measure the status and trends of these key resources potentially affected by GCD operations and assess whether the trends are consistent with GCDAMP goals. However, monitoring is also necessary to ensure compliance with other environmental statutes, including the Endangered Species Act (ESA) and the National Historic Preservation Act (NHPA). Therefore, the GCDAMP core monitoring program is intended to meet the requirements of the GCPA while also supporting requirements for monitoring to meet other relevant environmental compliance mandates associated with federally listed endangered species and federally managed and register-eligible historic properties that occur within the Colorado River ecosystem (CRE).

1.3 Boundary and Definition of the Colorado River Ecosystem

The GCDAMP Strategic Plan (2003) defines the geographic scope of the adaptive management program as "the Colorado River mainstem corridor and interacting resources in associated riparian and terrace zones, located primarily from the forebay of Glen Canyon Dam to the western boundary of Grand Canyon National Park" (fig. 1). This definition effectively constrains the scope of the GCDAMP monitoring activities. Factors such as climate change or changes in resource conditions outside the immediate scope of the GCDAMP are assumed to be outside the purview of the core monitoring program.



A map of the Colorado River ecosystem from the forebay of Glen Canyon Dam to upper Lake Mead National Recreation Area

1.4 History of Monitoring the Colorado River Ecosystem below Glen Canyon Dam[1]

Management of the Colorado River requires efficient, effective monitoring of ecosystem resources and processes; however, establishing priorities for key resources and selection of appropriate monitoring parameters has proven to be a difficult process. Selection of appropriate monitoring variables has been hampered in the past by challenging logistics and a poor understanding of how rivers constrained in a bedrock channel, as opposed to alluvial rivers, function ecologically (Schmidt and others, 1998), limited data on many biological resources (Stevens, 1989), limited synthesis of data, poor understanding of monitoring as a scientific process, and inconsistent science administration, including information management. In this section, we document the history of efforts to understand what to monitor and how to monitor the resources and physical processes of the Colorado River from lower Lake Powell through Grand Canyon.

1.4.1 Pre-GCES Era (1921–82)

The earliest monitoring undertaken in the Colorado River ecosystem consisted of streamflow measurements made by the U.S. Geological Survey at Lees Ferry, starting in May 1921. In 1929, the

[1] This history of monitoring of the CRE below Glen Canyon Dam is based on a 2004 briefing document prepared for the GCDAMP by Dr. Lawrence E. Stevens of the Grand Canyon Wildlands Council, Flagstaff, Ariz., titled, “A Brief History of Monitoring the Colorado River Ecosystem.”

USGS started collecting suspended sediment samples at that site as well and conducted similar measurements at a second stream gage near Phantom Ranch. Monitoring was conducted by USGS technicians on a daily basis at the Lees Ferry and Grand Canyon streamflow gages (river miles, RM 0 and 87, respectively) from the 1920s until the fall of 1972, when the daily suspended sediment sampling was discontinued.

Environmental management and monitoring of the river corridor in Grand Canyon has historically been stimulated by recreation concerns. Owing to dramatic increases in river running and poor waste management practices in the 1960s, the National Park Service implemented an ecological inventory of the river corridor from 1973 to 1977 (Carothers and Aitchison, 1976; Carothers and others, 1979); this was the first comprehensive inventory of the river ecosystem. A primary component of this work initially was to inventory all campsites in the river corridor and assess their condition (Weeden and others, 1975). Through this initial inventory work and subsequent research efforts, numerous environmental issues that are recognized as problems today were identified, and groundwork for much of the subsequent river corridor science was established. Issues identified by Carothers and Aitchison (1976) included (1) identification of the significance of dam impacts on the riparian corridor (see also Turner and Karpiscak's [1980] photo-rematching efforts), (2) human waste management (Carothers and others, 1979), (3) monitoring camping beach erosion rates (see also Howard and Dolan, 1981), (4) nonnative burro damage to the riparian zone, (5) the need for an ongoing biological inventory program (see also Stevens, 1976; Ruffner and others, 1978; Sutkus and others, 1978; Carothers and others, 1979; Brown and others, 1987; Phillips and others, 1987), (6) endangerment of native fish, and (7) *Pogonomyrmex* ant infestation and sand discoloration of beaches in the absence of flooding. In a final phase of the inventory project, Phillips and others (1977) produced a riparian vegetation map of the river corridor. Calibration of that map could have established total riparian habitat area; however, further analysis of the map was not pursued.

Early monitoring and research efforts anticipated many issues that continue to be central concerns for National Park managers and that have a prominent role in the GCDAMP today. The initiation of fish monitoring arose from the original recognition by Miller (1946) of the endangered status of Colorado River fish, several of which were federally protected before the Endangered Species Act of 1973 was passed. The work of Carothers and Minckley (1981) set the stage for monitoring humpback chub spawning, which has been further refined and continues to the present. The recreational research of Shelby (1976) and his colleagues demonstrated significant impacts of boat types and crowding on visitor experience, laying the groundwork for subsequent National Park Service recreational management and monitoring programs. Also, Silverstein and Laursen (1976) identified the potential for erosion and worsening of rapids through debris flows. Collectively, these early research projects identified key river corridor management problems, presented baseline data, and helped solve several vexing environmental problems (see specifically issues 2 and 4, above).

1.4.2 Glen Canyon Environmental Studies Era (1982–96)

Although the National Park Service's 1973–77 ecological inventory work provided a more refined understanding of the ecological structure of the river corridor, subsequent National Park Service management focused more broadly on resources and recreational issues. This brought about an understanding that the issues involving river flow rates caused by Glen Canyon Dam management were beyond the scope of National Park Service jurisdiction.

In 1980, a strong public outcry was provoked by the Bureau of Reclamation Finding of No Significant Impact for rewinding Glen Canyon Dam's hydroelectric generators and increasing diurnal flow fluctuations. In response to that public concern, then Secretary of the Interior James Watt initiated the 1982–97 Glen Canyon Environmental Studies program (GCES). Phase I of the GCES (1983–87) produced more than 40 research studies, and Phase II resulted in nearly 100 studies. These research efforts identified virtually all of the contemporary issues related to river and dam management (Stevens and Gold, 2003).

The National Research Council (NRC) conducted independent reviews of the GCES program, producing several important syntheses and program critiques (NRC 1987, 1991, 1996). Their 1991 synthesis was particularly important for bringing together the state of knowledge on the system for the impending EIS. Walters and others (2000) observed that the GCES studies were primarily research and not monitoring, and they further observed that monitoring is critical for informing long-term adaptive management of the river. The need for planning a long-term monitoring program for this river ecosystem was recognized and highlighted during the GCES Phase II and its National Academy of Sciences review (NRC 1996).

National Academy of Sciences Monitoring Symposium (1992)

Much of the present adaptive management monitoring program for the Colorado River is directly or indirectly derived from the Environmental Impact Statement (U.S. Department of Interior, 1995) and Record of Decision (U.S. Department of Interior, 1996), but most of the monitoring guidance therein is derived from a 1992 NAS (National Academy of Sciences) symposium on long-term monitoring of the Colorado River (National Research Council, 1992). The NAS assisted the GCES in conducting a 2-day symposium following the Delphi format in Irvine, CA, bringing together leading experts on many aspects of ecosystem monitoring, river ecology, and Grand Canyon studies. The symposium, which was overseen by William Lewis, emphasized interactions between disciplines as well as integration of information. The meeting was organized around four disciplines found to be important by the NAS: geohydrology, environmental chemistry and biology, sociocultural resources (power generation, nonuse values, and cultural values), and information management. Gary E. Davis and L.H. MacDonald presented position papers on ecosystem monitoring objectives and practices from the perspectives of the National Park Service and the Environmental Protection Agency, respectively. Both emphasized that monitoring is a scientific process, based on adequate inventory, clearly defined management goals and objectives, and with appropriate reporting and information management. Geohydrological monitoring issues focused on climate, mainstream sediment transport, sediment resources, and tributary processes. Biological-chemical monitoring and research issues included native fish, trout and water temperature, the aquatic food base, riparian and endangered terrestrial resources and linkages, and air pollution. Sociocultural position papers were presented on cultural resource monitoring, recreation, and power economics. Information management issues that were addressed included program development, GIS applications, and Lake Powell. The 1992 symposium also endeavored to integrate these monitoring topics with break-out groups.

Although the 1992 symposium was regarded as a success by the participants, the results of the symposium proved difficult to incorporate into a coherent monitoring program for use in the 1995 final EIS. Duncan Patten (GCES senior scientist) cited several challenges to developing a monitoring program for the EIS: a lack of political agreement on relationships among variables, a lack of political consensus on program directions, and a lack of clearly defined desired future resource conditions.

GCES Era Monitoring Efforts

At about the same time that the NAS reviews were in progress, researchers and cooperators working for the GCES began acquiring data and testing various protocols in anticipation of developing future monitoring programs for aquatic and terrestrial resources. Initial efforts focused primarily on acquiring baseline inventory data about the resources of concern, such as archaeological sites and native fishes (for example, Fairley and others, 1994; Valdez and Ryel, 1995). Particularly with regard to fishes, this baseline data revealed longitudinal patterns in fish distribution, and was subsequently used to structure initial monitoring efforts. In addition, some effort was also directed toward pilot monitoring programs during the GCES era. For example, L.E. Stevens and numerous academic colleagues initiated new monitoring programs for several natural resources in the river corridor in 1989–90, including aquatic food base, avian studies (general and endangered species), sandbar erosion, and riparian resources. These monitoring programs were based on several premises, as described below:

1. Given that these were initial monitoring programs, it was anticipated that the early data would serve as a baseline and that the protocols would need reconsideration. Therefore, a synthesis and critical review were conducted early in each program, and baseline findings were published in various reports and peer-reviewed journals (Beus and others, 1992; Brown and Stevens, 1992, 1997; Brown and others, 1989, 1994, 1998; Stevens and others, 1995, 1997a, 1997c; Sublette and others, 1998).

2. Variation in the distribution of ecological resources and processes was strongly influenced by local and reach-based variation among the geomorphic settings, with debris-fan complexes and reaches of the river identified by Schmidt and Graf (1990) and Stevens and others (1995, 1997a, 1997c), along with dramatic downstream variation in aquatic productivity associated with the clear tailwaters below GCD giving way to progressively more turbid, less productive, and somewhat warmer waters far downstream. Site selection typically involved a stratified random sample selected from the overall population of available study sites, but included some sites (for example, sandbars) that had an extensive history of study. Several sites were selected in each reach, and response variables (sandbar area or volume, standing mass, or riparian vegetation cover and diversity) were measured on a regular (annual or more often) basis for the first several years. Subsequent syntheses of monitoring data provided clarification of the timing of measurements.

3. It was recognized that developing aerial mapping technologies and GIS held great promise, so analyses of aerial data (for example, sandbar distribution, backwaters, riparian, and upland vegetation) were initiated or explored to determine the value of such data, and accuracy of interpretation (Schmidt and others, 2004).

4. The initial monitoring studies emphasized the need for understanding dam impacts in relation to reference sites. Monitoring is a scientific endeavor, in which data from reference sites or controls are needed to distinguish ecosystem effects related to dam operations from, for example, climate effects. However, the issue of scientific controls has rarely been addressed by GCDAMP studies because early on the GCDAMP leadership decided that only field work geographically constrained to Grand Canyon would be recommended for funding.

The decision of the GCDAMP leadership that research and monitoring conducted by GCMRC will be geographically constrained to the Colorado River and limited tributary reaches within Grand Canyon places limits on the amount of learning that can be gained from comparison to controls. For example, Cataract Canyon in Canyonlands National Park (a much less regulated reach of the Colorado River upstream from Lake Powell) has many characteristics of free-flowing Western rivers, including high spring flows, enormous sediment loads, and seasonally warm water. Some AMWG members have expressed the desire to mimic these characteristics in Grand Canyon. However, the native fish populations in that reach appear to be in poor condition, although there are logistical limits on sampling there. A serious examination of control site data could greatly alter and potentially enhance future program directions in Grand Canyon.

The GCES riparian vegetation monitoring program focused on analysis of randomly selected plots stratified by river reach and associated with large debris fan/eddy complexes. Control plots were established in tributaries well beyond the influence of the Colorado River. These vegetation study sites were also selected for sandbar erosion studies. The sandbar studies focused on the area and volume of sand stored in an eddy, sandbar history through analysis of aerial photographs, the mechanisms of erosion (seepage erosion, hydraulic aggradation and degradation, wave action, wind action, and trampling), and responses of sandbars to initial EIS related experimental releases from Glen Canyon Dam during 1990–91. This monitoring program also recognized that vegetation data on whole debris fan/eddy complexes were needed for habitat analysis for terrestrial fauna. Therefore, these debris fan/eddy complexes with study plots and sandbar erosion data were also used to initiate a vegetation mapping project using true color aerial photographs. In addition to plot analyses, this program involved random stops to evaluate nonnative plant invasions (Stevens and others, 2001; Stevens and Ayers, 2002).

Other biological monitoring programs initiated or carried out in the GCES Phase II era (1989–95) included several avian and endangered species monitoring efforts. Brown and Stevens started a bald eagle monitoring program in 1988 that carried forward into the mid-1990s (Brown and others, 1989, 1998; Brown and Stevens, 1992, 1997). Sogge and colleagues developed and tested monitoring protocols for southwestern willow flycatchers (*Empidonax trailii extimus*; Sogge and others, 1997). Yard developed methods for assessing riparian bird diets (Yard and others, 2004), but those approaches have not been used in recent years.

Stevens and colleagues developed a census technique for monitoring waterbirds throughout the river corridor (Stevens and others, 1997a), compiling waterbird information from pre-dam river runner diaries, and drawing together 21 years of post-dam waterbird observation data that provided detailed insights into the positive impacts of Glen Canyon Dam on waterbird diversity and distribution; however, key questions about habitat use and visitor impacts on waterbird movement remain unanswered.

Meretsky, Stevens, and others developed small-plot monitoring protocols for the Kanab ambersnail (*Oxyloma haydeni kanabensi*s) during1994–97 (Meretsky and Stevens, 2000; Meretsky and others, 2000.) Those techniques have been used by the Arizona Game and Fish Department to monitor snails at Vaseys Paradise and at a successful second population establishment site downstream in Elves Chasm.

Lake Powell water quality data have been collected since the 1970s, especially temperature, pH, specific conductance, and dissolved oxygen, as well as some data on plankton distributions and concentrations. Some of the resulting data have been synthesized, peer-reviewed, and published, most notably by Hueftle and Stevens (2001) and more recently by Vernieu and others (2005).

Monitoring and assessment of archaeological and historical cultural sites by the National Park Service started in the late 1970s and continued, using a variety of forms and protocols, through the 1980s and early1990s. In 1993, the National Park Service implemented a monitoring program for archaeological sites that focused on documenting the presence of impacts from visitor use and erosion.

Tribal involvement with monitoring cultural resources in the CRE increased dramatically as a result of Native American involvement in the preparation of the Glen Canyon Dam EIS in the early 1990s. Recognition of the importance of traditional cultural properties and ethnobiology resulted in a flurry of cultural research for the 1995 final EIS (U.S. Department of Interior, 1995), and an ongoing tribal participation process. After completion of the EIS, several of the tribes developed proposals for monitoring resources of tribal concern; these proposals were implemented to various degrees as compliance monitoring activities tied to the National Historic Preservation Act Programmatic Agreement for Cultural Resources.

Several inventories of campsites in the CRE were conducted during the GCES era by Brian and Thomas (1984), Kearsley and Warren (1993), and Kearsley and Quartaroli (1997). Some aspects of recreational experience monitoring initiated by Shelby (1976) and his colleagues in the 1970s were carried forward by Brown and Hahn-O'Neill (1987). Recreation economics data and power generation data were compiled for the EIS, but little synthesis was accomplished, except in relation to impacts from individual flow experiments (Harpman, 1999). Nonuse value monitoring has not been pursued following work programmed under the GCES (Loomis and others, 2005a).

1.4.3 GCMRC Era (1997–present)

Following completion of the Operations of Glen Canyon Dam Final EIS in 1995, the DOI established the GCMRC in Flagstaff, Arizona. One of the primary objectives of the GCMRC is to provide long-term monitoring data on the status and trends of CRE resources below the dam. These data were intended for use by managers to evaluate the effectiveness of approved alternative dam operations (preferred alternative of the final EIS) relative to resource objectives identified within the EIS (see Lovich and Melis, 2007, for a summary and update on status and trends of all resources).

The draft final EIS contained a draft monitoring plan for resources below Glen Canyon Dam as an appendix (referred to here as the Patten plan). This plan was developed by GCES Senior Scientist Duncan Patten during the EIS period, in collaboration with many cooperators between 1990 and 1993. The Patten plan was reviewed by a National Academy of Sciences review committee in 1994 (National Research Council, 1994); this review recommended further development of the plan before implementation (including cost estimates for each monitoring element), but the requested revisions were never completed.

Initiation of the Protocol Evaluation Panel Process to Review and Refine Monitoring Protocols

In 1996, one of the first tasks undertaken by the GCMRC was to evaluate all previous science activities relative to perceived or documented long-term monitoring needs. The GCMRC proposed that previous or ongoing monitoring activities initiated by the GCES and carried forward in the GCMRC era would be evaluated jointly by cooperators, staff, and external peer reviewers through a process termed the Protocol

Evaluation Panel (PEP) review. The PEPs would be conducted through a series of meetings and workshops that focused on monitoring methods specific to each of the resource areas of concern, as defined in the 1995 EIS. Final reports from the PEPs would include recommendations for additional research and development, as needed to fully identify appropriate monitoring protocols for long-term implementation.

The first PEP review meetings were convened in the late 1990s to evaluate historically conducted remote sensing (analog air photography missions and associated change detection and mapping) and physical resource (primarily flow and sediment) measurements and modeling research. Following PEP meetings conducted in 1998–99 on physical resources (1999) and remote sensing (1998), additional reviews were conducted by the GCMRC on the terrestrial ecosystem (1999), aquatic ecosystem (fishes and aquatic food web [2000]), cultural resources (2000), Lake Powell and integrated quality of water (2001), survey control procedures (2002), and recreation (2005). With the exception of a PEP review in the area of economics, initial PEP reviews were completed for all resource areas by 2006.

In response to initial PEP reviews, new research in areas of monitoring development began in 2000 (remote sensing initiative, terrestrial, physical and modeling, etc.) and continues to the present (2010) with aquatic food web research and other projects derived from the various PEP review recommendations. The remote sensing initiative final report was completed in 2003. Sediment research toward monitoring began in 2001 and a final sediment monitoring PEP report was completed in 2006. Research aimed at terrestrial ecosystem monitoring began in 2001, and the final PEP review on both native and nonnative species was conducted in 2007. Research and development in the area of native fishery monitoring in both the main channel of the CRE and its tributaries began in 2000; the final fisheries (native and nonnative) PEP was completed in May 2009. Development of monitoring protocols in the areas of cultural and aquatic food web resources are currently the focus of research initiatives ongoing since 2005. Lacking any monitoring programs for socioeconomics, a formal PEP review for economics has yet to be convened, but a workshop conducted in December 2009 resulted in the development of a multi-year plan for developing future socioeconomic research and monitoring projects.

Development of Conceptual Ecosystem Model to Enhance Monitoring

One challenge following completion of the 1995 Operation of Glen Canyon Dam Final Environmental Impact Statement (FEIS) was to identify and implement monitoring efforts that would produce scientific data suitable for evaluating the new operating policy at Glen Canyon Dam. At that time, there was also a sense among managers and scientists that additional, comprehensive syntheses of available data needed to be undertaken with respect to major resource categories, such as sediment and fisheries. In addition, the need for development of a conceptual model for the CRE, consistent with the adaptive environmental assessment and management process, was identified by the USGS GCMRC and its cooperators.

This modeling effort began in 1998 and continued concurrently with the establishment of the AMWG and the development of the group's strategic goals for the CRE (1998–2002). There were three key objectives for the conceptual modeling exercise:

1. Conduct an exhaustive knowledge assessment of the various elements of the ecosystem on the basis of existing data and hypotheses posed in the EIS (and within the context of workshops that supported stakeholder and scientist interactions).

2. Identify, through modeling and simulation, data or knowledge gaps that were impediments to developing realistic simulations.

3. Identify future research directives (both experimental and otherwise) that would effectively fill knowledge gaps in the program related to management needs.

Development of the physical elements of the model (the conceptual Grand Canyon Ecosystem Model or GCEM) proceeded relatively quickly, mostly because there were abundant data in some key areas (hydrology, sediment, and river flow) and an operational model for the Colorado River Basin (RiverWare™) had already been developed by the Bureau of Reclamation. Other critical areas of the model development, however, were limited by the paucity of available data related to biology and sociocultural resource areas (Walters and others, 2000).

By 2000, it was clear that certain critical modules of the model could not even reliably predict the general direction of ecosystem resource responses to potential treatments of management actions, such as the response of native fishes to warmer water conditions through implementation of a proposed temperature control device. Although water could be routed through the ecosystem with confidence, there was considerably less confidence about the longer term relationship of flows to fine-sediment flux and sandbars. The inability of the GCM to accurately simulate higher level trophic (for example, fish) responses in critical areas was also a cause for concern among managers. Some progress has been made in recent years on improving modeling capabilities, but our existing modeling capabilities continue to fall short of being able to accurately predict experimental outcomes and require further work before they can serve as reliable tools to inform policy decisions.

The largest contribution made by the conceptual modeling project was the identification of various experimental flow and nonflow treatments that needed to be tested to provide managers with scientifically based options for most effectively meeting the proposed management goals. Experimentation has long been identified as a sign of “active” adaptive management and has been shown to be an efficient means of resolving the uncertainty associated with various alternative management policies (Walters and Holling, 1990). Simultaneously, the modeling project helped identify additional monitoring data that would be required to more fully evaluate the influence of the modified low fluctuating flow policy on downstream resources of concern. Although evaluation of all the resources outlined in the EIS has not been possible because of program funding limitations, the GCM has identified the general linkages between the various resources as related to dam operation. The experimental designs proposed and implemented in the GCDAMP have been a direct and logical outcome of conceptual modeling activities. Although still not complete, the experimental results to date have greatly advanced ecosystem understanding. Ultimately, the knowledge gained through these scientific activities in the CRE should lead to improved management options for GCD.

Development of a Long-Term Core Monitoring Plan

The need for a long-term core monitoring plan for the GCDAMP was identified as a critical program need by GCMRC managers and stakeholders at the inception of the Glen Canyon Dam Adaptive Management Program. Despite the recognition that such a plan was essential for the program to function effectively, completion of a long-term core monitoring plan has been an elusive goal for a variety of reasons. One important factor was a decision made at the outset of GCMRC's inception to undertake a systematic development of monitoring programs that involved the establishment of protocol evaluation panels for each key resource area, followed by 4–5 years of piloting monitoring protocols, then a period of analysis, synthesis, and revaluation, culminating in the implementation of long-term monitoring protocols. This process, which requires 4–5 years of research and development (R&D) for each key resource, got underway in 1998, starting with the physical science program, and is still in progress for some elements of the program (for example archaeological and tribal resources, aquatic food base, recreation, and socioeconomics).

Other factors that have hindered rapid progress in the development of a core monitoring plan are (1) lack of agreement among AMP stakeholders about the purposes and objectives of monitoring in general, (2) lack of agreement among AMP stakeholders and scientists about what should be included within a core monitoring plan (that is, what defines *core* monitoring as opposed to other kinds of monitoring, such as monitoring effects of experimental actions or monitoring of specific management actions), and (3) lack of agreement about what levels of precision and accuracy in monitoring data are necessary to achieve program goals. The goal of this current plan is to outline a scientific process to support GCDAMP decision-making to overcome these obstacles.

In addition to the creation of the PEP process, GCMRC initiated several planning efforts in subsequent years in an attempt to make progress towards development of a sound core monitoring plan for the GCDAMP. These initiatives included a multi-attribute trade-off analysis workshop in winter 2003 and an in-depth knowledge assessment workshop in July 2005. The Adaptive Management Program stakeholders also attempted to define their highest priority research and monitoring information needs by participating in a priority-setting workshop in 2004. In addition to these short-term initiatives, there was a major planning effort, led by GCMRC in collaboration with the Core Monitoring Team (CMT), an ad hoc group of the TWG, that tried to define a comprehensive long-term monitoring plan, and a second effort by an AMWG ad hoc committee known as the Science Planning Group (SPG), that tried to develop a long-term experimental plan. Both of these planning efforts fell short of their intended objectives, but each one made substantial contributions towards refining the scope and direction of a future monitoring plan, as described below.

Initial Attempts at Developing a Core Monitoring Plan, 2004–05: In March 2004, a core monitoring ad hoc committee composed of members of the TWG and GCMRC staff was convened by a decision of the AMWG. This group of individuals, referred to as the Core Monitoring Team (CMT), represented a cross-section of GCDAMP resource management concerns and scientific disciplines. It was envisioned by AMWG that the CMP would be developed collaboratively by this team. GCMRC would retain primary authorship of the CMP, while other members of the AMP would contribute sections.

Although the CMT strived for a minimalist strategy, this goal went largely unrealized. The CMT decided that the following resource categories of concern would be covered in the CMP: (1) sediment; (2) wildlife/vegetation; (3) fish; (4) food base; (5) register eligible historic properties; (6) other cultural resources of tribal concern; (7) hydrology; (8) water quality; (9) recreation; (10) threatened and endangered species; (11) power; and (12) non-native species. The CMT affirmed the importance of relating monitoring activities to questions arising out of the AMP strategic plan. Relevant fundamental questions included the following: (1) What and why do managers need to know? (2) Where do they want to know it? (3) How frequently do they need to know? (4) What are the general methods to obtain this information? (5) What is the level of precision/accuracy needed? (6) How will the monitoring data be presented? (7) Is it answering the managers' questions?, and (8) What are the metrics of success, and how is success defined?

During the September 2004, meeting of the CMT it was decided that monitoring activities for which a methodology still needed to be developed should not be handled the same way as projects that were already underway. Therefore, it was proposed and accepted by consensus of the CMT that the proposed monitoring activities would be classified as either "green," "yellow," or "red" depending on where they fit within the development cycle. Green projects were existing monitoring projects that had been evaluated by a PEP and implemented for one to several years using methods deemed adequate for long-term monitoring. Yellow projects had undergone a PEP review and were scheduled for completion and external peer review in the near future (FY05 or FY06). Red projects were still under development and needed a PEP evaluation in FY 2005 and beyond.

Incorporating the input from the CMT, a third draft of the CMP was distributed to the TWG on September 24, 2004, and was discussed at the March 10–11, 2005 meeting of the CMT. During this meeting, it was decided that monitoring activities that were still under development should not be included in the core monitoring plan, but should be included in a research plan. Therefore, the CMT members decided that all "yellow" and "red" projects would be removed from the CMP and placed in a yet to be developed research plan. A second outcome of this meeting was the recognition that even "green" projects still required refinement with respect to clear linkages to AMP goals, management objectives (MOs), information needs (INs), and compliance mandates, and also with respect to issues of data quality, accessibility, and analysis.

In March, 2005CMT subcommittee members decided that a complete revision of the current CMP was impractical within the timeframes allowed in the current development schedule and that a provisional plan would have to suffice for 2005–06. Therefore, a fourth draft of the CMP, this time composed only of the "green projects," was prepared in April, 2005. At the April 11–12, 2005, CMT meeting, some CMT members expressed the opinion that the existing draft plan was fundamentally flawed in both format and content. Criticisms included the following:

1. The plan did not provide the level of detail desired by AMP members.
2. The plan lacked information on the accuracy, precision, and frequency needed to ascertain change over time.
3. The plan did not provide an ecosystem perspective.
4. The plan was not integrated between scientific disciplines.
5. There was continuing debate over what is core monitoring vs. other kinds of monitoring.
6. There was disagreement over whether yellow and red projects should be part of the plan or part of a different plan.
7. The plan did not provide enough detail as to how monitoring projects addressed AMP goals.

Some of these issues reflect the concerns of individual stakeholders, and others reflect group consensus. For example, the group agreed that the entire CMP needed to be reoriented around AMP goals and the data necessary to support those goals, rather than continuing along the path of attempting to evaluate the existing GCMRC monitoring program on a project-by-project basis. There was also group consensus that the CMP should address at least some aspect of all the resources identified in the AMP goals, excluding goals 3 and 12. In addition it was recognized that an essential component of the plan was still missing—an ecosystem perspective. Furthermore, the CMT determined that the plan was hampered by the lack of a clear definition by stakeholders of what core monitoring was trying to achieve within the AMP, including fundamental requirements such as how much change in a resource needs to be detected over what period of time. There was general agreement that these fundamental issues needed to be resolved through additional TWG discussion.

The CMT subsequently determined that even if existing projects met all the evaluation criteria, budget realities would continue to constrain AMP monitoring activities and that therefore, a process needed to be developed that further prioritized AMP strategic goals, management objectives, and information needs so that rational decisions could be made relative to which monitoring activities would be funded at what levels and which ones would receive less funding or none at all. Once the CMT recognized that they needed to undertake an entirely new process for evaluating proposed monitoring activities, the group decided that GCMRC should complete a provisional plan for FY06 quickly and with minimal additional effort so that an entirely new, AMP goal-oriented core monitoring plan could be developed in the future.

Adaptive Management Work Group Prioritization Workshop, August 2004: Concurrent with the initial stages of the core monitoring planning effort, and as one direct outgrowth of it, the AMWG held a workshop in August 2004 to develop and prioritize management questions to guide the budget process. The workshop resulted in prioritizing a set of stakeholder generated questions . These questions helped to define the main resource concerns that the majority of stakeholders felt warranted greater emphasis in future research and monitoring programs. The top five AMWG priority questions in 2004 were identified as follows:

> ***AMWG Priority 1****: Why are the humpback chub not thriving, and what can we do about it? How many humpback chub are there and how are they doing? (GCDAMP Goal 2)*
>
> ***AMWG Priority 2****: Which cultural resources, including Traditional Cultural Properties (TCPs), are within the Area of Potential Effect, which should we treat, and how do we best protect them? What is the status and trends of cultural resources and what are the agents of deterioration?*
>
> ***AMWG Priority 3:*** *What is the best flow regime?*
>
> ***AMWG Priority 4:*** *What is the impact of sediment loss and what should we do about it?*
>
> ***AMWG Priority 5:*** *What will happen when we test or implement the Temperature Control Device (TCD)? How should it be operated? Are safeguards needed for management?*

The top five AMWG priority questions provided the basis for prioritizing resource concerns through the SPG process and prioritizing research and monitoring activities in the FY2007-2012 Monitoring and Research Plan that was subsequently recommended by the AMWG and approved by the Secretary of Interior in December, 2007.

Tribal Monitoring Workshop, April 2005: GCMRC convened a workshop with tribal stakeholders to review existing tribal monitoring approaches and to identify opportunities for integrating tribal monitoring programs with other new or ongoing Western science–based monitoring programs, where practical and feasible. In the course of this workshop, it became clear that the tribes did not want to change their monitoring approaches or rely exclusively on Western scientific methods to evaluate the state of the Grand Canyon ecosystem. The tribes maintained that they needed to assess resource conditions according to their own cultural beliefs and values, and they felt that their monitoring approaches also helped to achieve other important tribal objectives such as connecting youth with elders' traditional knowledge and strengthening their cultural connection with Grand Canyon. The workshop led to the development of several short "position" papers, which were later presented to the AMWG and discussed in some detail at subsequent TWG meetings. One outcome of these subsequent discussions was that the tribes received additional funding from Reclamation to pursue their monitoring projects independently from GCMRC.

Knowledge Assessment Workshop (KAW), summer 2005: Concurrent with the initiation of the Science Planning Group (see below), GCMRC convened a group of stakeholders and subject experts to review the state of current knowledge for each of the key resource categories identified in the AMP strategic plan. This assessment was intended to document knowledge about the various experimental treatments that had been conducted since operations were first altered in 1991. Specific objectives of the knowledge assessment were to (1) evaluate the uncertainties that persist regarding individual resource attribute responses of the Colorado River ecosystem to the various management actions (both flow and nonflow elements) undertaken as experiments over the last two decades, (2) develop strategic science questions that needed to be addressed to further reduce the uncertainties associated with the various flow and nonflow treatments, and (3) identify research and monitoring strategies that could be undertaken to answer the science questions.

The 2005 knowledge assessment was conducted within two workshops (May and July 2005), both of which promoted information transfer between scientists, as well as focused discussions between scientists and managers about past research and monitoring relative to various treatments. This exercise resulted in a categorization of the state of existing knowledge into three broad categories: (1) existing knowledge about a given resource was sufficient to determine both general trends and to quantify the rate and amount of change, (2) knowledge was sufficient to determine general trends, but not to quantify rate or amount of change, and (3) knowledge was not sufficient to reliably determine even general trends in condition/status. The KAW highlighted crucial gaps in existing monitoring and research programs, prompting further analysis and consideration of how to fill those knowledge gaps through future monitoring and research efforts.

Science Planning Group Activities, 2005–06: Termination of the Core Monitoring Team approach to developing a core monitoring plan coincided with the initiation of the Science Planning Group (SPG) in summer 2005. The primary purpose of the SPG was to develop a long-term experimental plan, but in the course of this effort, several activities were undertaken that helped to further the aims of core monitoring plan development. Specifically, the SPG revisited, refined, and prioritized the resource goals and core monitoring information needs for the program. The results of this prioritization exercise, reflected in Appendix A, have been used to guide the development of this current plan.

The SPG also recognized the need for the GCDAMP to more explicitly define the goals of the AMP and the desired future conditions of resources that the program seeks to maintain or enhance. The SPG did not succeed in defining specific desired future conditions (a.k.a. “target conditions”) for key resources, but it did help to shine a light on this key deficiency in the program—a deficiency that continues to hinder our ability to determine whether or not the GCDAMP is achieving its stated goals.

Development of a Strategic Science Plan and Monitoring and Research Plan, 2006–07: In the winter of 2005–06, with the arrival of a new GCMRC chief (the fifth in as many years), GCMRC decided to reassess the process being used to develop a core monitoring plan and approach it in a more logical, step-down fashion. Specifically, GCMRC decided to develop a series of strategic planning documents, starting first with a 5-year strategic science plan that explicitly addressed the priority management questions identified in the August 2004 AMWG workshop and the strategic science questions that had emerged from the 2005 KAW. This was followed by development of a 5-year Monitoring and Research Plan (MRP) that laid out a year-by-year approach for systematically tackling the knowledge gaps and research questions identified in the KAW.

The MRP also laid out a four-step process for developing scientifically robust, peer-reviewed monitoring protocols to address each of the resource goals identified in the 2003 AMP Strategic Plan. The first step involved the development of a General Core Monitoring Plan to provide a comprehensive overview of the information needs, proposed projects, and estimated budget requirements to comprehensively assess the status and trends in resource conditions, as proposed in the original AMP strategic plan. This document is that general plan, and it completes the first step in the four-step process.

Chapter 2. GCDAMP Monitoring Needs

Resources in and along the Colorado River in Grand Canyon have experienced profound changes as a result of the installation and operation of Glen Canyon Dam (GCD). Installation of a dam far from the river headwaters alters the river's physical and biological characteristics (Araújo and others, 2009; Rehn, 2009). In some cases, the river may return to a more natural state with increasing distance from the dam (the serial discontinuity concept; see Stanford and Ward, 2001, and references therein); however it is highly unlikely that the Colorado River can be restored to an entirely natural, pre-dam condition (Stevens and Gold, 2003). The operation of GCD makes the physical and biological components of the Colorado River below the dam distinct from less regulated analogs in the region (Stevens and others, 1997a), increasing the need to study and monitor the system in order to make informed decisions. The maintenance or improvement of natural resources in the Colorado River in Grand Canyon requires recognition that (1) profound physical and biological changes have occurred, and (2) maintenance and restoration activities are constrained within this altered ecosystem. For example, the sediment resources of the current system are limited and will require careful management if goals dependent on sediment conservation are to be achieved (Wright and others, 2008b).

Because the interactions among physical and biological ecosystem elements (Ricklefs, 1993) often lead to state changes that are unpredictable from studying the elements in isolation (Odum, 1977; Townsend and others, 2008), it is important for GCMRC to pursue monitoring in an ecosystem context. Ecosystem monitoring is most effectively pursued by teams of researchers from different backgrounds that are focused on developing a better understanding of the ecosystem as a whole (Odum, 1977). Together with numerous cooperators, GCMRC provides the diverse multidisciplinary research team needed to study and improve our understanding of the Grand Canyon ecosystem.

2.1 Monitoring within the Glen Canyon Dam Adaptive Management Program Strategic Plan Framework

The GCDAMP has identified 12 diverse resource-oriented goals and associated management objectives to guide research and monitoring activities. The resource goals encompass diverse ecosystem components that interact at various trophic levels. No single conceptual approach can capture all of the potential interrelationships among ecosystem elements; this difficulty is compounded by the diversity of the GCDAMP goals and the need to present research and monitoring results to stakeholders with widely varying interests. In an effort to present the different goals in as straightforward a manner as possible, while also relying on accepted scientific literature definitions, GCMRC distinguishes among the 12 GCDAMP goals by categorizing them as either resources or ecosystem drivers/stressors (Vinebrooke and others, 2004; Lamon and Qian, 2008; Townsend and others, 2008), which may produce either positive or negative influences on resources (Chapin and others, 1996). For GCMRC to provide meaningful information and recommendations to GCDAMP stakeholders and managers, it is critical to describe how the CRE elements enumerated in the goals are interrelated.

It is practical, and consistent with an ecosystem approach, to consider the goals in a hierarchy (fig. 2), envisioned as an inverted pyramid populated with some of the relatively higher trophic level resources at the top, deriving energy, nutrients and/or habitats from lower trophic levels farther down the pyramid.

The goals that are highest in the trophic web are those relating to humans and their cultural values—the goals that seek to protect resources reflecting basic human needs and habitat requirements (goals 9, 10, and 11) or that seek to protect specific species that Euro-American and traditional Native American cultures have deemed to be exceptionally valuable (goals 2, 3, 4, 5, plus specific components of goal 6). Laws and policies (for example, the National Historic Preservation Act, Endangered Species Act, Grand Canyon Protection Act) reinforce cultural values attributed to specific elements of the ecosystem, especially cultural resources (goal 11) and endangered native species (goals 2, 3, and 5). Supporting these higher levels in the hierarchy are the biological and physical drivers or stressors of the ecosystem such as the terrestrial and aquatic food web (goals 1 and 6), sediment (goal 8), and the water resource (goal 7) that may or may not provide adequate nutrition and habitat for supporting other elements of the ecosystem. Maintaining an active, effective adaptive management program and the data associated with monitoring and research (goal 12) supports all of the goals from the apex of the inverted pyramid. This hierarchy views Grand Canyon from a “bottom-up” perspective largely because the ecosystem is strongly influenced by the river, its hydrology (including variable and changing climate), and its canyon-bound geomorphological setting (Stevens and Gold, 2003).

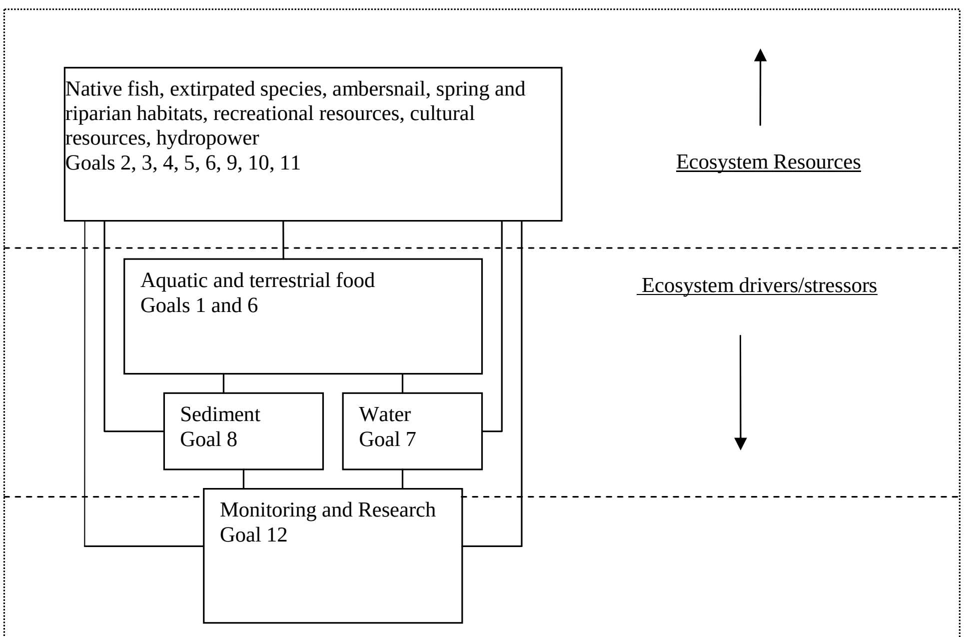


Figure 2. GCDAMP Goals in a conceptual ecosystem hierarchy

For GCMRC to provide meaningful information to GCDAMP stakeholders and managers, it is critical to describe not only the status and trends of the CRE elements enumerated in the goals, but also how ecosystem drivers or stressors impact those resource status and trends. Only rarely will a single driver or stressor act on a single resource (Townsend and others, 2008). It is thus necessary to monitor both resources and stressors.

Monitoring is the subject of this plan, but monitoring results must be combined with research to develop an understanding of both the resources and the drivers and stressors that impact the resources, comprising the basis of ecosystem management. Research is needed to clarify what to measure and how best to measure it. Research efforts being conducted by GCMRC and its cooperators are described in documents such as the Monitoring and Research Plan (U.S. Geological Survey, 2007) and other work plans.

Figure 3 illustrates the overall context of core monitoring in the GCDAMP. Core monitoring is a central component of many of the technical components of the GCDAMP. Core monitoring relies on inputs from AMP goals, conceptual models, resource inventories that establish basic information on the distribution of resources, and R&D to develop monitoring protocols. The output from core monitoring helps to assess the effectiveness of experimental actions or management actions and informs the development and validation of predictive models. Core monitoring also informs assessments of progress towards meeting AMP goals and desired future resource conditions.

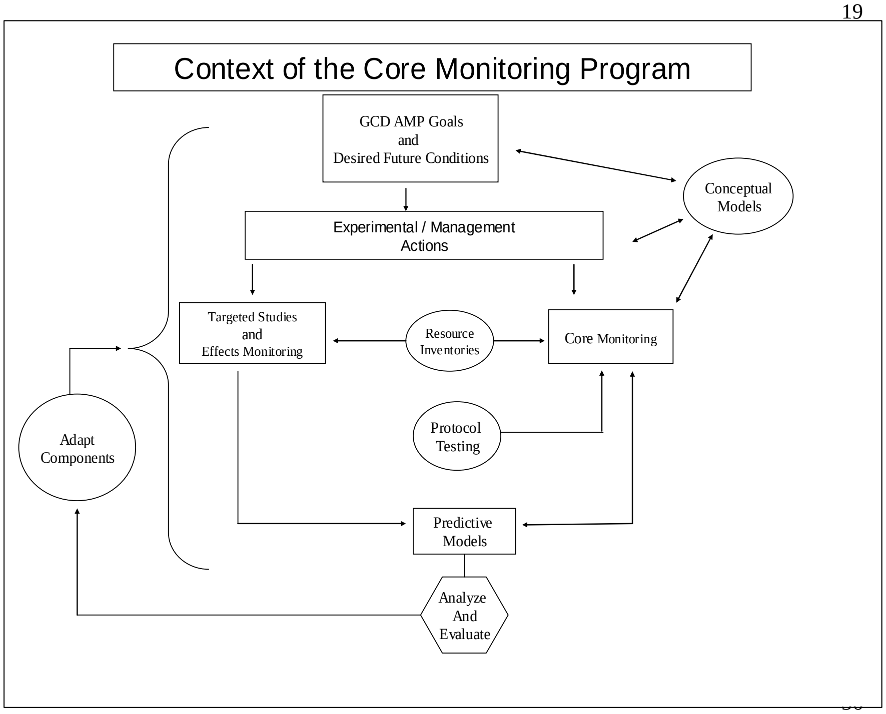


Figure 3. Core monitoring in the context of the Glen Canyon Dam Adaptive Management Program.

There is a large and expanding body of literature about how to design and implement ecosystem monitoring programs (for example, Busch and Trexler, 2003; Williams and others, 2007). Although specifics vary from program to program, the following key components are generally accepted to be part of any well-designed monitoring program:

- Clear definition of monitoring purpose(s) (with purposes clearly linked to program objectives)
- Definition of target conditions with which to evaluate progress towards achieving desired future conditions
- Use of conceptual and/or predictive model(s) to guide and inform monitoring program design
- Identification of key ecosystem indicators
- Explicit sampling designs
- Definition of data management, analysis, reporting, and archiving procedures

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To be useful in a monitoring context, management objectives should be specific and unambiguous, measurable with appropriate field methods and data, results oriented, and achievable (Williams and others, 2007). The current management objectives in the GCDAMP 2003 Strategic Plan meet some, but not all, of these criteria. The GCDAMP Strategic Plan defines broad resource-focused goals (see table 1) and multiple management objectives under each of the goals. Although general individual resource goals have been qualitatively defined for the GCDAMP, these do not provide much specificity, nor are they linked by an overarching goal such as restoration, or balancing goal outcomes among competing mandates. The GCDAMP would benefit from additional efforts by the stakeholders to further identify specific overarching goals and define attainable performance measures.

The core monitoring program implemented by GCMRC and cooperators is intended to inform managers and stakeholders as to whether AMP goals and objectives as define in the AMP Strategic Plan (GCDEAMP 2003) are being met. Measurable objectives or desired future conditions (DFCs) have yet to be defined and approved, although the development of target conditions has recently (2010) become a priority of the Department of the Interior and an ad hoc group of the AMWG. In the absence of clearly defined measurable and attainable objectives, Core Monitoring Programs are being designed to report both quantitative and relative measures of change (for example, a resource is increasing or decreasing relative to a previous baseline measurement). Once specific target conditions have been defined, the core monitoring programs can be further refined to produce data specifically addressing those targets.

GCMRC proposes the following guidelines for use by managers and stakeholders in developing DFCs:

Target conditions need to be

- measurable
- geographically specific
- feasible both financially and scientifically
- attainable
- written at a level of detail consistent with current knowledge
- relatively easy to understand

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- compatible with the AMP goals and management objectives

2.3 Core Monitoring Information Needs and Indicators of Resource Condition

A suite of core monitoring information needs (CMINs) is defined in the GCDAMP strategic plan (2003) for each goal. The CMINs are tied to the management objectives identified under each goal. After AMWG prioritized key research questions in August 2004, the GCDAMP's 2005–06 Science Planning Group (SPG)—an ad hoc committee of the AMWG—refined and prioritized the CMINs under each strategic goal (see Appendix A for the final list of revised and prioritized CMINs). This core monitoring plan relies on the revised and prioritized list of CMINs to guide development of the long-term core monitoring program.

Although the CMINs identify basic information needed by managers to evaluate the success of the AMP, some CMINs require further interpretation by scientists in order to be implemented in a monitoring context. For example, the "condition" of the rainbow trout fishery cannot be monitored directly but must be defined in terms of specific measurable "indicators" of condition. For rainbow trout, for example, overall condition is determined from monitoring data that measure length, weight, and number of captured fish. These individual condition indicators are then run through a simple algorithm to develop a standardized assessment of overall "condition factor" for rainbow trout (Anderson and Gutreuter, 1983).

Definition of core monitoring protocols first requires determination of the indicators best suited to meeting the CMINs of the GCDAMP. The specific indicators measured for each resource are described in Chapter 4.

2.4 Relationship between Monitoring and Modeling

Conceptual models are best used to organize thinking and focus discussions about the ecosystem in question, since new data generally lead to a better and sometimes different understanding of how the ecosystem works. For any monitoring program, understanding key linkages in the models is essential to the process of data analysis and interpretation (Kurtz and others, 2001).

During FY2010–11, GCMRC is planning to continue to expand and refine specific sub-elements of the Colorado River conceptual ecosystem model where significant new information is available. This includes understanding the effects of the interrelationship among flows, temperature, and sediment conservation and evaluating factors that may be responsible for recent increases in native fish. This may be accomplished by linking Lake Powell and downstream temperature simulations to fine sediment, food web, and fisheries sub-models. Development of terrestrial landscape models relating dam operations to cultural and recreational resource responses is also being considered.

One fundamental linkage among modeling, monitoring, and active adaptive management is the use of monitoring data collected during major policy experiments (e.g., high flow tests) to test key hypotheses about ecosystem processes and function. If the same models are supplied with different forcing conditions, perhaps similar to those that would be realized with the implementation of a different management policy, they may provide quite disparate predictions of resource trend. In this case, past monitoring data and models cannot offer much insight into optimum policy choices. However, if resource status and trends are monitored during one, or preferably multiple experiments, the observed resource trends can be compared to the model outputs to attempt to identify which hypothesis (embedded in one of the models) appears most likely to be governing resource response. Paired monitoring and modeling to discriminate among alternative hypotheses of system function has been described as a defining characteristic of active adaptive management, and lies in stark contrast to less informative surveillance monitoring (Yoccoz and others, 2001; Nichols and Williams, 2006).

2.5 Integration of Monitoring and Management Activities across GCDAMP Programs

The GCMRC Strategic Science Plan (U.S. Geological Survey, 2007) explicitly emphasizes the need to employ an interdisciplinary, integrated science approach over the next 5 years to better support the AMWG’s goals of managing and sustaining competing resource values to benefit both humans and the natural ecosystem. An underlying premise of both the GCDAMP Strategic Plan (2003) and the GCMRC Strategic Science Plan (2007) is that single resources should not be studied in isolation from each other or from the sociocultural context in which they occur (see fig. 4).

INTEGRATED CORE MONITORING PROGRAM

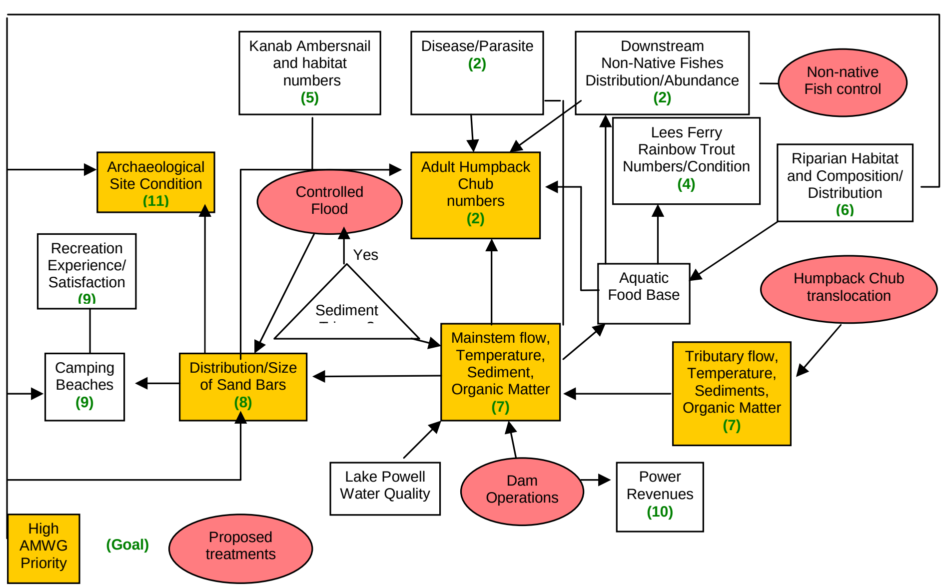

Figure 4. Conceptual diagram of linkages between various resource categories, monitoring data, and potential management actions. Numbers within boxes indicate associated GCDAMP resource goals, and shaded ellipses indicate a spectrum of both experimental flow and nonflow management policies.

Monitoring will continue to be tied to core monitoring information needs related to specific GCDAMP goals, but an explicit objective of this plan is to ensure that information will be compatible among the various monitoring and research projects. This is to be achieved by explicitly identifying needed inputs for each monitoring program that will come from or are dependent on outputs from other monitoring and research programs, and by identifying the appropriate output formats required to address other monitoring program needs. The use of outward-looking matrices (see example in fig. 5 below) provides one simple mechanism for articulating linkages and enhancing integration across monitoring program boundaries.

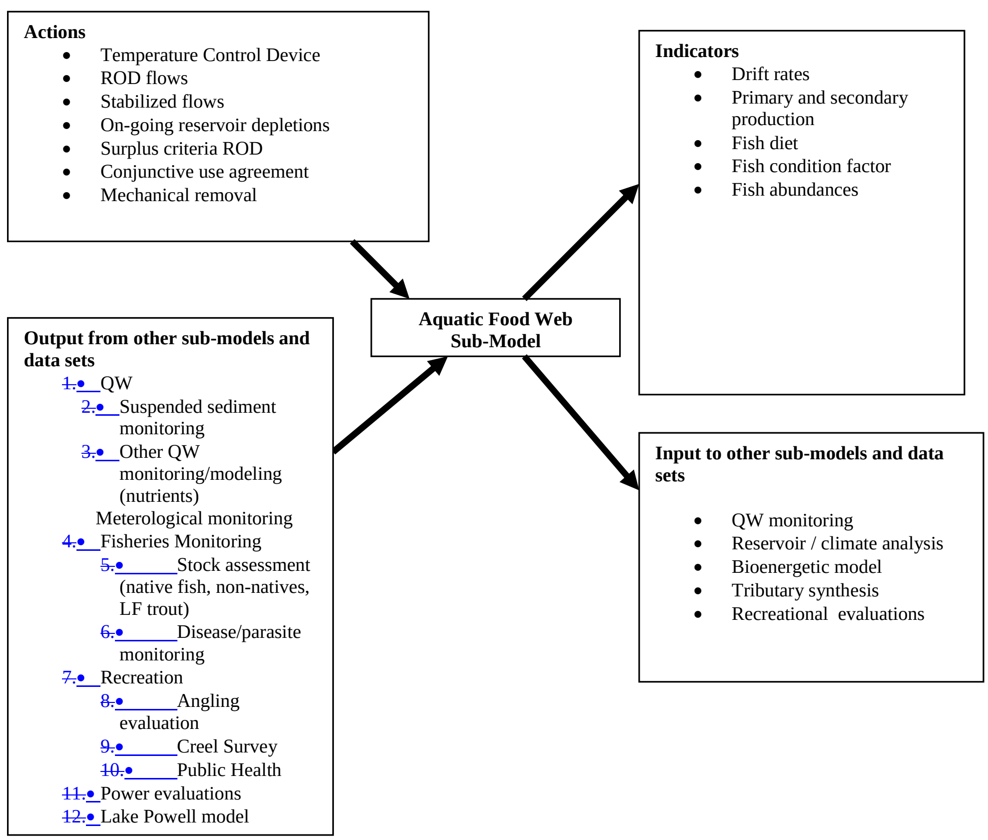

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Figure 5. An outward-looking matrix for the aquatic food web program.

2.6 Integration with Other Monitoring Programs in the Region

This general core monitoring program is being designed not only to improve integration across program areas, but to improve integration with other ongoing monitoring efforts that lie outside the purview of the GCDAMP, but are nonetheless relevant to evaluating progress towards achieving AMP goals. In biology, for example, the U.S. Fish and Wildlife Service is currently working in partnership with GCMRC to collect scientifically robust monitoring data that serve the need for compliance with both the Endangered Species Act and the Grand Canyon Protection Act. In the recreation arena, GCMRC and Grand Canyon National Park are collaborating in the collection of historical data about campsite distribution and quality to serve the needs of both the Park's Colorado River Management Plan (CRMP) monitoring program and the GCDAMP. Specific examples of current GCDAMP monitoring programs that are being implemented collaboratively to meet multiple agency needs include the following:

1. Mainstem fish monitoring and humpback chub monitoring. Monitoring of native and nonnative fishes in the mainstem Colorado River and the Little Colorado River has been the result of a close, productive collaboration among GCMRC, the Arizona Game and Fish Department (AZGFD), and the U.S. Fish and Wildlife Service (USFWS). The monitoring protocols have been developed through a three-way consultation that involved meeting multiple times per year; all three agencies have worked together to present monitoring protocols for review by the 2009 Protocol Evaluation Panel for Grand Canyon Fishes. Following recommendations of the 2009 PEP, the three agencies are now working together to conduct data analysis in response to PEP critical reviews and recommendations.

2. Rainbow trout monitoring. GCMRC collaborates with the AZGFD to monitor the rainbow trout population from Glen Canyon Dam to Lees Ferry. This collaboration has resulted in a shared, integrated approach to the development and implementation of monitoring techniques to address GCDAMP goal 4. Both GCMRC and AZGFD personnel work on the monitoring methods, data collection, data interpretation, and report writing. Both agencies worked closely with the 2009 PEP for Grand Canyon Fishes to review and revise monitoring methods. The two agencies are working together to incorporate monitoring of early life stages of rainbow trout in collaboration with Ecometric, Inc., a private cooperator.

3. Kanab ambersnail monitoring. GCMRC collaborates with the AZGFD to monitor the Kanab ambersnail at Vaseys Paradise and Elves Chasm; on-site monitoring and conservation actions have been led by AZGFD. Grand Canyon National Park has recently committed to participate in this monitoring effort as part of their Colorado River Management Plan, and shared photo monitoring from river left, opposite Vaseys Paradise, is being coordinated among GCMRC, AZGFD, and the Park.

Outside of the GCDAMP, various research and monitoring programs are being implemented to meet specific resource management needs at Glen Canyon National Recreation Area, in Grand Canyon National Park, and on Hualapai and Navajo Nation lands. National Park Service and tribal resource management programs relate to ongoing mission-driven or mandated management actions such as implementation of the Colorado River Management Plan. On National Park Service lands, such management actions form the core of park activities related to natural, cultural, and recreational resources. Similar programs may be found on tribal lands adjacent to the parks along the Colorado River. All of these activities, although occurring outside of the formal GCDAMP process, nonetheless may provide critical information that could be linked to ongoing GCDAMP efforts.

In the early 1990s, responding to criticism that it lacked basic knowledge of natural resources within park units, the National Park Service (NPS) initiated its own Inventory and Monitoring Program in an effort to detect long-term changes in biological resources (National Park Service, 1992). At the time of the program's inception, basic biological information, including lists of plants and animals, was absent or incomplete for many park units; in fact, in 1994, more than 80 percent of NPS units did not have complete inventories of major taxonomic groups (Stohlgren and others, 1995).
A host of NPS-sponsored research and monitoring programs are currently underway within Glen and Grand Canyons to address key resource concerns that may indirectly address some of the interests of the GCDAMP. Included are baseline programs such as mountain lion (*Felis concolor*) and big horn sheep (*Ovis candensis*) inventories, threatened and endangered species inventories (for example southwestern willow flycatcher (*Empidonax trailii extimus*) and spotted owl (*Strix occidentalis*)), and monitoring of springs hydrology and neo-tropical birds. In addition to natural resource inventories and monitoring, in recent years the NPS has undertaken some research related to recreational use of the Colorado River to inform development of the CRMP, Backcountry Management Plan, and Aircraft Management Plan.

Species inventories and long-term monitoring have both direct and indirect value for the management of Grand Canyon National Park and Glen Canyon National Recreation Area, and the GCD monitoring program and adaptive management program have direct relationships to this NPS program. The GCMRC, through its monitoring programs, is able to provide to the NPS changes in species lists that are not only useful in resource interpretation and facilitating visitor appreciation of natural resources, but are also critical for making management decisions. In addition, knowledge of which species are present, particularly species of management concern, where they occur, and the status of their populations provides for informed planning and decision making on the part of the NPS.

In addition to information on the biological systems of the river corridor, GCMRC also provides to the Park Service information on changes occurring to recreation and cultural resources in the river corridor. Information from GCDAMP activities has assisted the NPS in quantifying camping beach availability and condition for the CRMP, while previous beach inventories form a core component of current GCDAMP-related campsite assessments. Currently, GCMRC is developing new monitoring protocols to measure physical changes at archaeological sites related to dam operation effects. These quantitative measurements will complement and enhance other non-quantitative management-oriented monitoring data that NPS routinely collects at these sites.

Chapter 3. Development of Individual Core Monitoring Plans and Management Strategy to Support Them

After information needs are identified in adaptive management programs, development and implementation of monitoring programs typically proceed in three phases (Atkinson and others, 2004):

1. Resources are inventoried and key relationships between physical process, species, habitats, and other causes of variation such as dam operations are identified.

   This was largely completed for most GCDAMP resource goals by the early 2000s

2. Long-term monitoring protocols and sample designs are pilot tested.

   This step has been the focus for GCRMC during the past 8-10 years

3. Long-term monitoring and adaptive management activities are implemented.

   This is where we are now

As discussed in chapter 1, the GCDAMP Monitoring and Research Plan (U.S. Geological Survey, 2007) lays out a four-step process for defining and refining core monitoring projects associated with various GCDAMP goals and key resources based on the best currently available information. This general Core Monitoring Plan (CMP) is the first step (1). The remaining three steps comprise the following activities:

2. Annual Information Needs Workshop (multiple resources may be addressed)
3. Scientific Protocol Evaluation Panel (PEP) reviews
4. Core Monitoring Program report review and approval

This chapter describes steps 2-4 in detail, including information necessary to support the development and implementation of individual core monitoring plans in Step 4. This plan outlines a flexible approach which integrates risk assessment, trade-off analyses, and specified criteria in the development of the individual plans so that managers will have the information necessary to make informed decisions about the scope, intensity, and cost of the individual core monitoring programs and overall cost of the final core monitoring program.

3.1 Process to Develop Individual Core Monitoring Plans

The development of individual core monitoring plans tiers from and directly reflects the program goals, management objectives, and core information needs previously articulated by AMWG, and described within the 2003 AMP Strategic Plan. The AMP Strategic Plan, in turn, lays the foundation for other planning documents, including the 2007 Strategic Science Plan (SSP) and the 2007-2011 Monitoring and Research Plan (MRP) (U.S. Geological Survey, 2007). This CMP builds on these existing plans.

None of the aforementioned plans are intended to be static documents. As information is developed and management priorities are addressed, the plans will need to be revisited and may need to be updated to reflect current program priorities in accordance with the approved science planning process (Figure 6).

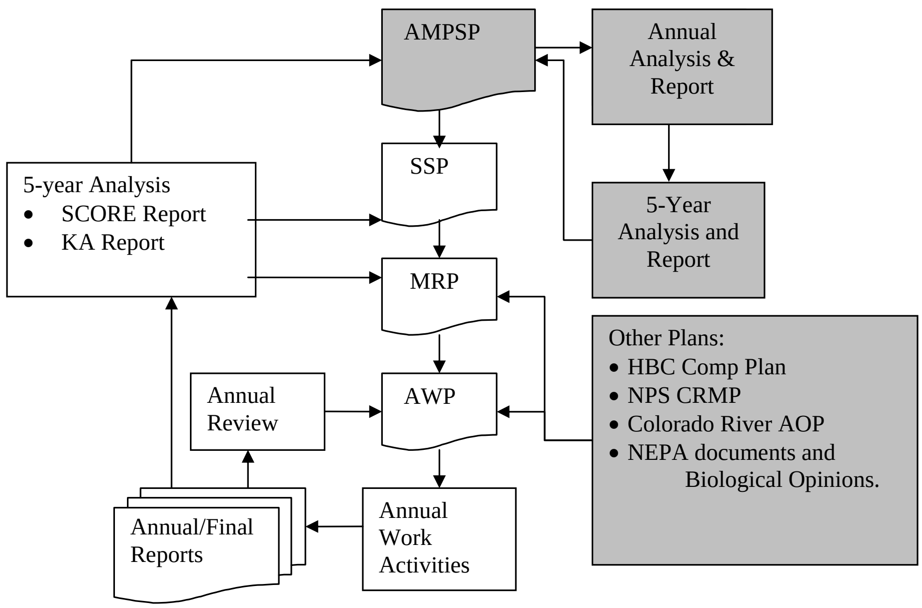

Figure 6. Collaborative science planning and implementation process. The Glen Canyon Dam Adaptive Management Program and the U.S. Department of the Interior have lead responsibility for the shaded boxes. The GCMRC has lead responsibility for the boxes that are not shaded.

Until such time as the AMP Strategic Plan is revised, GCMRC will rely on the goals, objectives and key definitions described in the 2003 plan, as well as the strategies and priorities identified in second-tier plans that have been formally reviewed and approved by AMWG for guiding the development of the core monitoring program. The general four-step process for defining and refining core monitoring projects incorporates flexibility to respond to changing AMP priorities and refinement of information needs. Depending on the scope and complexity of proposed monitoring plans, a range of options may be developed through this process, with varying tradeoffs of cost, statistical precision, and extent. GCMRC can articulate measures of risk associated with these choices, to the extent practicable, but managers must ultimately make choices about how much risk is acceptable and how to implement and pay for the program. It is likely that the AMP will choose lower risk, and thus more costly, options, initially. Thus, the cost estimates in this plan likely bracket the upper end of possible funding needs.

3.1.1 Information Needs Workshop

Step 2 of the four-step planning process involves conducting annual information needs workshops. GCDAMP monitoring programs are currently in various stages of development, with some being ready for long-term implementation and others still undergoing research and development. After each project

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Formatted: Indent: Hanging: 36 pt, Bulleted + Level: 1 + Aligned at: 18 pt + Tab after: 36 pt + Indent at: 36 pt, Tab stops: 9 pt, List tab + Not at 18 pt + 36 pt has been test piloted, it will be subject to a PEP review prior to finalization of the long-term monitoring protocols. This review will be preceded by a TWG information needs workshop to reaffirm and clarify the core monitoring information needs (CMINs) identified in the GCDAMP Strategic Plan (2003) and updated by SPG(Appendix A).

GCMRC will annually conduct a TWG information needs workshop to review and refine specific information needs and the proposed scope of monitoring for specific resources. The workshop will also identify specific questions that managers would like to have addressed in the follow-up protocol evaluation panel for each resource goal. For example, in FY2009 a TWG information needs workshop was held to review the CMINs associated with native and nonnative fish monitoring.

The schedule for conducting information needs workshops on other core monitoring projects is shown in table 2 at the end of this chapter. This is the point where needed risk assessments and trade-off analyses will be discussed between GCMRC and TWG and integrated into the monitoring plan development. If requested, GCMRC will provide to TWG a discussion of the trade-offs and potential choices in the protocols that would be reasonable to consider, based on GCMRC experience in developing the protocols. These options can be reviewed with TWG prior to GCMRC developing a final core monitoring proposal in Step 4.

3.1.2 Scientific Protocol Evaluation Panel Reviews

Step 3 of the four-step planning process involves conducting scientific protocol evaluation panel (PEP) reviews to review the monitoring needs articulated by managers during the information needs workshop, review the results of pilot monitoring efforts and other relevant research and development activities, and recommend future monitoring protocols and other technical specifications for the monitoring project. These PEP review panels are comprised of independent scientists who have no vested interest in GCDAMP. The scope of the PEP's review will be articulated in writing in advance of the PEP and supported with relevant literature. The following information will be collected, compiled, and distributed to the panels in advance of the review:

- GCDAMP management objective and information needs, as refined in the annual information needs workshop
- Past and presently used monitoring protocols, including their technical or scientific basis
- Information on existing protocols, including methods and articles that describe various monitoring approaches
- Requested risk assessments or trade-off analyses

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The review process may also involve reviewing technical presentations from GCMRC and other researchers, as well as field trips. The panel develops its final report and recommendations in an executive session. The PEP report presents findings and recommendations to the GCMRC chief and the science advisors. The report reviews the positives and negatives of current monitoring protocols, and makes recommendations for improvement. The results of each PEP evaluation are reviewed by TWG members, and comments are forwarded to the GCMRC chief for consideration before new or modified monitoring procedures are developed. A more detailed discussion of the PEP process is provided in Appendix B.

3.1.3 Step 4: Core Monitoring Program Reports/Individual Core Monitoring Plans

Step 4 of the 4 step planning process involves preparing a detailed individual core monitoring plan (report) that incorporates the results of information needs workshops and the PEP evaluations and recommendations, as well as TWG input. Each core monitoring report (CMR) will include the following information:

- GCDAMP goal(s) addressed, including CMINs
- Project title
- Principal investigator(s)
- Geographic scope
- Justification for monitoring effort including criteria for protocol inclusion and risk assessments for critical monitoring choices
- Project goals, tasks, and schedule by task and CMIN
- Key science questions and managers' information needs addressed
- Linkages to other resources processes and models
- Monitoring protocols, including sampling designs, level of data resolution, accuracy and precision assessment, etc.
- Expected outcomes, including outputs by fiscal year, reports, guidelines, models, etc.
- Projected cost of project or program by fiscal year using trade-off analyses describing a range of choices and costs based on risk assessments

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Each draft final individual core monitoring plan will be reviewed by the science advisors and then provided to the TWG for their final review, deliberation, and endorsement. When requested by TWG, trade off analyses will be conducted and summaries describing various suites of choices for the overall monitoring program will be provided. Issues related to the report will be resolved at the TWG level or elevated to the AMWG and/or Secretary's designee, if needed.

3.1.4 Principles of Individual Core Monitoring Plan Development

Environmental decisions in the GCDAMP generally involve complex scientific and technical issues, plus a wide variety of program participants. Scientific uncertainty, value conflicts, ecosystem, and social dynamics all contribute to difficulties with decision making. The goal of the process described in this chapter is to further refine those choices through a collaborative relationship between TWG, AMWG, and GCMRC. To accomplish this, the development of individual core monitoring plans will adopt a collaborative framework utilizing (a) program Goals and CMINs, (b) criteria for element inclusion within plans, and (c) trade-off analyses.

3.1.4.1 Goals and CMINs

The results of the 2005 Science Planning Group (SPG) prioritization of CMINs (see Appendix A) have been used to guide the development of the monitoring protocols for the individual core monitoring plans. The priorities and ranking of core monitoring information needs by the SPG are primary criteria used in developing the individual plans.

In the future, quantitative indicators of desired future conditions (DFCs) may be defined by TWG and AMWG to further focus core monitoring approaches. Until quantitative DFC are developed, this program will move forward with developing individual monitoring plans based on existing AMWG guidance, and incorporating trade-off analyses and risk assessments as appropriate, with the recognition that some plans may need to be revisited and refined after DFCs are established. At that point, plans can be modified to be more responsive to the DFCs. It is likely that in the absence of clearly articulated DFCs, the plans will have to be broader in scope, and thus may be more costly to implement in the near term.

3.1.4.2 Criteria

The primary criteria for the development of monitoring protocols and the eventual core monitoring plans themselves are the CMINs, (Appendix A). In the future, the TWG may develop additional specific criteria for determining which elements of a given plan are essential to include and which ones are less essential. These criteria could include:

- CMIN Priority: a specific resource or a specific indicator of resource condition is -a high priority for the program to monitor
- Confidence: activities with high confidence of relating to changes in dam operations or -eventual definition of DFCs
- Adequacy: to answer critical questions and inform critical decisions in the program.

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3.1.4.3 Trade Off Analyses for Risk Assessment Purposes

As needed, trade-off analyses will be conducted to provide managers with information needed for subsequent risk assessments that they may wish to perform in order to weigh the risks of making decisions based on monitoring data of various levels of accuracy or precision and their associated costs.

Examples of trade-off analyses that might be undertaken include:

- Analyses of trade-offs between statistical precision, sampling intensity/extent and costs, and the scientific implications of these trade-offs. (A series of options might be evaluated which show how the power is reduced, or other effects including costs are altered, by either reducing or increasing sampling intensity or extent)

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- Trade-offs in monitoring design and statistical rigor (including the use of power analysis to develop designs and set sampling levels to achieve desired precision)

The current work on the Goal 2 fish program illustrates how trade-off analyses may be incorporated into future core monitoring plans. First, GCMRC held an information needs workshop with TWG members identifying critical information needs and integrated that information with their task to the PEP for the review of the fish program. The PEP considered these issues along with the proposed monitoring protocols and requested a number of analyses (e.g., sensitivity, risk assessment, etc.) to test various scenarios on how to modify the program to be responsive to GCDAMP needs. GCMRC is conducting these analyses and intends to bring forward a plan in summer 2010 that incorporates these analyses for TWG to review and consider, so that TWG and AMWG can assess the risks and benefits of alternative approaches when deciding whether to approve a core monitoring plan for long-term funding.

In order for managers to make good decisions, the necessary decision support system must be in place to fully evaluate risk, costs, and the ability to meet program goals. Following guidance provided by Maness (2005), the tradeoff system should have the following objectives:

1) Fully identify the costs, benefits and reversibility of decisions where possible to do so.

2) Use discussion and consensus to carefully craft a vision of the overall goals of the management paradigm, including ethical or other considerations that define the boundaries of decision making. The vision should describe the higher standard required for high cost and/or irreversible decisions. Standards should be based on the Safe Minimum Standard argument.

3) Build a public trust in the process of resolving conflicts about the balance of inputs, outputs and attributes to support the vision.

4) Continually improve performance and goal setting as learning occurs and new information becomes available.

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Although this program does not have DFCs in place, it is possible to move forward using trade-off analyses to weigh the various types of considerations under each specific core monitoring plan. Trade-off analyses could take many forms. GCMRC will discuss with TWG members how trade-offs could be described during the information needs workshop and will develop core monitoring plans with sufficient information to allow TWG to understand and weigh the risks and trade-offs associated with a given approach; however, TWG needs to develop its own process for ultimately deciding how to agree upon the scope of individual core monitoring plans.

3.2. Implementation of Core Monitoring Plans

The four-step approach to developing core monitoring protocols has been developed by GCMRC in order to meet the diverse information needs of GCDAMP stakeholders using a scientifically defensible, peer-reviewed process.

Projects that are approved for core monitoring status will receive first consideration for funding each year. Core monitoring projects will be reviewed during the development of the GCMRC annual or biennial work plan and may be revised to incorporate new information, findings, and monitoring techniques that may improve their effectiveness. After FY2015, a more comprehensive review of core monitoring projects will be conducted at 5-year intervals.

3.2.1 Implementation Timelines

Although sufficient science has been completed to define some of the required long-term monitoring methods for fine-sediment mass balance, terrestrial vegetation, and monitoring native and nonnative fishes, several other areas of monitoring have not yet been completely resolved. Areas of monitoring where research and development on monitoring are still underway and for which PEPs are planned between fiscal years 2010 and 2015 include the following subject areas:

- aquatic food web and downstream water quality (nutrient mass balance and trophic linkages)
- cultural resources and archaeological sites
- Lake Powell water quality
- campsites
- socioeconomics

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Other projects that are currently in various stages of research and development will be brought forward for review over the course of the next 5 years with the goal of having a fully developed core monitoring program in place by FY2015. The proposed schedule for undertaking core monitoring reviews of all projects is summarized in Table 2.

Table 2. Proposed schedule for core monitoring program development.

Goal	Resource	Completed PEPs	R&D/Pilot Phases	CMIN Workshop/Final PEP	CMP Report	Implement CMP
1*	Food base	FY00	FY06–08	FY11	FY11	FY12
2	Native fish	FY00	FY10	FY09	FY10	FY11
4	Lees Ferry trout	FY00	FY01–06	FY09	FY10	FY10
5	Kanab ambersnail	FY00	FY01–10	FY11	FY11	FY12
6	Riparian and spring communities	FY00	FY01–06	FY07, FY12	FY07	FY08
7*	Quality of Water	FY98 FY02	FY98–06	FY11	FY12	FY13
8	Sediment	FY98 FY02	FY98–06	FY06	FY07	FY08
9**	Recreational Experience Quality	FY05	FY07–11**	FY12**	FY12*	FY12*

10	Hydropower	N/A	FY07	FY09	FY10	FY11
11	Cultural Resources	FY00	FY07–12	FY13	FY13	FY13

* The GCMRC currently plans to conduct a single protocol evaluation panel to review aquatic food base studies, downstream water-quality monitoring, and Lake Powell monitoring

** Specifically campsite monitoring

3.2.2 Implementation of Individual Core Monitoring Programs

Development and implementation of each GCMRC core monitoring projects generally follows a similar phased approach, as outlined in Table 3. The process depicted in Table 3 will be used to guide development and implementation of all core monitoring projects described in Chapter 4.

Table 3. Programmatic approach used by GCMRC to guide development and implementation of the core Monitoring Program for the GCDAMP (After Palmer and Landis, 2002; Turner and others, 2009).

Element	Activity	Tools
Pre-planning	Define goals and information needs Define project elements	Information Needs Workshop PEP reviews of R&D, pilot programs, and previous related monitoring programs
Planning	Develop General Core Monitoring Plan Develop detailed Core Monitoring Project plan, including: • Monitoring design • Measurement and analysis protocols (SOPs) • Quality Assurance Plan • Data Management Plan	Peer review by internal staff Independent peer review NPS staff review (for permitting)
Implementation	Conduct staff/cooperator training	Training guide and certification forms
	Collect, record, control data	Scientific notebooks, field forms, data recorders
	Collect and control samples (if required)	Sample handling manual Labeling procedures
	Calibrate and maintain equipment	Standard operating procedures (schedule for routine maintenance and calibration of equipment)
	Conduct audits	Audit form
	Re-monitor/re-measure	Field data collection forms, monitoring or re-measurement schedule
Data Assessment	Assess data quality: data review, verification, and validation	Data entry checks, illegal data filters, outlier detection, internal consistency checks
Analysis	Conduct analysis of data	Modeling Statistical analysis of validated data
Data Management	Finalize dataset	Database standards

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Element	Activity	Tools
		Metadata standards Archive procedures
	Distribute data	Web site
Reporting	Prepare reports and fact sheets	Data synthesis Edit to final draft stage
	Review reports and fact sheets	Independent peer reviews in accordance with USGS Fundamental Science Practices
	Finalize reports and fact sheets	Address peer review comments Final editing
	Disseminate deports and information	Web site Stakeholder workshops Annual Reporting meetings
Continual improvement	Periodically review project	Peer review panels (PEPs)

3.2.3 Incorporating Future Technical Innovations into Monitoring Programs

New and innovative approaches are constantly being found as development of individual monitoring protocols proceeds. The GCMRC believes that long-term monitoring protocols should continue to evaluate new and improved methods when available and as appropriate through time. Project budgets should ideally be increased annually by a few percent to enable the projects to continue evaluating new methods and monitoring instruments and to cover periodic independent reviews.

A key failing of the historical monitoring program has been to make a variety of changes in trend monitoring methods without continuing parallel sampling using old methods for a limited period of time; the use of old and new methods in parallel allows scientists to cross calibrate trend indicators. Parallel sampling efforts are especially important when evaluating new noninvasive sampling methods or changes in sampling efforts.

Besides requiring sufficient ongoing funds, any evaluation of new methods must be systematic such that data collected remain fully comparable through time, including comparing newly proposed methods to existing methods. Changes in data collection and sampling design that cause “disconnects” in long-term data streams are to be avoided. New methods will be evaluated while previous data collection methods are continued (parallel sampling) to ensure that cross-calibration of trend indicators is possible. This is particularly important when new methods are proposed with the intention of reducing costs—an inevitable concern with any long-term monitoring program.

After a period of parallel data collection, full external peer review of the data comparisons, environmental impacts, and costs will be conducted prior to making any changes in the monitoring approach that would forego previously established monitoring methods or data. This is one example of the commitment to goal 12 for ensuring a quality adaptive management program for the GCDAMP.

Evaluation of noninvasive sampling methods as a basic component of maintaining quality monitoring programs may include the following activities:

- Remote sensing for riparian sediment, vegetation resources, and campsites
- Remote sensing for evaluation of fine-scale and longitudinal thermal regimes
- Use of automatic counting systems (for example, passive integrated transponder (PIT) tags in the Little Colorado River)
- Dissolved oxygen (DO) meters to measure diurnal and seasonal changes as a measure of ecosystem function
- Use of acoustic methods for assessing fish distributions and longitudinal densities
- Estimation of food base drift densities with acoustic methods
- Use of ground-based, oblique lidar for detecting changes in archaeological sites and sediment deposits
- Use of side-scan sonar and multi-beam acoustic backscattering data to map channel bed substrates
- Use of airborne water-penetrating Lidar (green lasers) to map channel bed topography
- Use of other airborne digital sensors at higher altitudes that reduce over-flight intrusiveness

3.3 Program Management and Role of Cooperators

The establishment of GCMRC as an independent, policy-neutral science center that is not affiliated with a particular stakeholder group or management agency is a fundamental principle of the GCDAMP. In keeping with this principle, this plan assumes that the GCMRC will exercise overall responsibility for the management and implementation of the Core Monitoring Program for the AMP. More specifically, the role of GCMRC will be to design, implement, and oversee the implementation of all aspects of core monitoring as defined above in Table 3. This plan also recognizes that several land and resource management agencies, including the NPS, USFWS, AZGFD, and the Tribes, have statutory or regulatory responsibilities for long-term management of resources in Grand Canyon. In addition, the USGS, the parent organization of GCMRC, includes many leading experts in river science. Collectively, these agencies/entities have technical skills and capabilities that can assist in conducting some of the core monitoring work being recommended by the GCDAMP.

Although GCMRC has the overall lead for the GCDAMP core monitoring program, Federal and State agencies and the Tribes are an integral part of several ongoing GCDAMP monitoring efforts, including monitoring of humpback chub and other native fishes, rainbow trout and other nonnative fishes, hydrology, archaeological resources, and traditional cultural properties. Having these agencies/entities as active partners in the GCDAMP science program helps meet their statutory responsibilities and facilitates the integration of the scientific information into management processes and decisions.

GCMRC will use the most cost-effective mechanisms to implement core monitoring projects, working with the TWG to develop choices for core monitoring using trade-off analyses. In general, GCMRC will prepare Requests for Proposals and use an open, competitive process for awarding funding for implementation of core monitoring projects. Limited competition cooperative agreements and/or contracts in accordance with Federal regulations may be used to conduct specific core monitoring tasks (for example, data collection , QA/QC, etc.) if potential Federal and State agencies and the Tribal cooperators agree to (a) conduct the required work at a fair cost, (b) meet the required technical specifications as determined by GCMRC based on consideration of PEPs, Science Advisor, and TWG recommendations, and (c) comply with independent peer review requirements established by GCMRC. Periodic evaluations will be conducted to ensure that cooperators are meeting these fundamental requirements. GCMRC scientists may conduct field research and monitoring under the same conditions. In every case, the USGS will hold its own proposals to the same level of rigorous outside peer review as all others.

3.3.1 GCMRC Staffing Requirements

The types of staff needed within the GCMRC to oversee, implement, and maintain a core monitoring program (2012 and beyond) will be different from those needed to initially develop the program (1995–2012). Research and development activities require high level researchers to develop and test new technologies and monitoring processes. Long-term monitoring requires more technical staff to implement or oversee monitoring activities, provide training to staff and cooperators, analyze data, and report the results in a timely manner. Some shifting in GCMRC staffing will be needed as the program moves from a research and development phase to the core monitoring phase. Since being established in 1995, the GCMRC has strategically maintained a high degree of flexibility in its organization so that the permanent portion of the staff can be adapted to core monitoring needs as they become better understood and supported by the stakeholder program.

The GCMRC's estimated general staffing requirements to implement core monitoring based on the current inclusive nature of the CMINs ("high" category of implementation) and identified monitoring needs consist of the following:

- **Core Monitoring Program Management** – 4.0 Full-Time Equivalent (FTE) permanent positions at the (Government Service) GS-11 to 15 range (senior ecologist, science chief, biology, physical and modeling, sociocultural, data management, logistics program manager)
- **Data Acquisition, Storage, and Analysis – 4**.0 FTEs at the GS-7 to 14 range (biometrician, database manager, GIS technician, data archivist and remote sensing analyst)
- **Physical Science, Survey, and Modeling –** 7.5 FTEs at the GS-7 to 13 range (research hydrologist, hydrologist, hydrologic technician, surveyor)
- **Biological Science –** 7.5 FTEs at the GS-05 to 13 range (aquatic ecologist, fish biologist, biological technician, terrestrial biologist, limnologist or hydrologist)
- **Sociocultural Science –** 2.0 FTEs at the GS-09 to 11 range (geographer, cultural monitoring data analyst, and recreation data analyst)
- **Logistics –** 1.0 FTEs at the (Wage Grade) WG-08 range (logistical support technician)

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The estimated total staff needed to support full implementation of the CMP is *approximately* 26 full-time equivalent positions within the GCRMC. Because of the recurring and long-term nature of core monitoring, many of the positions will be permanent full-time positions. As such, under full implementation of the CMP, the number of full-time permanent positions at GCMRC would need to ~~is projected to~~ grow from 19 to 26 between now and 2015. Administrative and general IT/computer support will be provided through the USGS Southwest Biological Science Center, the current administrative support center for the GCMRC.

3.3.2 Information Outreach

The role of outreach is covered by GCMRC's publications and outreach coordinator. This position, along with the GCMRC program managers, and the chief and deputy chief of the GCMRC, share the responsibility of getting new information out to the public and managers in a timely and useful format. Much of this is accomplished through frequent stakeholder interactions (Federal advisory committee meetings) and will be done to a greater degree in the future through data series reports, web seminars, and fact sheets. All this information, including monitoring data, will be accessible through the GCMRC website. Regarding monitoring data, the DASA program manager is the primary contact for providing technical assistance related to data access.

3.3.3 Logistics and Permitting

The GCMRC provides complete logistical support for 20–40 research, monitoring, and administrative river trips through Grand Canyon annually. These trips range in length from 7 to 21 days and from 4 to 36 people in size. Trips comprise a variety of motor- and oar-powered boats operated by contracted boat operators. Monitoring projects operating in the Glen Canyon reach of the Colorado River (Glen Canyon Dam to Lees Ferry) are supported by a variety of motor-powered boats operated by GCMRC researchers and contracted boat operators. Additionally, monitoring activities on the Little Colorado River are supported by helicopter services contracted with the Bureau of Reclamation.

The trip planning and scheduling process begins in the fall when the logistics coordinator, in cooperation with contracted PIs, program managers, and staff work together to generate a draft schedule of trips for the fiscal year. The schedule includes launch and take-out dates, numbers of personnel, and specific boat and boat operator requests for each trip. Researchers must submit a Trip Request Form a minimum of 60 days prior to the scheduled launch date. This form provides information for two purposes: (1) determine and schedule logistical and support services, and (2) complete a GCNP River Trip Application in order to meet the GCNP 45-day deadline for submitting access permit applications.

Effective communication with PIs and sensitivity to and awareness of the challenges they face in implementing their core monitoring projects enables the GCMRC to offer more customized (and therefore more cost-effective and productive) logistical support than other support strategies utilized previously. Retaining control over the process of supporting trips also facilitates compliance with NPS regulations and allows greater control over issues sensitive to the general public and the "recreational river community." When feasible and practical, multiple monitoring projects will be scheduled together on a single trip to reduce costs and trip numbers and to promote more integration between the various monitoring projects. As details of sampling design in each of the long-term monitoring projects become better known, planning discussions focused at improving integration of monitoring activities will continue, including input from the various project chiefs and the logistics program manager as to the feasibility of further combining trips and activities.

3.3.4 Core Monitoring Program Costs

A variety of sources have been used to estimate the annual costs of core monitoring activities if fully implemented, as shown in table 4. A number of the projects, particularly those that have completed the research and development and PEP review and recommendation steps, appear with detailed budgets in the GCMRC's biennial FY2011~~0~~–12~~1~~ work plan and budget. The total annual cost for quality of water and sediment monitoring projects related to goals 7 and 8 are the best known of the 11 projects described in this plan. The other nine monitoring projects are associated with "ballpark" estimates because their associated R&D and PEP review phases are not yet completed.

The total gross cost for the core monitoring program, if fully implemented, is estimated at approximately $6,000,000 annually, representing about 60 percent of the total Glen Canyon Dam Adaptive Management Program annual budget (on the basis of the FY2010 total). ~~-~~Where possible, costs shown in table 4 have been derived from the monitoring project descriptions contained in the FY2010–11 annual work plan. In cases where the provisional monitoring projects are not yet underway and therefore not described in the annual work plan, best estimates of the project costs have been made by the various program managers who oversee development of the proposed monitoring.

The estimated gross costs for each project (Table 4) have been broken down into several categories, including the proportion of each project that will be directly supported by the GCMRC science and management staff, the logistics needs, the portion that is intended to be outsourced through contracts or cooperative agreements, other related expenses and estimated indirect costs for implementing the projects. Currently these are considered to be general estimates, but project costs derived from annual work plans (such as goals 7 and 8) are thought to be close to the projected longer term costs, assuming annual indexing for inflation. The logistics budgets are distributed across GCMRC monitoring projects based on a formula proportional to use of services. The formula takes into account contractor costs, trip size and length, and a percentage of operating expenses, salaries, and permitting costs.

The funding needs projections are based on the estimated cost to implement core monitoring to meet currently identified information needs (CMINs). The ultimate cost of individual core monitoring programs will~~may~~ be determined ~~adjusted~~ based on consideration of trade-offs between costs, precision and program needs. Further description of the review and approval process can be found in Appendix TWG, which describes the TWG role in the process.~~However, reaching those decisions through a collaborative approach will be difficult and may require facilitation as the GCDAMP has had difficulty in reaching these types of decisions in the past.~~

Table 4. Summary breakdown of annual estimated costs (direct and indirect) for each core monitoring project.

Goal	Project	Total gross costs including program managers	Total indirect costs	Total direct cost	GCMRC salaries and benefits	Logistics	GCMRC / USGS other costs	Outsourced (conducted outside USGS)
1	Food Web	392,847	68,180	324,667	281,667	30,000	13,000	—
2	Native Fish	1,474,608	157,975	1,316,633	226,746	233,000	62,000	794,887
3	Extirpated Species	—	—	—	—	—	—	—
4	Rainbow Trout	160,328	22,897	137,431	82,431	15,000	—	40,000
5	Springs / KAS	127,555	19,855	107,700	84,178	5,000	—	18,522
6	Riparian Vegetation	268,371	40,416	227,955	132,955	30,000	15,000	50,000
7a	Quality of Water—Lake Powell	288,301	47,448	240,853	173,853	—	46,000	21,000
7b	Quality of Water—Downstream including Suspended Sediment Transport and Mass Balance	1,056,672*	183,389	873,283	337,624	62,593	473,066	—
8	Sediment	758,123*	111,685	646,438	377,601	62,622	44,802	161,413
9	Recreation	231,920	33,781	198,139	134,639	8,000	3,000	52,500
10	Hydropower	39,193	6,802	32,391	32,391	—	—	—
11	Cultural	607,798	104,253	503,545	186,545	60,000	247,000	10,000
12a	Remote Sensing & Change Analysis	791,562	90,181	701,381	232,823	40,000	45,530	383,028
12b	Program Management & Overview	160,492	27,854	132,638	132,638			
	TOTALS	**6,357,771**	**914,717**	**5,443,054**	**2,416,091**	**546,215**	**949,398**	**1,531,350**
	* The estimated annual cost for monitoring is based on the FY2010–11 work plan and budget where the project already exists and has been described and proposed as a core monitoring effort following completion of Protocol Evaluation Panel review and recommendations to the TWG. All others remain in the R&D phase pending final review and recommendations to the TWG.							

Chapter 4. Core Monitoring Proposals by GCDAMP Goal

Prior research and development efforts and results of past PEP reviews have focused on developing core monitoring activities for each of the Glen Canyon Dam Adaptive Management Program (GCDAMP) goals. The resources that are central to these goals are summarized in figure 7. All but one of the resources of concern (hydropower) are downstream components of the Colorado River ecosystem, but hydropower is another important resource of interest to the GCDAMP, and one that is directly tied to daily dam operations. A summary of the monitoring tasks tied to each goal is provided in table 4, followed by descriptions of individual project proposals.

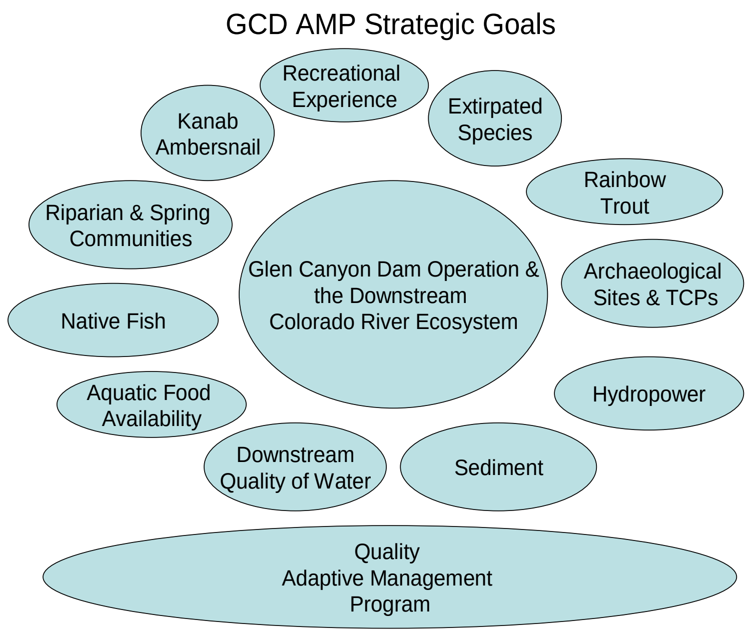

Figure 7. Overview of natural, sociocultural, and recreational resources that are influenced by the operation of Glen Canyon Dam. The focus of core monitoring is on Record of Decision operations approved by the Department of the Interior in 1996, including modified low fluctuating flows, beach/habitat building flows, habitat maintenance flows, and occasionally other types of experimental dam operations, such as steady flows and alternative fluctuating flows.

In each of the monitoring proposals, we distinguish between the signals that monitoring must detect and the parameters that have been selected for repeated measurement. The “signal” is the response that monitoring seeks to detect over some specified time scale to track the status and trend of stakeholder-identified resources (presumably to be compared with future stated desired conditions that might be attained through some combination of dam operations and other management actions). The “parameters”, which may also be termed “indicators” of condition, are the specific measurements of particular physical or biological variables that have been selected for monitoring the associated signal.

In some cases, the relationship between the signal and the parameter is clear. With respect to water temperature, for example, the signal targeted for monitoring is the annual or longer term trend in mainstem or nearshore water temperature at various downstream locations. Thus, the parameter being monitored is hourly mainstem water temperature at selected representative locations. For sediment, however, the relationship between the sediment conservation signal and monitoring parameters is more complex. Although sandbars are of great management interest, it is known that sandbar size is highly variable and that long-term trends in sandbars are tied to the status of the overall sediment budget. Thus, the key signal for sediment monitoring is the status of the fine-sediment mass balance. Therefore, monitoring parameters must be selected to track that signal, in addition to any monitoring of the sandbars and related habitat resources.

For native fish, the repeated catch data for humpback chub includes length and weight, as well as location caught and mark-recapture history (related to age and growth rate). However the signal of interest to managers is the adult population trend of age 4 or older fish, as determined by periodic estimates of adult abundance derived from the repeated catch data. Recruitment trends for chub and other native species would presumably also be an important signal to report, as well as annual distributions of length-frequency data for select species (another means of assessing juvenile recruitment).

The descriptions of proposed core monitoring activities that follow are presented in the order they appear in the 2003 AMP strategic plan; however, they could be presented to reflect the bottom-up trophic structure and function of the Colorado River ecosystem, as described in the previous chapter of this plan:

- Maintain a high-quality monitoring, research, and adaptive management program (goal 12)
- Establish water temperature, quality, and flow dynamics to achieve the GCDAMP ecosystem goals (goal 7)
- Maintain or attain levels of sediment storage within the main channel and along shorelines to achieve the GCDAMP ecosystem goals (goal 8)
- Protect or improve the aquatic food base so it will support viable populations of desired species at higher trophic levels (goal 1)
- Maintain or attain viable populations of existing native fish, remove jeopardy from humpback chub and razorback sucker, and prevent adverse modification to their critical habitat (goal 2)
- Maintain a naturally reproducing population of rainbow trout above the Paria River, to the extent practicable and consistent with the maintenance of viable populations of native fish (goal 4)
- Restore populations of extirpated species, as feasible and advisable (goal 3)
- Maintain or attain viable populations of Kanab ambersnail (goal 5)
- Protect or improve the biotic riparian and spring communities, including threatened and endangered species and their critical habitat (goal 6)

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- Maintain or improve the quality of recreational experiences for users of the Colorado River ecosystem, within the framework of the GCDAMP ecosystems goals (goal 9)
- Maintain power production capacity and energy generation, and increase where feasible and advisable, within the framework of the adaptive management ecosystem goals (goal 10)
- Preserve, protect, manage, and treat cultural resources for the inspiration and benefit of past, present, and future generations (goal 11)

Understanding the proposed approach to goal 12 requires some additional explanation because it has both global and specific elements. First, goal 12 encompasses many elements of administering the various science and support programs of the GCMRC, such as Physical/Modeling, Biology, Sociocultural, Logistics, and DASA (data management and GIS support). In addition, there is also the oversight provided by the chief and associated staff in managing budgets and programs, facilitating interactions with stakeholders and policymakers, and ensuring that appropriate levels of external peer review and fundamental science practices are consistently followed. Second, the GCMRC, through focused activities led by the DASA program, commits to providing quadrennial airborne overflights of the entire Colorado River ecosystem to provide systemwide data on terrestrial resources (see goal 12 remote sensing project description for details below). These periodic overflights are scheduled in coordination with dam operations at consistently similar, relatively low steady flows to ensure that change detection analyses conducted by various users are comparative over time—a major emphasis of the monitoring program. The overflights are a foundational component of the long-term monitoring program and are intended to provide data pertaining to several resource goals, such as sediment, recreation, cultural resources, fish habitats, and riparian vegetation. The dual elements of goal 12 are segregated on this basis, as shown in table 4.

Because information is still being developed to reliably define the monitoring methods and associated costs for the above resource areas, descriptions of the entire suite of activities required for the long-term monitoring program and associated costs in this draft plan are estimates. Nevertheless these cost estimates will be useful in long-term budget planning for the GCDAMP to ensure that adequate resources are available for core monitoring.

Table 5. Summary of proposed focus, scope, and parameters for core monitoring (to be determined more precisely after completing core monitoring information workshops and a final protocol evaluation panel [PEP] technical review) by Glen Canyon Dam Adaptive Management Program

GCDAMP Goal	Focus	Geographic scope	Parameters	Frequency
1. Aquatic food availability				
1a. Aquatic food base	Total organic carbon budget	Glen Canyon Dam (GCD) to Pearce Ferry	Primary production, tributary inputs	Annually
1b. Diet, density, and predation	Invertebrate production	GCD to Pearce Ferry	Biomass and density of dominant taxa	
2. Native fishes				
2a. Lower 1,200 m Little Colorado River (LCR)	Maintain reproduction, evaluate recruitment	Lower 1,200 m in LCR	Population status, trends, and condition factors	
2b. Lower 15 km LCR	Evaluate survival and recruitment	Lower 15 km in LCR	Population status, trends, and condition factors	
2c. Mainstem native fishes	Evaluate survival and recruitment	GCD to Diamond Creek	Population status, trends, and condition for multiple size classes	Three times annually
2d. Parasites and disease	Evaluate parasites and diseases that may negatively impact native fishes	GCD to Diamond Creek	Infection rates and densities	Biannually
2e. Mainstem Nonnative Fishes	Minimize impacts to native fishes	GCD to Pearce Ferry	Population status, trends, and condition factors	
3. Extirpated species	No current activity	N/A	N/A	N/A
4. Lees Ferry rainbow trout and other nonnatives	Sustainable, high quality angling	Glen Canyon tailwaters	Population status, trends, and condition for multiple size classes	Seasonally
5. Kanab ambersnail (KAS)				
5a. KAS population	Snail and egg abundance	Vaseys Paradise		Annually
5b. KAS habitat	Area and vegetation types (quality)	Vaseys Paradise		Annually
6. Riparian and spring communities	Discerning impacts of dam operations on vegetation	GCD to Diamond Creek	Vegetation communities: species composition, density, and distribution	Annual sampling with 5-year mapping updates
7. Lake Powell quality of water	Lake Powell water-quality parameters	Lake Powell	Temperature, conductance, dissolved oxygen, pH, oxidation-reduction potential, turbidity	Quarterly

GCDAMP Goal	Focus	Geographic scope	Parameters	Frequency
7. Downstream discharge and quality of water				
7a. Discharge	Water discharge and stage in the Colorado River ecosystem (CRE)	GCD to Diamond Creek	Surface water records (stage and discharge)	15 minutes
7b. Inorganics	State of the sediment mass-balance on the reach scale; Sediment grain size, Track tributary-supplied water, organics, and dissolved constituents	GCD to Diamond Creek	Suspended-sediment concentration and grain size, specific conductance	15 minutes
7c. Chemistry	Oxygen content in Glen Canyon reach and full water chemistry downstream	Glen Canyon reach, Lees Ferry and above Diamond Creek gaging stations	Dissolved oxygen, full water chemistry as part of AZDEQ at the Colorado River at Lees Ferry gaging station and NASQWN at the Colorado River above Diamond Creek gaging station	15 minutes for dissolved oxygen, four times annually at the Lees Ferry gaging station and seven times annually at the gaging station above Diamond Creek
7d. Temperature	Water temperature through the CRE	GCD to Diamond Creek	Degrees Celsius (°C)	15 minutes to hourly
8. Sediment	Track changes in sandbar area and volume; measure changes in deep eddy and channel pool sediment volume; track changes in sediment grain size	45 long-term sandbars and long reaches between gaging stations	Repeat topographic and grain size surveys	Annual to every 5 years (depending on survey; higher-elevation sandbar surveys may occur more frequently than those including bathymetry and grain size)
9. Recreational Experience				
9a. Campsites	Area, quality, and distribution	Campable area at long-term sandbars and remotely sensed data elsewhere; AAB sites	Campable area above and below active fluctuating flow range	Annually

GCDAMP Goal	Focus	Geographic scope	Parameters	Frequency
9b. Experience quality	Recreational attribute trade-offs	GCD to Pearce Ferry	Full suite of attributes contributing to recreational experience	Every 5 years
10. Hydropower				
10.1 Power generation and costs	Kilowatts and costs	GCD	Hourly generation capacity, replacement market values	Hourly and daily
11. Cultural Resources				
11a. Archaeological sites	Resource condition and physical stability	Sample of sites in CRE	Erosion rates, surface stability	Biannually
11b. TCPs (Traditional Cultural Properties)and tribally valued resources		Selected sites in CRE	?	Annually
Goal 12. Quality Adaptive Management Program, including quadrennial (digital remote sensing data)				
12.a. Assurance of a quality monitoring program	Integrated ecosystem science approach	All GCDAMP Resources of the CRE	Physical, biological, and sociocultural, plus quality data management and integrated analyses	Annually
12.b. Remote sensing activities	Emphasis on terrestrial resources above 8,000 cfs	Systemwide remotely sensed imagery	Terrestrial substrates, vegetation, recreational camp areas and archaeological sites and perhaps others	Quadrennially

Summary

Most of the monitoring projects described above—such as the downstream quality of water, suspended-sediment mass balance, or the model-derived estimate for adult population of humpback chub and other native fish—require field efforts in combination with some level of analysis prior to annual reporting (written and oral presentations to stakeholders in January of each year). Other monitoring projects simply provide a continuation of a specific time series for a parameter of interest, such as temperature recorded at various downstream locations, following adopted quality assurance protocols prior to annual reporting. In total, these monitoring tasks are intended to track the status and trends of each of the downstream resources of concern within the GCDAMP, as well as hydropower which is not a downstream resource, but is closely tied to Glen Canyon Dam operation.

Management of the wide array of data collected from these core monitoring tasks is a critical and complex undertaking in itself, with quality assurance protocols needing to be implemented at key steps along the way prior to annual reporting and data serving. Elements of goal 12 include quality management of the monitoring data and periodic acquisition of remotely sensed, digital imagery, along with serving and supporting data requests from scientists and managers. The change detection analyses and reporting tied to remote sensing efforts are described in the goal 12 project description in this chapter. Chapter 4 of this plan is devoted to data management and reporting, as well as the more research-focused activities that rely on monitoring data, such as periodic knowledge assessments, intra and interdisciplinary syntheses, and ecological modeling.

Goal 1: Protect or improve the aquatic food base so that it will support viable populations of desired species at higher trophic levels

Statement of Problem

The use of large rivers for navigation, power generation, water supply, pollution disposal, flood control, and riparian/floodplain use often results in greatly altered freshwater ecosystems. Large rivers in the Western U.S. have been extensively dammed for water storage and power generation; these dams alter the physical habitat and temperature regime in predictable ways (Ward and Stanford, 1983; Stanford and Ward, 2001). For example, the Green River in Utah below Flaming Gorge Dam lost most of its mayfly species after dam construction (Vinson, 2001), and now supports a productive nonnative trout fishery.

The downstream sections of the Colorado River in Arizona have been physically and biologically altered since construction of Glen Canyon Dam. Water temperatures in most years are uniformly cold at ca. 9°C, whereas prior annual temperatures fluctuated from 2 to 26°C (Voichick and Wright, 2007). In addition, variability in discharge is greatly reduced compared to the pre-dam era, but daily variation has increased greatly due to hydropower generation. Sediment supply is greatly reduced because sediment that normally would come from upstream is trapped behind Glen Canyon Dam. This sediment reduction has increased the level of light in the water, contributing to high algae concentrations, especially near the dam upstream of sediment-laden tributaries (Stevens and others, 1997c). Invertebrate assemblages are species-poor and consist mainly of nonnative amphipods (*Gammarus*), black flies (*Simulium*), midges (Chironomidae), and oligochaetes (Stevens and others, 1997c), and the river was recently invaded by nonnative New Zealand mud snails (*Potamopyrgus antipodarum*; Benenati and others, 2002).

Parameters/Indicators to Be Monitored, Monitoring Signals, and Reporting Variables

GCMRC is conducting research to determine what core aquatic food base components to monitor to best inform management. We are pursuing a strategy of determining the amount of carbon being fixed, consumed, ingested, and egested in the biological ecosystem components from algae and plants (primary producers that fix carbon in photosynthesis) up through the highest trophic level, fish.

Our current methods will provide the foundation for future monitoring efforts plus a dataset that can be used to predict how environmental scenarios and management strategies (e.g., prolonged drought, increased temperature, and flow regime modifications) alter the flow of energy through biotic components of the ecosystem. This foundation is based on rates of reach-scale primary and secondary production, diet analysis and stable isotopes, and rates of energy transfer within the food web.

Links to Other Program Elements

An important part of maintaining biological integrity at higher trophic levels is ensuring that there is a sufficient food supply to support them. The GCDAMP has recognized this relationship with the development of goal 1. Developing an understanding of how energy, as measured by elemental carbon, is stored and transferred in the ecosystem is a critical management information need. For example, low temperatures decrease rates of fish and invertebrate growth; carbon inputs have changed with the installation and operation of Glen Canyon Dam; high light increases rates of primary production; nonnative mud snails may represent a dead-end for carbon flow in the food web; and nonnative trout may compete and prey upon native fishes. Measuring energy flow at both the ecosystem scale and through the food web is required to understand how management actions can affect animal populations in the river.

Core Monitoring Information Needs

The core monitoring needs for goal 1 require determination of the composition and biomass of primary producers and benthic invertebrates. Following the direction of the 2001 PEP (Anders and others, 2001), GCMRC is measuring energy flow through aquatic organisms which in turn will be used to determine which species are most important to monitor in order to provide managers with an evaluation of the relative health and function of the system. The complete list of CMINs is provided in Appendix A.

Summary of Previous Work

A food base monitoring program was established by GCMRC in 1997 via a competitive Request for Proposals process; investigators from Northern Arizona University were awarded contracts to conduct this program. The food base monitoring program was discontinued in 2003 owing primarily to the recommendations of the Protocol Evaluation Panel (Anders and others, 2001) and Scientific Advisor Panel (Palmer and others, 2004). Both panels indicated that a food base monitoring program needed to more completely describe the linkages between lower trophic levels and fish for it to be effective. That is, the food base monitoring program was measuring biomass and abundance of lower trophic levels but it was unclear which components of the food base were most important to fish. The current monitoring research and development project is making estimates of the major carbon inputs (that is, particulate and dissolved organic matter from Lake Powell, particulate and dissolved organic matter from tributaries, particulate and dissolved organic matter from Lees Ferry tailwater algae production, particulate organic matter from riparian vegetation, and particulate and dissolved organic matter from downstream algal production), invertebrate production, and fish production, as well as quantifying the flux of energy among these trophic levels using a combination of gut content analysis and stable isotopes analysis for each of six sites along the Colorado River. The data will be used to develop quantitative food webs that identify the dominant or critical pathways of energy flow leading to native and nonnative fishes; these dominant or critical pathways will be the focus of the core monitoring program.

Summary of Monitoring Project

Geographic Scope

In its current research phase the aquatic food base project has sampled the aquatic biota quarterly on full-river field trips (Lees Ferry to Diamond Creek) four times per year. Monthly sampling has been conducted at Lees Ferry and at Diamond Creek.

Temporal Scope

In June 2009, we will scale back field activities to include the following:

- monthly visits to Lees Ferry to collect invertebrate drift samples and recalibrate dissolved oxygen monitors,
- monthly visits to Diamond Creek to recalibrate dissolved oxygen monitors for continuous assessment of community production and respiration, and

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- quarterly visits to Lees Ferry and Diamond Creek to collect the full suite of food base samples that were collected during the initial phases of this project.

We propose maintaining this level of sampling effort until the aquatic food base core monitoring begins. At this time, the maximum estimated level of effort needed for the future core monitoring program is monthly sampling at Lees Ferry and Diamond Creek and 1–2 river trips per year.

Methods

The new food base initiative is using a variety of techniques (gut content analysis of invertebrates and fish, stable isotope analysis of all trophic levels) to determine the important linkages between lower trophic levels and fish. Further, the food base initiative is also making regular measurements of biomass and abundance of lower trophic levels. The frequency and spatial extent of these measurements is comparable to previous food base monitoring efforts.

The new food base initiative measures rates of carbon flow through all trophic levels including the ecosystem metabolism, invertebrate secondary production, trophic basis of production of the macroinvertebrate primary consumers, and carbon flow to fish. We are attempting to measure whole-stream primary production and community respiration at the reach scale, which integrates metabolism in a several-kilometer river reach. We are also measuring taxon-specific rates of secondary production of invertebrates and fishes. Ultimately, we will link these energy flows together in a quantitative food web using the trophic basis of production approach (Benke and Wallace, 1980; Hall and others, 2000; Rosi-Marshall and Wallace, 2002), as suggested by prior program reviews (Anders and others, 2001; Palmer and others, 2004) that called for shifting the emphasis of the monitoring plan from a focus on biomass to one on energy flow.

Program Status and Implementation Schedule

GCMRC plans to end the full-river research trips in 2009, will but continue to conduct monthly sampling at Lees Ferry and Diamond Creek on the Colorado River through June 2009. Development and evaluation of food base monitoring protocols began in 2005 and will continue into early FY2010. Recommendations for core monitoring of the aquatic food base elements will be delivered at the end of FY2010. It is anticipated that GCMRC will initiate of the aquatic food base core monitoring in FY2011. A protocol evaluation panel review of the aquatic food base monitoring program is anticipated in approximately FY2011 after delivery of the final report of the research and development project.

Goal 2: Maintain or attain viable populations of existing native fish, remove jeopardy for humpback chub and razorback sucker, and prevent adverse modification to their critical habitats

Statement of Problem

The humpback chub is a large-bodied cyprinid fish endemic to the Colorado River basin. There are six populations of humpback chub, the largest of which is currently the Grand Canyon population (U.S. Fish and Wildlife Service 2002a, 2008a). As one of the only remaining native fish of the Colorado River that occurs in Grand Canyon, it is an indicator of aquatic ecosystem health. Because this endangered species and associated critical habitat occur below, and may be affected by, Glen Canyon Dam, conservation of the species and its habitat are environmental concerns for the GCDAMP. Pursuant to the 2008 Biological Opinion of Glen Canyon Dam operations, the USFWS requires an annual assessment of the humpback chub in the Colorado River below the dam, to gage progress toward recovery and to determine if or when reinitiation of Endangered Species Act consultation may be required. Annual humpback chub monitoring is needed to support the annual stock assessment.

In addition to dam operations, humpback chub and other native fish may be affected by other natural and human-caused factors, including climate, nonnative fish species, and diseases (especially parasites). The highly variable infestation rates of parasites make it difficult to assess their impact to humpback chub population viability, and more work is needed to address this issue. The adult humpback chub population size has varied since 1989 (Coggins and Walters, 2009) when intensive monitoring programs for this species were established; monitoring data provide quantitative information for investigating what factor or factors cause population size changes.

Nonnative fishes are thought to pose a significant threat to survival and recovery of native fishes in Grand Canyon (Gloss and Coggins, 2005; Pine and others, 2009). Monitoring changes in the abundance and distribution of nonnative fishes is needed to determine the scope of nonnative control activities that may be initiated. For example, an estimate of rainbow trout abundance will determine if or when control efforts for that species will be initiated.

The razorback sucker, the other endangered species mentioned in goal 2, has not been observed in Grand Canyon since the 1980s. Ongoing monitoring efforts continue to look for this species, but the GCDAMP does not currently implement a specific program for the its conservation. Other native fish species also serve as indicators of ecosystem health in the Colorado River ecosystem, so GCMRC and cooperators also monitor bluehead sucker (*Catostomus discobolus*) and flannelmouth sucker (*Catostomus latipinnis*).

Parameters/Indicators to Be Monitored, Monitoring Signals, and Reporting Variables

Fish population sizes and trends are the primary signals monitored within goal 2 activities. The age-structured mark-recapture (ASMR) model of Coggins and others (2006) is the primary tool used to track the multiyear status and trends of the humpback chub population in Grand Canyon. The closed population estimate of humpback chub in the Little Colorado River (LCR) conducted by the USFWS provides a useful year-to-year monitoring assessment of the population, as that tributary is where the bulk of the population reproduces. The ASMR model depends on mark-recapture data for humpback chub that are collected each year. Catch per unit effort values are the other data most often collected for assessment of the other fishes in Grand Canyon.

Multiple monitoring efforts per year have allowed researchers to put unique identifying tags in more than 24,000 humpback chub that are 150 mm or longer to date. Researchers are currently experimenting with putting these tags in smaller size fish to allow assessments of year-class strengths at one age earlier (one year earlier) than is now possible (good estimates of cohort strength are not obtained now until the fish are at least 3 years old, and tagging at 100 mm would move this down to 2 years old). These passive integrated transponder (PIT) tags allow for tracking individual humpback chub capture locations and length, the primary data that feed into the ASMR model. The ASMR model determines the status and trend of the Grand Canyon adult ($\geq$ 4 years old) humpback chub population in the latest draft recovery goals for the species (U.S. Fish and Wildlife Service, 2008a). The USFWS determined that if the Grand Canyon humpback chub adult population estimate drops to 3,500 individuals, then consultation with the Bureau of Reclamation will need to be reinitiated.

Status and trends of bluehead sucker and flannelmouth sucker are also monitored by existing efforts. Relative capture rates are recorded, and most of the larger individuals of these fish species are also given PIT tags when captured.

Links to Other Program Elements

Scientists and managers working in Grand Canyon recognize that the status and trends of humpback chub are influenced by biological and physical factors, many of which are monitored by other GCMRC monitoring projects. The aquatic food base results will help determine what food resources may be available for humpback chub and other native fishes. Results of nonnative fish monitoring and risk assessment provide critical information to managers considering what management actions may be taken to conserve humpback chub, such as whether competition or predation, or both, are more critical issues to be addressed by managers. Physical factors that likely influence fish include water temperature and turbidity, factors monitored under goals 7 and 8. Part of the humpback chub habitat has a dynamic nature because of the sand and fine sediment that moves through the system, a physical factor also monitored as part of goal 8. Fish, like all other animals, require food for survival, and their sources of food are monitored under goal 1 monitoring activities. The terrestrial environment, monitored under goal 6, may contribute both shoreline cover and organic inputs into the aquatic system, and so is another biotic factor to consider for its association to humpback chub.

Core Monitoring Information Needs

The CMINs for humpback chub focus on tracking various size classes of the Grand Canyon humpback chub population. Core monitoring needs also recognize that predation, competition, and disease may all play some role in humpback chub population health and so also seeks to monitor nonnative fishes and disease. The core monitoring needs also mention the razorback sucker, but since the species has not been observed in Grand Canyon since approximately the mid-1980s, it is not a focus of current efforts in Grand Canyon. The complete list of CMINs is provided in Appendix A.

Summary of Previous Work

The humpback chub, first described from Grand Canyon (Miller, 1946), is the only remaining member of the genus *Gila* inhabiting the Colorado River between Glen Canyon Dam and Grand Wash Cliffs (two other *Gila* species used to be found in Grand Canyon). This species was the first to be listed as endangered by the USFWS, in 1967, and it is protected under the Endangered Species Act of 1973, as amended (16 U.S.C. 1531-1543). Because of their legal status, humpback chub are the subject of a high level of effort to not only monitor their Grand Canyon population but also to conduct research (described elsewhere) to investigate the causes of their population fluctuations.

Scientific assessment of the fish community of Grand Canyon was initiated in the mid-20th century with the work of R.R. Miller (1946). W.L. Minckley began investigating these species in the 1960s, Suttkus and Clemmer (1977, 1979) were investigating the fish community of Grand Canyon in the 1970s, and C.O. Minckley (1996) was investigating them in the 1980s and 1990s. M.E. Douglas and P.C. Marsh (1996) carried on investigations in the 1990s, as did various USFWS personnel (e.g., see Gorman and Stone, 1999; Stone and Gorman, 2006, and references therein). Coordinated multi-agency native fish monitoring was supported by the Bureau of Reclamation in the late 1980s and into the 1990s (Valdez and Ryel, 1995). With the completion of the 1996 EIS and ROD, the GCMRC took the lead, on behalf of and with financial support from the GCDAMP, in monitoring the Colorado River fish community in Grand Canyon. Current monitoring is conducted in association with the USFWS and AZGFD. Tribal stakeholders in the GCDAMP, particularly Hualapai tribal members, have participated in some of the native fish monitoring and management actions in Grand Canyon. At various times private contractors have also played an important role in conducting and supporting native and nonnative fish monitoring, especially in the 1990s and early 2000s. Most of the data generated by these efforts is summarized in the fish database now maintained by GCMRC.

The historic dataset and the ongoing activities described above constitute a nearly unparalleled collection of mark-recapture data, beginning in 1989. Since 2001, a number of open population mark-recapture abundance estimation models have been constructed to infer LCR humpback chub population dynamics. ASMR, developed by Coggins and co-authors (Coggins and others, 2006), is the latest model. This peer-reviewed model has been updated twice with more current data since original publication (Coggins, 2007; Coggins and Walters, 2009).

Two annual Colorado River trips were conducted during 2002–06, with the first concentrating on the stratified random design, and the second focusing on multiple aggregation sites (Johnstone and Lauretta, *in review*). In 2007 two trips focused efforts mainly in the LCR inflow reach timed to roughly coincide with the LCR sampling—or concurrent sampling. This concurrent sampling approach was implemented to compare the resultant closed population estimation with the performance of the open population estimation model, ASMR; as noted, the USFWS has concluded that ASMR performs well (U.S. Fish and Wildlife Service, 2008a), so additional concurrent sampling is not expected in the future.

Summary of Monitoring Project

Monitoring of humpback chub has been spatially focused on the LCR and the mainstem Colorado River near the mouth of the LCR (RM 57-65.4), sometimes called the LCR reach. Other native and nonnative species are also captured with these efforts, primarily bluehead sucker and ictalurids (catfish species). Locations and strategies are discussed further below. To date, the mainstem monitoring project has been the primary method of gathering information about other native and nonnative species in the Colorado River.

Parasite monitoring has focused on the nonnative Asian tapeworm (*Bothriocephalus acheilognathi*). This intestinal parasite is found in highly variable infestation rates in humpback chub and other native and nonnative fishes of Grand Canyon (Linder and others, 2008).

Monitoring of Grand Canyon fish species, especially humpback chub and rainbow trout, was reviewed by an independent protocol evaluation panel (PEP) in 2009. The panel recommended a shift in monitoring effort with the caveat that their recommendation should be subjected to a review of the available data to include modeling exercises that model the monitoring shifts they recommended. The review recommended by the PEP will be conducted during fiscal year 2010. Assuming that their specific recommendations are supported by the data review; the monitoring the PEP recommended will be partially implemented in 2010 with full implementation in 2011. If the data do not support the specific PEP recommendations, then the GCDAMP will return to fish monitoring protocols implemented in 2009 and 2010.

The 2009 PEP for Grand Canyon fish observed that current monitoring of humpback chub in the LCR may be more intensive than necessary. If the LCR monitoring could be reduced, efforts could be shifted to the mainstem Colorado River where many questions about native and nonnative fish remain unanswered. Additional fish monitoring in the mainstem Colorado River would allow for broader geographic sampling and additional surveys for the presence of both native and nonnative fishes, thereby achieving multiple aims.

Geographic Scope

Owing mainly to the reproductive status of the LCR inflow aggregation of humpback chub (hereafter referred to as the LCR humpback chub population) and the distribution of this population in both the LCR and the main channel of the Colorado River near the confluence of the LCR, monitoring strategies differ among the LCR population and the remaining eight aggregations. Current LCR monitoring for humpback chub includes two mark/recapture trips in the lowest 13.6 km of the river, deploying one pair of trips in the spring and one pair of trips in the fall. The spring trips are conducted in parallel with an intensive spring monitoring trip of the lower 1,200 m of the LCR, monitoring and recording native and nonnative fishes. The 2009 PEP recommended that a single pair of trips be deployed in the spring each year, supplemented by some of the locations currently monitored by the monitoring project in the lowest 1,200 m of the river.

Monitoring of the mainstem Colorado River is currently conducted using two electrofishing trips in the spring of each year, deployed approximately 60 days apart. The 2009 PEP recommended that mainstem electroshocking should continue, but that additional mainstem monitoring trips should be deployed in the late summer and fall using different gear types. These trips would attempt to sample with multiple gear types at locations that are determined by historic aggregation locations of humpback chub and potential congregation points for nonnative fishes, such as tributary mouths, interspersed with randomly assigned locations.

Humpback chub distribution in the mainstem Colorado in Grand Canyon has been characterized as occurring in nine discrete locations or aggregations: 30 Mile, RM 29.8–31.3; LCR Inflow, RM 57–65.4; Lava Canyon to Hance, RM 65.7–76.3; Bright Angel Creek Inflow, RM 83.8–92.2; Shinumo Creek Inflow, RM 108.1–108.6; Stephen Aisle, RM 114.9–120.1; Middle Granite Gorge, RM 126.1–129.0; Havasu Creek Inflow, RM 155.8–156.7; and Pumpkin Spring, RM 212.5–213.2 (Valdez and Ryel, 1995). Of these, only the LCR Inflow is recognized as a reproducing population in that it consistently demonstrates some level of successful recruitment (Kaeding and Zimmerman, 1983; Valdez and Ryel, 1995; Gorman and Stone, 1999; Coggins and others, 2006; Coggins, 2007). The remaining eight aggregations most likely exist as a result of either downstream transport of juvenile humpback chub from the LCR inflow aggregation, or relict fish (30 Mile population) produced in years immediately after construction of Glen Canyon Dam (Valdez and Ryel, 1995). However, limited reproduction of humpback chub has been documented upstream of the LCR inflow in the 30 Mile reach (Valdez and Maslich, 1999), and humpback chub produced there again in 2005 and 2006 may have overwintered (Andersen and others, *in prep.*). Limited movement has been documented between the LCR inflow and the other aggregations (Paukert and others, 2006).

Parasite monitoring of humpback chub is also conducted on the LCR. This geographic focus is due to the relatively high catch rates of humpback chub in this tributary and because of the logistic feasibility of establishing temporary tanks that allow for nonlethal parasite monitoring.

Temporal Scope

Humpback chub and other fishes are monitored primarily between February and October. Task-specific timing is presented with the individual projects in the Methods section below.

Methods

The following projects present the current methods for monitoring humpback chub and other fishes found in Grand Canyon. These brief descriptions also indicate how the projects are anticipated to change in response to the recommendations of the 2009 PEP for Grand Canyon fishes, subject to additional analysis and review in FY 2010. If the data analyses conclude that the protocol changes recommended by the PEP are not warranted, methods will revert to those conducted in 2009 and 2010.

Annual Spring and Fall Humpback Chub Abundance Assessments in the Lower 15 km of the LCR

This project, which has been ongoing since 2000, produces annual assessments of the abundance of humpback chub more than 150 mm in total length (e.g., Van Haverbeke and Stone, 2009, updating the work of Douglas and Marsh, 1996). The spring sampling is intended to coincide with the peak of humpback chub spawning in the LCR, likely providing our most reliable estimate of annual spawning magnitude. The fall sampling is aimed primarily at providing an estimate of the abundance of subadult fishes rearing in the LCR. These efforts rely on multiple event mark-recapture analyses of PIT tag data to produce abundance estimates using closed population models. Four 12-day trips into the LCR are conducted to collect the data needed to construct these estimates. These trips occur in the spring (April and May) and in the fall (September and October). Sampling is predominantly conducted using hoop nets evenly distributed throughout the lower 15 km of the LCR.

The 2009 PEP recommended that this full protocol (two mark-recapture trips in each of two seasons) may be unnecessary and that there were advantages to sampling endangered humpback chub less frequently, especially to reduce handling. They recommended combining some of the locations and efforts of the lower 1,200 m monitoring (see following paragraphs) into two spring mark-recapture trips. The PEP further recommended that LCR sampling only be conducted in the spring, when the largest numbers are observed, or perhaps on an alternating schedule, where it was conducted in the spring one year and the fall in the following year. A seasonally alternating schedule would allow for observing and tagging different age classes of humpback chub in different years, so an alternating schedule may be recommended by the 2010 data review.

Annual Spring Relative Abundance Assessment in the Lower 1,200 m of the LCR

This project, which was established by the AZGFD in 1987, has operated continuously through 2008 with the exception of the years 2000–01 (Ward and Persons, *in review*). This program produces annual assessments of the relative abundance (that is, catch per unit effort, CPUE) of all size classes of humpback chub, flannelmouth sucker, bluehead sucker, speckled dace, and a host of nonnative fishes in the lower 1,200 m of the LCR. Data are collected during a 30–40 day period in spring using hoop nets set in standardized locations distributed throughout the reach. This effort represents the longest and most consistent database available to infer trends in the LCR humpback chub population. It provides an independent assessment of the spring population estimation trips.

The 2009 PEP for Grand Canyon fish recommended that some of the methods and locations of this sampling be incorporated into a spring sampling trip consisting of two trips to conduct mark and recapture sampling (see section above). Methods to be incorporated would consist of including additional hoop net mesh sizes. The reporting conducted in this current project, where all species captured are recorded, is recommended for inclusion into a single spring sampling project.

Annual Spring/Summer Humpback Chub Relative Abundance Assessment in the LCR Inflow (RM 57–65.4)

This project has been conducted since 2002 with the primary objective of estimating the relative abundance and distribution of native fishes between Lees Ferry and Diamond Creek. These efforts are concentrated in the mainstem reach above and below the mouth of the LCR because this is where the bulk of the Grand Canyon humpback chub population is found (Paukert and others, 2006). However, sampling is conducted according to a stratified random design that distributes the effort broadly throughout the entire river from Lees Ferry to Diamond Creek as well as focusing on index sites that correspond with humpback chub aggregations, including the LCR Inflow reach, RM 57–65.4. Sampling is conducted using hoop nets and trammel nets.

Sampling with hoop nets is expected to continue for the foreseeable future in conjunction with mechanical removal of nonnative fishes in this reach. Hoop nets have yielded useful data regarding the juvenile humpback chub in this reach, so deployment of this gear is recommended for continuation. Deployment of trammel nets is expected in the fall in future years provided mainstem water temperatures do not rise above 20 °C. Cooler water temperatures were found to have lower negative impacts on native Colorado River fish captured with trammel nets (Hunt, 2008).

Mainstem Monitoring of the Grand Canyon Fish Community (Lees Ferry to Diamond Creek)

This project collects mainstem Colorado River fish community data from at least Lees Ferry to Diamond Creek. As time, personnel, and logistics permit, sampling continues downstream to the Grand Wash Cliffs (upper Lake Mead) in some years. The project employs boat-mounted electrofishing. Two passes with this method are deployed between February and April. A stratified random approach is used, but this project also samples the previously described aggregations of humpback chub. Data collected by this project supports the ASMR model of humpback chub abundance and trends. Nonnative species encountered are also documented.

The 2009 PEP recommended that this project be continued, potentially dropping back to a single trip, especially if clear water for increased captures is present. The PEP recommended that additional mainstem monitoring should be added in the fall months to meet the information needs articulated by the GCDAMP and managers. To meet this recommendation, a mainstem trammel netting trip will be deployed in approximately September. Deployment of this gear requires net sets of 2 hours or less, and revisiting the sets to remove captured fish. Assuming mainstem water temperatures of 20 °C or less, trammel nets will be deployed with motorboat support. Site selection will account for regular (annual or semi-annual) visits to documented humpback chub aggregation reaches, tributary mouths, and stratified random sites to represent geomorphic reaches.

The 2009 PEP recommended another mainstem monitoring trip be conducted to deploy multiple gear types. Assuming the 2010 data analyses support the protocol shifts recommended by the PEP, time and personnel will permit the deployment of a multiple-gear monitoring trip. This trip will be an oar-supported trip deployed in October to investigate the fish community composition during the time of year when water temperatures released from Glen Canyon Dam are near their highest for the year. As with the September trammel net monitoring, this trip will monitor at humpback chub aggregation sites, tributary mouths, and stratified random sites on a multiyear rotation. This trip will also deploy seines in a sample of backwaters in each geomorphic reach. The objective of the multigear monitoring is to determine presence/absence of new or expanding populations of nonnative fishes, as well as investigating possible expansions of the humpback chub aggregations.

Annual Assessment of the Overall LCR Humpback Chub Population Abundance and Recruitment

GCMRC plans that the updating ASMR model continues to be the method for gathering and assessing the humpback chub mark-recapture data. The model results have been published in peer-reviewed reports at approximately 2-year intervals; the 2009 PEP recommended a 3–5 year reporting interval for updates of the ASMR. The ASMR model was most recently updated with the work of Coggins and Walters (2009) using data through 2008. GCMRC projects that the next update of the ASMR model will be conducted to support a full Grand Canyon resource assessment in 2011, and the following update would be conducted in 2014.

Periodic Assessment of Asian Tapeworm Infestation Rates of Humpback Chub in the LCR

As recommended by Linder and others (2008), the infestation rates of humpback chub by Asian tapeworm will be estimated at approximately 5-year intervals.

Program Status and Implementation Schedule

The PEP for Grand Canyon fish was conducted in May 2009. Their final report is anticipated by the end of FY2009. GCMRC has initiated implementation of the PEP recommendations in FY2010 and 2011, with additional data analysis in FY2010. Release of a core monitoring report for native fishes is planned for FY2011.

Goal 3: Restore populations of extirpated species, as feasible and advisable

Statement of Problem

Some of the vertebrate species no longer found in Grand Canyon are known from historical records. At least two species of fish listed as endangered conducted part of their life history in Grand Canyon but are currently extirpated. These species are the Colorado pikeminnow (*Ptychocheilus lucius*; U.S. Fish and Wildlife Service 2002b, 2008b, and references therein) and razorback sucker (U.S. Fish and Wildlife Service 2002c, 2008c, and references therein). Both of these species, but especially Colorado pikeminnow, traveled long distances in their lifetimes, and so may currently be limited by the installation of dams from carrying out critical life history functions (Bestgen and others, 2007). Monitoring specifically for Colorado pikeminnow has not been conducted because of the expectation that the dams have excluded this long-distance traveler, so it is not considered further here. Because razorback sucker may have been present in Grand Canyon as recently as the 1980s, and suitable habitat may still exist, the focus of recent, preliminary restoration efforts has been on the razorback sucker.

The river otter (*Lutra canadensis*) has also been documented from Grand Canyon (Burt, 1976) but is not a current resident and so could be considered an extirpated species that may be considered for reintroduction, as feasible and advisable. Monitoring for river otter has not been occurring, and so is not addressed in this text, but it might be reconsidered at a later date.

Restoring extinct species to the Colorado River would provide evidence of at least a partial return to natural ecosystem function, consistent with the GCPA. Such restoration would also be consistent with National Park Service goals of maintaining natural ecosystems in parks for the enjoyment of present and future generations.

Parameters/Indicators to Be Monitored, Monitoring Signals, and Reporting Variables

The most active current (2009) efforts to restore extirpated species are the investigations of the potential to restore razorback sucker to the Colorado River in and above Lake Mead. This effort is currently in an experimental phase, and GCMRC is exploring restoration potential with a large group of agencies. Potential support to the effort from GCMRC could take the form of providing aerial photography of the region, monitoring physical habitat characteristics, or monitoring biological characteristics. Biological characteristics could include the aquatic food base, the fish community, and presence and composition of riparian vegetation. These activities could be conducted in the future if cooperators agree on a research and monitoring approach.

Links to Other Program Elements

Successful reestablishment of extirpated species into the Colorado River or the associated riparian habitat would be evidence of some return to historic ecosystem conditions. Restoring ecosystem conditions increases the probability that the CRE can provide ecosystem services to humans, including water supply, recreation, and aesthetic enjoyment.

Core Monitoring Information Needs

The core monitoring information need for goal 3 is determination of the feasibility and advisability of restoring species into the Colorado River in Grand Canyon. The complete list of CMINs is shown in Appendix A.

Summary of Previous Work

A small population of razorback sucker has persisted in Lake Mead, downstream from Grand Canyon (Albrecht and others, 2008). Razorback suckers have been documented spawning in Lake Mead, so there is the potential that they could make use of the Colorado River in Grand Canyon for at least some phases of their life cycle. Scientists and managers are exploring potential strategies for expanding the current range of razorback sucker to include the Colorado River upstream from Lake Mead. Investigations to date have been conducted by the Bureau of Reclamation, Southern Nevada Water Authority, Nevada Department of Wildlife, and their contractors and cooperators. Grand Canyon National Park and GCMRC are working with existing researchers to explore the potential of expanding the current razorback sucker distribution upstream in the Colorado River.

The 2007 Biological Opinion for the coordinated operations of Lakes Powell and Mead (a.k.a., the shortage criteria BO) calls for the Bureau of Reclamation to determine whether the Colorado River above Lake Mead is suitable for razorback sucker. With additional support, GCMRC could expand existing monitoring efforts to the following:

- Extend aerial overflight beyond Diamond Creek downstream to Lake Mead to map potential habitat
- Monitor and model food base below Diamond Creek
- Monitor fish community below Diamond Creek

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Agency representatives met in March 2009 to discuss these and other potential projects that may support razorback sucker habitat suitability studies. A broader work plan is being considered, but there was general agreement that monitoring of this population in Lake Mead in the near future is important for understanding how the population is behaving and the potential for additional expansion.

Summary of Monitoring Project

Geographic Scope

The project's exact geographic extent remains to be determined, but generally includes the Colorado River at and above Lake Mead. It may be expanded if species other than razorback sucker are considered.

Temporal Scope

In the absence of a longer term plan there is no established time frame for reintroduction of razorback sucker or any other species.

Methods

As noted above, the current monitoring for razorback sucker is conducted in Lake Mead. A number of agencies—including the Bureau of Reclamation, Southern Nevada Water Authority, Nevada Department of Wildlife, Grand Canyon National Park, Arizona Game and Fish Department, and GCMRC—are discussing opportunities for learning about the feasibility and advisability of razorback sucker repatriation efforts for the Colorado River, upstream from Lake Mead. These agencies met in March 2009 and agreed that the monitoring in Lake Mead sponsored by the Southern Nevada Water Authority and the Bureau of Reclamation would continue at least through 2009.

Estimated Annual Funding for Extirpated Species Core Monitoring Program

Because projects for razorback sucker monitoring upstream from Lake Mead have not yet been defined, funding for core monitoring has not yet been estimated.

Goal 4: Maintain a naturally reproducing population of rainbow trout above the Paria River, to the extent practicable and consistent with the maintenance of viable populations of native fish

Problem Statement

The GCDAMP desires to maintain a viable sport fishery for rainbow trout (RBT) between Glen Canyon Dam and the Paria River (the Lees Ferry reach); this fishery is a popular recreational activity for local and visiting anglers. Rainbow trout stocked into this reach of the Colorado River have reproduced (Korman and others, 2005), but growth and recruitment into the adult population is variable from year to year (Coggins, 2008; Korman and Campana, 2009; Arizona Game and Fish Department, unpublished data). Results of monitoring conducted by the AZGFD suggest that recruitment may be density dependent, as relative catch rates are inversely proportional to RBT condition. The density dependence of this population is further supported by the observation that young RBT survive at higher percentages in the absence of a large adult population than when large numbers of adults are present (Korman, 2009). Recent studies conclude that RBT growth and survival are, at least partially, dependent on habitat conditions below the dam, which in turn are controlled by dam operations (Korman and Campana, 2009). Monitoring of all life stages of this species informs our understanding of their population dynamics which in turn informs recommendations for dam operations that may best meet GCDAMP goal 4. Monitoring of the Lees Ferry RBT population is an important component of ongoing efforts to assess the impacts of this species on humpback chub and other native fishes.

Parameters/Indicators to Be Monitored, Monitoring Signals, and Reporting Variables

Monitoring of the numbers, body condition, and growth of RBT has revealed an inverse relationship between these two variables. Both are important to managers because number of individuals caught, and size and condition (relative health, or plumpness) of individuals caught are important measures of angling success. Therefore, monitoring includes collecting field data necessary to compute relative abundance of rainbow trout, measured as catch per unit effort, and depletion estimates of nearshore densities, a condition factor. Relative spawning success and growth rates of young fish have been evaluated with an experimental program studying early life stages of RBT in the Lees Ferry reach. Measures of density can be extrapolated from catch per effort divided by area sampled.

The 2009 Grand Canyon Fishes PEP recommended that the fish monitoring in the Lees Ferry reach also include monitoring of nonnatives. This recommendation reflects the occasional captures of nonnative fishes that may occur because of passage through GCD due to illegal stocking. Randomized sampling will report presence/absence of nonnative fishes, with more frequent sampling at known nonnative aggregations, such as the so-called Carp Pond backwater.

Links to Other Program Elements

Measures of the status and trends of the Lees Ferry RBT fishery inform management decisions regarding this fishery. Rainbow trout exhibit only limited piscivory (that is, fish eating), but when their numbers are elevated they may have a measurable effect on native fishes in Grand Canyon (Coggins, 2008 and references therein). When GCMRC and cooperating agencies removed RBT and brown trout (*Salmo trutta*) from the mainstem Colorado near the mouth of the LCR, the reach was often repopulated by RBT entering the reach from upstream (Coggins, 2008). Because of the potential for negative impacts to native fishes from piscivory, and also from competition for food resources (Valdez and Ryel, 1995), it is important to understand the status and trends of the Lees Ferry RBT population.

Core Monitoring Information Needs

The GCDAMP monitoring needs for the Lees Ferry RBT population call for annual assessment of the population, including population estimate, growth rate, condition, and density. A complete list of CMINs is provided in Appendix A.

Summary of Previous Work

Monitoring of the adult RBT population in the Lees Ferry reach is led by the AZGFD, and the GCMRC participates in this effort by contributing to data analysis, by storing data, and through logistics support. Scientists and managers studying this population have realized that many of their questions regarding the population had to do with the earliest life history stages, so GCMRC entered into a cooperative agreement with Ecometric, Inc., a private contractor whose studies have led to a better understanding of where and when redds (rainbow trout nests for egg-laying) are produced, the relative growth and survival of young RBT under given dam operations, how the eggs and larvae survive in response to flows, and where early life stages of RBT are to be found in the Lees Ferry reach (Korman, 2009, Korman and Campana, 2009). These early life stage monitoring techniques were reviewed by the 2009 PEP that did not recommend continuation of the young life stage studies. However, the early life stage work will be maintained specifically to gage the response of these life stages to specific dam releases.

Summary of Monitoring Program

Geographic Scope

Monitoring of the RBT population occurs in the Lees Ferry reach of the Colorado River, from Glen Canyon Dam to Lees Ferry, near the mouth of the Paria River.

Temporal Scope

Rainbow trout monitoring has typically been conducted 3–5 times per year between February and November. Monitoring of spawning and juvenile survival and growth has involved monthly sampling between February and September.

Methods

A regular monitoring program, deploying from 3 to 5 monitoring trips per year, has been implemented by the AZGFD since 1991, with support by GCMRC since 1996. The number of annual monitoring trips has been dependent on the activities and actions planned for any given year; for example, more RBT monitoring trips were conducted in 2008 to increase understanding of the RBT response to the March 2008 high flow experimental release from GCD (Hilwig and Makinster, *accepted*).

Typical RBT monitoring has included electrofishing at 25 or more stratified random and 9 fixed transects in an augmented, serially alternating sampling design (Urquhart and others, 1998). Each transect is sampled with single pass, boat-mounted electrofishing. Captured fish are measured and weighed and inspected for tags. In the fixed transects, RBT greater than 150 mm total length are implanted with a PIT tag and their adipose fins are clipped for future assessment of PIT tag retention rate. In addition, RBT more than 200 mm in total length are tagged with individually numbered external Floy tags to help assess RBT movement.

The 2009 PEP recommended that the current level of effort being conducted to monitor RBT in the Lees Ferry reach should be redirected. The change of direction would include the following:

- Conduct randomized monitoring but discontinue the fixed site monitoring. Both efforts do not appear to be necessary in every year because the multiyear trends in both efforts consistently yield similar catch per unit effort results.
- Additional randomized monitoring should now include sampling for other nonnative fishes as well as RBT.
- Additional monitoring efforts should include monitoring of known nonnative fish populations, such as the Carp Pond backwater.

For future years the Lees Ferry reach should monitor all species present—RBT as well as other species. To assess the responses of fish in this reach specifically to experimental dam releases, the fall steady flows 2008-2012, the young RBT assessments of redds, larvae, and young-of-year will continue. To the extent practicable, Lees Ferry fish monitoring will extend downstream from the mouth of the Paria River, but not farther than Badger Rapid (approximately RM 6). Additional collections downstream of the Paria River are intended to investigate whether RBT and other fish species are moving downstream of the input of this major tributary.

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Goal 5: Maintain or attain viable populations of Kanab Ambersnail

Statement of Problem

The Kanab ambersnail is a federally listed endangered terrestrial mollusk that inhabits moist habitats, often near water sources. It is naturally found at Vaseys Paradise, a perched spring and associated wetland that cascades off the canyon walls into the Colorado River in Grand Canyon near RM 32. Because of the snail's legal status and the potential for the population and its habitat to be affected by dam operations, this species has been included as a goal by the GCDAMP and monitoring of the species habitat is required by the Colorado River Management Plan and the Biological Opinion associated with operations of Glen Canyon Dam.

Parameters/Indicators to Be Monitored, Monitoring Signals, and Reporting Variables

Because of their small size, Kanab ambersnails are difficult, if not impossible, to monitor directly through population demographic approaches such as mark/recapture. Population estimates can vary widely from one survey to the next, sometimes by one or more orders of magnitude. Working with cooperators, led by the AZGFD, the GCMRC has continued attempts to count individual snails, but the GCMRC and its cooperators have also recognized that these counts are notoriously variable, so we have also instituted a protocol of monitoring the vascular plants cardinal monkeyflower (*Mimulus cardinalis*) and watercress (*Nasturium officianale*) on which the snails are commonly found at Vaseys Paradise. The parameters reported for this species and its habitat are extent of habitat area at Vaseys Paradise, total vegetated area, vegetated area above and below the 45,000 cfs stage elevation, and presence of Kanab ambersnails in each established plot.

Links to Other Program Elements

The habitat for Kanab ambersnail, primarily cardinal monkeyflower and watercress, may sometimes grow down the limestone substrate to near the river surface. When experimental high flows are released from Glen Canyon Dam, this habitat may extend below the elevation of the highest discharge water surface level. Therefore, Kanab ambersail habitat is most directly related to Glen Canyon Dam operations associated with high-flow experiments as well as monthly volumes. High-flow experiments that removed vegetation at Vaseys Paradise have occurred in 1996, 2004, and 2008. For the last two experimental high flows (2004 and 2008), personnel collected and temporarily moved the plants upslope at Vaseys Paradise to a location higher than the peak flow level during the flow test. When water levels returned to normal diurnal dam operations and discharge volumes (a matter of days), the plants were returned and were able to reestablish and thrive, again providing snail habitat. The springs at Vaseys Paradise are also identified as culturally important by some Native American tribes and have an aesthetic value to visitors along the river corridor.

Core Monitoring Information Needs

The core monitoring needs for Kanab ambersnail have been focused on tracking the status and trends of this species habitat at Vaseys Paradise. The complete list of CMINs is provided in Appendix A.

Summary of Previous Work

A systematic approach to monitoring the Kanab ambersnail and its habitat has been developed largely by the AZGFD with support from the GCDAMP, administered by the GCMRC. The monitoring approach, modeled after that of Stevens and others (1997b), has been used to monitor the Kanab ambersnail population in Grand Canyon, especially at Vaseys Paradise, for more than 10 years as of 2005 (Sorensen, 2005).

The AZGFD has produced a series of reports that document their efforts to monitor this species (e.g., Sorensen, 2005). The species and its habitat have been conserved during experimental high-flow events by physically moving, then replacing, the vegetation that provides the habitat for the species at Vaseys Paradise. The increase or decrease of habitat is influenced by discharge from the springs and river discharge volumes. Browsing animals such as bighorn sheep (*Ovis canadensis*) have also been known to affect vegetated areas occupied by the Kanab ambersnail. Both the monitoring and conservation actions have not only advanced understanding of the species' habitat needs but also provided compliance with USFWS requirements to protect the species.

Kanab ambersnails were listed as threatened based on the taxonomy completed in the late 1980s that suggested only a few populations of this animal existed in southern Utah and northern Arizona. However, unpublished data now in review suggest that the snails currently identified as Kanab ambersnail may in fact be members of a species of *Oxyloma* that is distributed throughout much of the United States and Canada in wet, terrestrial habitats. The USFWS is awaiting the results of this taxonomic review before concluding their species status review.

Summary of Monitoring Project

Geographic Scope

The project location is confined to Vaseys Paradise (RM 32)

Temporal Scope

Habitat area is surveyed in the fall and a census of the snails is conducted in spring and fall.

Methods

Monitoring follows the methods developed by Stevens and others (1997b) and also incorporate timed presence/absence and nearest-neighbor snail counts. In addition, the fall sampling includes sampling the upper vegetation zone snail population above the 100,000 cfs (2,833 cms) stage discharge height. Area of habitat patches, measured in the fall, are determined using traditional land survey methods that include a total station setup and rod-man selecting points that define individual habitat patches.

The method of Stevens and others (1997b) includes randomized 20 cm diameter subsamples of vegetation. Parameters recorded include plant species, plant height, soil moisture content, and distance of the subsample from the edge of the patch. Live snails or snail shells encountered in the subsample are measured for length and assigned to species (other snail species also inhabit the springs). The timed sampling and nearest-neighbor sampling is used to census snail numbers within patches. Snail numbers from sampling are compared between years to provide an idea of the stability of the population, but not population size. Habitat area is the primary parameter that is monitored for Kanab ambersnail.

Field data are entered into a Microsoft Excel spreadsheet and/or Access database. A summary report of these activities and monitoring results are provided by the AZGFD.

Program Status and Implementation Schedule

Monitoring of the Vaseys Paradise population, and also of an experimental translocated population downstream at Elves Chasm, is anticipated to continue in 2009, 2010, and 2011. This timing should allow the USFWS to receive outstanding documentation, especially Carver and others (*in prep*.), associated with an anticipated process to remove the species from the Federal Endangered Species list based on a taxonomic change. The GCDAMP should take advantage of this time period to determine if a locally rare, though broadly distributed, species such as the ambersnail continues to be a resource of concern for the GCDAMP. Grand Canyon National Park has indicated that they will continue to be concerned with, and manage for, the fate of this animal and its limited habitat, no matter its legal status. The GCDAMP may also choose to contribute to the protection of this limited resource.

Goal 6: Protect or improve the biotic riparian and spring communities, including threatened and endangered species and their critical habitat

Statement of Problem

The installation and operation of Glen Canyon Dam has changed the plant community composition along the river corridor from historic times. Where regular, large floods historically scoured the riparian zone, decreasing or eliminating plants along the water's edge, now the more constrained flow of the river has allowed for expansion and establishment of native and nonnative plant species (Stevens and Waring, 1986; Turner and Karpiscak, 1980; Ralston, SCORE, chap 5, 2005). Plants that were historically distributed along the historic flood levels (~85,000 cfs and greater) and away from the banks of the river are aging and showing signs of reduced recruitment because these locations no longer receive disturbance from floods (Anderson and Ruffner, 1987). Another result of reduced flooding has been the expansion of marsh communities (Stevens and others, 1995). Although these communities existed historically, they have expanded in the absence of regular flooding and scouring. The GCMRC projects within goal 6 are designed to better understand the effects of dam, climate, and other factors on the plant and animal distribution and diversity of the riparian zone.

An increased understanding of the riparian zone in the era following installation and operation of the dam is important for determining whether, and to what degree, the observed changes, especially in plant distributions, are driven by human or naturally caused factors, or both. Increased understanding supports efforts that may help protect sensitive or rare vegetation types, such as the upland mesquites or the lowland marshes. Both the plants and the animals of the riparian zone have cultural significance for native peoples, so understanding natural and human-caused influences on these resources increases the potential for developing effective conservation strategies.

Parameters/Indicators to Be Monitored, Monitoring Signals, and Reporting Variables

The GCMRC approach to monitoring the riparian ecosystem in Grand Canyon is diverse, reflecting the diverse resources found in this habitat. The principal resources to be monitored are vascular plants, arthropods (invertebrate animals including insects, spiders, mites, and other species), and to a more limited extent, birds. The GRCA currently monitors birds in association with their CRMP. Bird monitoring will be done in a manner that augments current monitoring of GRCA. GRCA has assumed leadership for monitoring the endangered southwest willow flycatcher in Grand Canyon, and monitoring this species is not addressed further here.

Riparian Vegetation

The distribution and composition of the plant community is monitored using remotely collected data that are processed and supplemented with field verification and data collection. The remote data will be used to assess the area occupied by overstory plants, including both native and nonnative vegetation. Field verification of the dominant cover class identified through image processing of remote data also records the presence of understory species that cannot be identified from overflight data. Reporting variables include composition (including ratio of native/nonnative species), distribution and area of marsh, new high water zone, old high water zone, and sand beach communities.

Arthropods and Birds

The goal of monitoring ground-dwelling arthropods (e.g., beetles, ants, spiders) and birds is to provide status and trends data on key species and community composition as one of several indicators of ecosystem condition. Bird habitat sampling will involve point counts at fixed sites that include current GRCA sample sites as well as larger vegetated sites. Sampling for ground-dwelling arthropods will involve pitfall trap sampling at fixed sites within the new and old high water zones. The traps will be checked, emptied, and reset for sampling on a monthly basis in the spring and summer. Sampling frequency is based on other sampling efforts in the Southwestern United States (Cobb and Delph, 2005). Seasonal and annual trends in composition and abundance for arthropods and birds will be reported relative to the old and new high water zones, and the relationships among arthropod or bird measured parameters and vegetation structure and composition, soil stability, and soil moisture will also be evaluated. Reported variables include abundance, richness, diversity, and distribution in old and new high water zones as well as relationships among community elements.

Links to Other Program Elements

The riparian plant community not only fixes carbon through photosynthesis, thereby producing plant tissue for use by other organisms, but also provides habitat for animals (both aquatic and terrestrial animals) and humans, and has implications for extent of associated sandbar stability. Native American tribes ascribe cultural resource values to many of the native terrestrial plants and animals. The link between vegetative production, richness and diversity, and these other resources is the response of vegetation to changes in operations through an increase or decrease of vegetated area and other parameters of vegetation change.

The composition and abundance of riparian vegetation, arthropods and birds provides links in assessing the overall condition of aquatic and terrestrial ecosystems. Information on the status and trends of ground-dwelling arthropod and bird assemblages integrates with monitoring data relating to (1) vegetation composition and structure, (2) soil stability and grain size, (3) upland hydrologic function, and (4) campable area. Arthropod values provide a linking dataset between the aquatic food base and diets of terrestrial and aquatic vertebrates such as rainbow trout and humpback chub.

Core Monitoring Information Needs

The core monitoring needs for goal 6 are tracking the abundance, composition, distribution, and area of the riparian and marsh habitats below Glen Canyon Dam; tracking the abundance and distribution of nonnative plants along the riparian corridor; and monitoring southwestern willow flycatcher and its food base, predominantly arthropods (Drost and others, 2003; Wiesenborn and Heydon, 2007). The complete list of CMINs is found in Appendix A.

Summary of Previous Work

The GCMRC goal 6 projects since 1996 have focused on increasing our knowledge about the plant community composition of the riparian zone and how vegetation responds to changes in dam operations. Animals in this zone have also been the subject of GCMRC research projects intended to lead to core monitoring (Spence, 2006). The Terrestrial Ecosystem Monitoring (TEM) project was initiated in 2001 and a final report was completed in 2006 (Kearsley and others, 2006). The project was conducted in response to PEP recommendations (Urquhart and others, 2000) to develop integrated monitoring approaches for the terrestrial ecosystem. Key findings related to vegetation response to general operations indicate that vegetation below the 35,000 cfs stage elevation responds to both operations and local weather, and vegetation above this elevation is mostly affected by local precipitation (Kearsely and others, 2006). These tendencies change under high flow or low steady flow conditions (Kearsley and Ayers, 1999; Porter, 2002).

Not surprisingly, richness and vegetated cover is related to water availability. Values associated with both of these parameters for vegetation generally increased at the 25,000 cfs stage elevation and gradually declined with increasing stage elevation (Kearsley and others, 2006). Vegetated cover, structure, and area are linked to bird abundances (Holmes and others, 2005) such that increases in these parameters are associated with increases in bird abundances and diversity. Birds utilize the structure for nesting habitat, and the diversity of plant species provides varied food resources for their diet (Yard and others, 2004).

Arthropods perform essential ecosystem functions such as decomposition, nutrient recycling, and pollination, and are an important food resource not only for other invertebrate species but also for higher level organisms. Their small size and rapid population growth rates result in their being responsive to both fine-scale spatial variation and short temporal scales. Consequently, arthropods are typically useful indicators of environmental change. Arthropods are likely to respond rapidly to management practices, potentially informing these decisions faster compared to longer-lived organisms. An inventory of arthropods for subsequent monitoring was initiated in the TEM project (Kearsley and others, 2006); the results of the inventory and distribution analysis indicate that abundance and diversity varies between zones and that there are several indicator species within each zone that can be used to monitor change within zones (Cobb and others, *in prep*.). The inventory samples provide a reference collection for a pilot monitoring project being conducted in Glen Canyon in 2009.

A final effort associated with terrestrial monitoring includes incorporating the use of data taken remotely (overflight imagery) for the purpose of assessing landscape-scale changes in riparian habitat. Remotely sensed data collected in 2002 were utilized by GCMRC to construct the first digital canyonwide plant community map of the Colorado River corridor below the dam (Ralston and others, 2008). The map allows the quantification of vegetated area cover within the new high water zone, old high water zone, sand beach community, and marshes. The use of sequential remotely sensed datasets (e.g., 2005, 2009) allows for change detection on a long-term basis relative to long-term operations.

Summary of Monitoring Project

Geographic Scope

This monitoring encompasses the Colorado River ecosystem from the forebay of Glen Canyon Dam to the westernmost boundary of Grand Canyon (RM -15 to 278).

Temporal Scope

Overflight data will be collected approximately every 4 years; ground-based vegetation sampling will coincide with overflights. Ground-based event monitoring will be conducted to supplement the quadrennial sampling as needed. Arthropod and bird monitoring would occur annually (April–September).

Methods

Riparian Vegetation

In 2009 and beyond, the GCMRC will continue to build on the work of Ralston and others (2008) by using quadrennial overflight data for the purpose of landscape-scale change detection. This will allow comparisons between years and an assessment of whether the abundance, distribution, and area of the riparian and marsh communities has changed between these years. Following recommendations of the 2007 PEP, the GCMRC intends to begin a schedule of vegetation sampling beginning in 2009 that coincides with overflights as well as biennial sampling. Sampling will consist of 100 sq m plots along the river that incorporate geomorphic features (e.g., debris fans, eddy bars, return channels) and hydrologic zones (fluctuating, new high water, old high water). Plot data will include presence/absence of species encountered and cover estimates, using a categorical cover scale, for each species. These data provide composition, abundance, richness, and diversity for all species as well as cover for the most dominant species within geomorphic and hydrologic contexts. Native and nonnative species will be identified and intersite variability will be assessed. These data are also used to identify alliance level vegetation classes for large-scale mapping.

An agglomerative cluster analysis using Sorenson's distance measure and Ward's method for linkage (McCune and Grace, 2002) will be used on the plot data to identify vegetation classes for mapping. Nonmetric multidimensional scaling (Minchin, 1987; McCune and Grace, 2002) will be used to explore compositional patterns in the vegetation and to determine assemblage groups. Sampling will also be conducted around high-flow experiments (HFEs) or other large-scale operational changes (as they occur) that might affect riparian and marsh vegetation to evaluate short-term effects of these operational changes. Funding for monitoring conducted in association with large experiments such as HFEs is anticipated to come from experimental funds, not the annual GCDAMP work plan designated for monitoring.

Change detection will be conducted using post-classification comparison (Singh, 1989) because we want to identify how much each vegetation class changes and the result of that change (e.g., arrowweed to bare ground or bare ground to coyote willow/*Baccharis*). Post-classification comparison requires independent classification of imagery followed by a comparison between classifications to determine the pixels with a change in classification between the dates. This methodology is preferred to image differencing because the sensors used for image collection may change. Ground truthing following map production will be used to accurately determine how areas changed. The comparisons in themselves should accurately determine area change, but may not accurately identify how (Weismiller and others, 1977; Stow and others, 1980). A change matrix will be used to represent area changes and the nature of change between classes occurring between years. These change matrices will be prepared for each zone and combined to present change within each geomorphic reach, since each reach can be compositionally different.

Arthropods and Birds

Beginning in 2010, the GCMRC intends to return to a program of terrestrial monitoring beyond vegetation to be conducted in coordination with GRCA's bird monitoring program. The focus of this monitoring is to be ground-dwelling arthropods, consistent with the recommendations from the 2007 terrestrial PEP panel (Cooper and others, 2008), but pending the outcome of a pilot project in Glen Canyon, and bird monitoring. Bird monitoring would augment the bird sampling (point counts) currently conducted along the corridor by GRCA to include larger vegetated sites not currently monitored by GRCA. Analysis of bird data will be dependent on GRCA reporting. Arthropod monitoring would be conducted using pitfall traps (pending coordination with GRCA) that are emptied on a monthly basis in association with bird monitoring trips and other resource monitoring trips throughout the spring and early fall. A protocol for this work has been developed and implemented for Mesa Verde National Park (Cobb and Delph, 2005) and is being piloted in Glen Canyon in 2009. Arthropod identification will be conducted in the laboratory using voucher specimens from the Terrestrial Ecosystem Monitoring (TEM) project.

With respect to analysis of arthropod samples, three types of statistical analyses will be used to test for effects of water zone on ground-dwelling arthropods. First repeated-measures ANOVA tests will be used to test for differences in arthropod abundances and species richness. A multiresponse permutation procedure will be used to determine arthropod community difference among water zones, and nonmetric multidimensional scaling scatter plot (Clark, 1993) will be used to examine similarities of arthropod assemblages among water zones based on Bray-Curtis distances (Beals, 1984; McCune and Beals, 1993). Finally, a species indicator analysis using a Monte Carlo test of significance will be conducted to determine if specific arthropod taxa are responding to water zone.

Program Status and Implementation Schedule

GCMRC has initiated the monitoring activities described in the Summary above for FY2009, 2010, and 2011, consistent with terrestrial PEP recommendations.

Goal 7: Establish water temperature, quality, and flow dynamics to achieve the GCDAMP ecosystem goals

Statement of Problem

The operation of Glen Canyon Dam and water quality conditions in Lake Powell strongly affect streamflow and water quality conditions on the downstream Colorado River. Dam operations are determined by regional climate, laws and policies governing water transfer volumes for various time scales, and consideration for downstream resources. Currently, normal dam operations include diurnal fluctuations in flow that are large in comparison to typical pre-dam conditions but lack the monthly variation and annual floods that were characteristic of the natural flow regime (Howard and Dolan, 1981; Topping and others, 2003). Because the dam and its large upstream reservoir block the supply of sediment received from upstream sources, suspended sediment concentrations below the dam are much lower than in the pre-dam period, resulting in a fine sediment (sand and finer) deficit in the river (Topping and others, 2000a, 2000b), as evidenced by observations of net sand export from Grand Canyon during periods of normal dam operations and low tributary sediment inputs (Topping and others, 2000a). The temperature regime has also been transformed from seasonally variable (0–30°C) to uniformly cold (~9°C; Voichick and Wright, 2007). These streamflow and water quality dynamics affect most aspects of the CRE in Grand Canyon and, thereby, directly or indirectly affect most resources that are a focus of adaptive management efforts.

Parameters/Indicators to Be Monitored, Monitoring Signals, and Reporting Variables

The key signals that monitoring must detect are the status of the sediment budget (on a time scale of weeks up to 3–5 years), and both short- and long-term trends in water temperature and other water quality parameters. To ensure detection of these signals, the parameters selected for long-term core monitoring are water stage and discharge (streamflow) and selected water quality parameters, which are water temperature, turbidity, suspended sediment concentration, suspended sediment grain size, dissolved oxygen concentration, pH, and specific conductance (salinity). Because inputs to the system cause downstream changes in these parameters, monitoring must occur at multiple locations in the CRE. To provide predictive capability, some parameters must be measured in Lake Powell and tributary streams.

Links to Other Program Elements

The streamflow record is a fundamental monitoring requirement that is linked to all other resources. An accurate streamflow record is necessary to (1) provide the legal record of water transfer from the upper to the lower Colorado River basin, (2) monitor compliance with the 1996 Record of Decision for the Glen Canyon Dam Environmental Impact Statement, termed the Modified Low Fluctuating Flow operation, (3) provide empirical data for temperature, suspended sediment transport, and other water quality models, and (4) associate dam release patterns with observed aquatic and riparian habitat conditions as well as the human recreation experience.

Measurements of suspended sediment concentration and grain size are required to calculate the sediment mass balance (budget), which is used to determine whether individual channel segments (48–97 km in length) are accumulating, evacuating, or conserving sediment over time scales of several weeks up to approximately 5 years, depending on actual tributary sediment inputs and dam operations. This tracking of the "sediment bank account" is required to determine the extent to which dam operations cause depletion of sand storage and when tributary inputs result in conditions that are favorable for possible high flows from GCD to redistribute sediment from the channel to build sandbars at higher elevations in the eddies and on the channel margins.

Temperature records are necessary to develop quantifications of aquatic productivity and aquatic habitat conditions, which are essential to understanding the dynamics of native and nonnative fish populations. Records of the other water quality parameters, such as dissolved oxygen, turbidity, and specific conductance, are required to understand aquatic ecosystem conditions and as input for aquatic ecosystem models. Monitoring of these parameters in the GCD forebay and throughout Lake Powell provides necessary input for models that predict water temperature and water quality in the downstream CRE.

Core Monitoring Information Needs

The core-monitoring information needs for streamflow and water quality are as follows:

- Monitor flow releases from GCD under all operating conditions, particularly related to flow duration, upramp, and downramp conditions. This monitoring supports nearly all other research and monitoring activities downstream from Glen Canyon Dam, including compliance with the 1996 Record of Decision related to the modified low fluctuating flow, occasional higher releases, such as the beach/habitat building flows, and other related experimental operations.
- Monitor and track tributary sediment input volumes and grain-size characteristics. This monitoring should encompass the Paria River and LCR stations, in addition to other major tributaries like Kanab Creek and Havasu Creek. This monitoring is a necessary component of the sediment mass balance, in support of goals related to fine sediment storage and sandbar maintenance (goal 8).
- Monitor and track mainstem Colorado River monthly sediment transport volumes and grain-size characteristics at the long-term USGS monitoring stations located at Lees Ferry, Grand Canyon, and Diamond Creek (RM 0, 87, and 226, respectively) and selected intermediate monitoring stations. This monitoring is also a necessary component of the fine sediment mass balance, in support of goals related to fine sediment storage and sandbar maintenance (goal 8). Spacing of measurement stations must allow computation of the fine sediment budget for river segments between 30 and 60 mi in length.
- Monitor water temperature in the mainstem, backwaters, and near-shore areas throughout the CRE. This monitoring supports aquatic food availability and native fish and rainbow trout goals (goals 2 and 4).
- Monitor seasonal and yearly trends in turbidity, specific conductance, dissolved oxygen, and pH in the mainstem Colorado River. This monitoring supports aquatic food availability and fish goals (as above).
- Monitor discharge and temperature of the mainstem Little Colorado River near the mouth. This monitoring supports aquatic food availability and fish goals (as above).
- Monitor the status and trend of water quality releases from GCD.

The complete list of CMINs is presented in Appendix A.

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Summary of Previous Work

Lake Powell

Lake Powell water quality has been monitored continuously from the early period of reservoir filling in 1965 to the present. The initial monitoring program was conducted by the Bureau of Reclamation until 1996, when it was continued by GCMRC with funding provided outside the scope of GCDAMP funds.

Since 1990, monitoring of the entire reservoir has occurred quarterly in most years and monitoring of the forebay area, immediately upstream from Glen Canyon Dam, has occurred monthly. Continuous measurements of water quality have been made within the Glen Canyon Dam power plant and in the tailrace since 1988. Samples are collected from these sites on a monthly basis.

A Protocol Evaluation Panel (PEP) review of the Integrated Water Quality Program was conducted in November 2000, resulting in several recommendations for integrating Lake Powell monitoring with other projects and incorporating the results of predictive modeling efforts (Jones and others, 2001). The water quality data from 42 years of Glen Canyon Dam's history have been compiled into a relational database and these data were published in a 2009 USGS Data Series report (Vernieu, 2009). The published data will be made available through the GCMRC Web site (www.gcmrc.gov*)*, along with annual updates.

Colorado River Downstream from Lake Powell

Systematic measurements of the discharge of water and the quality of water in the CRE began with the installation of the Lees Ferry gaging station by the USGS in May 1921 (Topping and others, 2003). Daily measurements of suspended-sediment concentration and temperature, and episodic measurements of other water-quality parameters were made by the USGS at multiple sites in the CRE until the early 1970s (Topping and others, 2000a). Concern over the effects of the operations of Glen Canyon Dam on the CRE resulted in a new emphasis on measurements and modeling of water quality in the early 1980s (National Research Council, 1996). Research resulting from the 1996 high flow experiment revealed that multiyear accumulation of fine sediment within the CRE was difficult to achieve and that existing models for sediment transport could not be relied upon to predict sand flux for sediment budget computations (Rubin and others, 1998, 2002; Topping and others, 1999, 2000a, 2000b, 2005; Rubin and Topping, 2001; Wright and others, 2005). These findings demonstrated the need to return to a more rigorous measurement program to enable tracking of the status of the sediment budget.

In August 1999, GCMRC initiated an intensive sediment sampling program that consisted of near daily suspended-sediment measurements at three gaging stations. Because substantial discharge-independent changes in suspended-sediment concentration were observed over timescales that could not be captured by this extremely costly quasi-daily program, laser and acoustic technologies for measuring suspended-sediment concentration and grain size were developed and tested beginning in 2001 (Melis and others, 2003; Topping and others, 2004, 2006b). These tests resulted in the current "mass balance" monitoring program that includes measurements of stage, water temperature, conductivity, and suspended-sediment concentration and grain size at 15-minute intervals for five locations between Lees Ferry and Lake Mead. As a complement to the monitoring program predictive models have been developed and tested for stage, discharge, sediment-transport, and water temperature (Wiele and others, 2007; Anderson and Wright, 2007; Wright and others, 2008a, 2008b).

Because fine sediment has been a central resource concern below Glen Canyon Dam, the suspended-sediment transport component of downstream quality of water monitoring has been subjected to its own protocol review. Two PEP reviews of the sediment and flow elements of downstream integrated quality of water (IQW) monitoring program have been conducted (Wohl and others, 1999, first sediment PEP report; Wohl and others, 2006, final sediment PEP report). An additional final review of the proposed program (GCDAMP Science Advisors, 2007) concluded that the proposed program (Topping and others, 2007, part 4, sediment protocol recommendations for core monitoring plan) should be expected to effectively address core monitoring information needs and strategic science questions for fine sediment. Thus, the core-monitoring program described herein differs from the program that is currently being conducted only in that it includes some additional water quality elements that are proposed but are not currently funded.

Summary of Monitoring Project

Lake Powell

It is anticipated that future monitoring will follow the established protocols that have been in place since 1996. However, based on publication and analysis of historic data, some aspects of the monitoring program may be revised in 2010 to maintain cost-effectiveness and applicability of the information collected to other resources. Reservoir sampling generally involves travel to a particular site by boat, recording observations of ambient conditions, collecting a depth profile of physical water quality parameters through the water column, and collecting samples at selected depths for chemical and biological analyses (fig. 7). Sampling at tailwater and inflow sites involves continuous and/or instantaneous measurement of physical parameters and collections of discrete samples from the stream site.

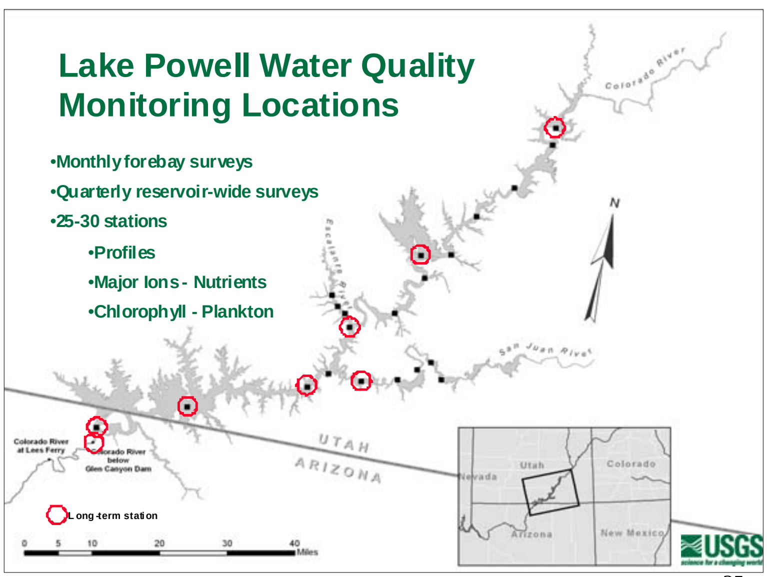

Figure 7. Monthly and quarterly survey locations for quality of water monitoring in Lake Powell.

Colorado River Downstream from Lake Powell

The current proposed core monitoring program (Topping and others, 2007) consists of remotely collected measurements of (1) mass balance parameters of water stage, suspended sediment concentration, and suspended sediment grain size, and (2) additional water quality parameters of temperature, specific conductance, turbidity, and dissolved oxygen concentration. Each of these parameters except dissolved oxygen is monitored at approximately 15-minute intervals at five mainstem stations located at RM 30, 61, 89, 166, and 225 (fig. 8). Water stage, temperature, specific conductance, turbidity, and dissolved oxygen concentration are monitored at RM 0. Dissolved oxygen concentration is also monitored immediately below Glen Canyon Dam and at RM 225. Also, on a near real-time basis, the concentration and grain-size distribution of the sand and finer material supplied by the major tributaries (Paria and Little Colorado Rivers) are computed using the real-time discharge data along with a geomorphically coupled flow and sediment-transport model (Topping, 1997). Sediment-transport measurements are collected on these two major tributaries using conventional and pump methodologies by the USGS Water Resources Discipline (WRD), Arizona and Utah Water Science Centers, and provided to the GCMRC laboratory. The mainstem stations are calibrated and maintained by field visits conducted at approximately 6-month intervals by GCMRC and USGS WRD Arizona Water Science Center.

The core monitoring plan recommends monitoring at two additional tributary locations on Havasu Creek and Kanab Creek, but installation and operation of those stations has not been funded. The current core monitoring plan may need to be reevaluated and modified in the future to address changes in GCDAMP goals, such as a potential need for more specific temperature monitoring data for testing and future implementation of a temperature control device, if such a device were ever to be funded and built.

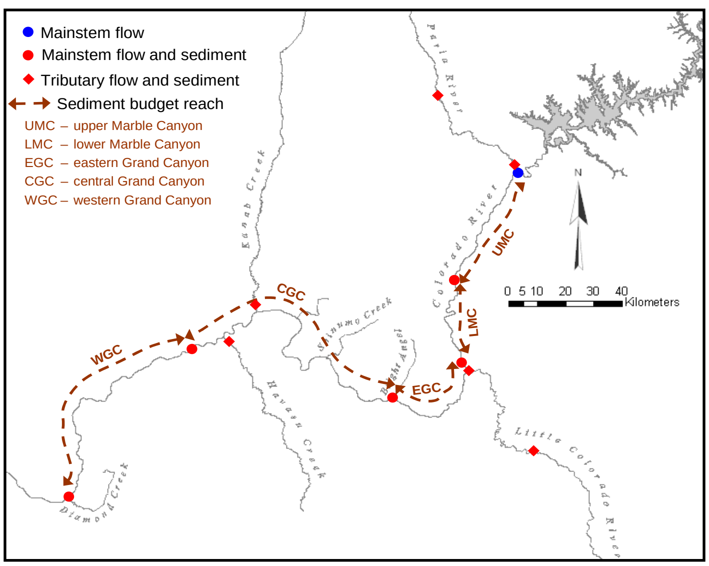

Figure 8. Location map showing streamflow, non-sediment quality of water and suspended-sediment transport data collection sites and fine sediment budget reaches. The parameters of the modified low fluctuating flow dam operation (U.S. Department of the Interior, 1995) are monitored as mainstem flow at the Colorado River near Lees Ferry gage shown at the top of the upper Marble Canyon reach.

Goal 8: Maintain or attain levels of sediment storage within the main channel and along shorelines to achieve the GCDAMP ecosystem goals

Statement of Problem

Closure of Glen Canyon Dam has resulted in at least a 90 percent reduction in sediment supply to the CRE in Grand Canyon (Topping and others, 2000a). Moreover, operations of the dam tend to result in a net export of sand and finer sediment in most years (Topping and others, 2000a). In response to this reduction in sand supply and the alteration of the natural hydrograph by dam operations, sandbars in Marble Canyon and the upstream part of Grand Canyon have substantially decreased in size (Schmidt and others, 2004) and are still in decline under normal power plant operations at the dam (Wright and others, 2005).

Parameters/Indicators to Be Monitored, Monitoring Signals, and Reporting Variables

The primary signal for fine sediment is the change in storage volume of the fine sediment below the 8,000 cfs water stage. Although the quality of water monitoring program tracks the fluxes of fine sediment and enables calculation of the change in storage, the uncertainty in these estimates accumulates and restricts the use of that method to time scales of 5 years or less. The essential data to detect trends in storage change over periods longer than 5 years are repeat measurements of channel bathymetry that are compared to determine change in storage between the measurement intervals. Because of technological and logistical constraints (discussed below), additional monitoring is required to track trends in high-elevation sand storage. For this monitoring, the essential parameters that must be measured are area and volume of sand exposed above the 8,000 cfs stage.

Links to Other Program Elements

Sediment forms the physical template for the CRE downstream from GCD. Sand and sandbars in and along the Colorado River were an integral part of the natural riverscape in Grand Canyon National Park, and are important for recreation, riparian habitat, native fish habitat, and many archaeological sites (Rubin and others, 2002; Wright and others, 2005).

Core Monitoring Information Needs

The core monitoring needs for sediment are the following:

- Within eddies, track the fine sediment area, volume, and grain size changes at all stages, by reach.
- In the main channel outside of eddies, track the area volume and grain size changes below the 5,000 cfs stage, by reach.
- Along the shorelines outside of eddies, track the area volume and grain size changes of sandbars above the 5,000 cfs stage.
- Track, as appropriate, changes in coarse sediment (> 2 mm) abundance and distribution.

A complete list of CMINs is shown in Appendix A.

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Summary of Previous Work

Growing concern about the effects of the operations of Glen Canyon Dam on the CRE led to the initiation of systematic measurements of sandbars in the 1970s (Dolan and others, 1974; Howard, 1975; Howard and Dolan, 1981). This sandbar-monitoring program was revisited in the 1980s (Schmidt and Graf, 1990; Beus and others, 1992), and eventually led to the long-term sandbar monitoring program conducted by the former Glen Canyon Environmental Studies and later the GCMRC in cooperation with Northern Arizona University during the 1990s and 2000s (Hazel and others, 1999; Schmidt and others, 2004). Evaluation begun in the 1990s and finalized in the geomorphic synthesis of Schmidt and others (2004) indicated that the observations of change made during these site-based programs were not necessarily representative of changes in the fine-sediment resource over longer reaches of the Colorado River, because these programs surveyed relatively small areas and the variability between sites was large. Moreover, the fact that substantial positive changes in sediment volume were observed in these site-based programs during periods when no sediment entered the system called into question the value of sediment budgeting based on monitoring of small sites (Hazel and others, 2006).

In contrast to the large variability within the site-based, long-term sandbar data, analysis of cross-section data collected by the USGS indicated near-universal scour of sediment from the CRE during the 1990s (Flynn and Hornewer, 2003). These observations led to the initiation in 1999 of flux-based monitoring. By 2001, research and development activities led to the current reach-based "Mass Balance Project" (goal 7) that combines conventional sediment transport sampling with sediment surrogate techniques to provide a high-resolution sand flux monitoring dataset used for calculating the fine sediment mass balance systemwide.

These previous research and monitoring efforts guided the development of the current fine sediment core monitoring plan. Results from the 2002–05 period of the mass balance project demonstrated that 90 percent or more of the fine sediment is stored in the eddies and channel at elevations lower than the 8,000 cfs stage (Hazel and others, 2006). This study also demonstrated that change in that low-elevation sediment storage computed from repeat measurements over short (~10 km) reaches is not consistent with the change in storage computed based on the measurements of sediment transport over longer (~50 km) reaches (Topping and others, 2006a). Although the measurements of sediment transport that are made as part of the Integrated Quality of Water's mass balance task (as mentioned above) will be used to detect changes in sediment storage in long reaches over short timescales (up to ~5 years), accumulated uncertainty in these measurements will prevent the determination of longer-term trends in sediment storage with adequate certainty.

Suspended sediment transport monitoring is necessary to track the accumulation and fate of tributary inputs and to provide information needed to plan high flow events. However, in order to determine whether sediment storage in the system as a whole is increasing, decreasing, or stable requires repeat measurements of sand storage throughout the entire system. For these reasons, fine sediment storage monitoring (goal 8) includes systemwide measurements of channel and eddy sand storage in addition to monitoring related to high-elevation sandbars, campsites, and backwaters.

Summary of Monitoring Project

The research and development phase for the sandbar and sediment storage monitoring program extended from FY1998 through FY2006. Thus, the current monitoring program is the outcome of this development period and has been fully evaluated through the sediment PEP process (Wohl and others, 1999; Wohl and others, 2006). The detailed core monitoring plan has been produced (Topping and others, 2007) and is being implemented, as summarized below.

The planned monitoring program for fine sediment storage (goal 8) builds upon the mass balance monitoring program, described under goal 7. Under downstream quality of water monitoring (goal 7), the flux of sand, silt, and clay is monitored into and out of long reaches of the river in the Colorado River ecosystem. These reaches are RM -15 to 0 (Glen Canyon), RM 0–30 (upper Marble Canyon), RM 30–62 (lower Marble Canyon), RM 62–88 (upper or eastern Grand Canyon), RM 87–166 (central Grand Canyon), and RM 166–226 (lower or western Grand Canyon). These sediment fluxes into and out of these reaches are integrated and then differenced to produce the "mass balance" sediment budgets. The sediment core monitoring program (goal 8) is designed to complement this flux-based monitoring with a geomorphically-based monitoring program.

Monitoring in-channel sediment storage – SedTrend

The primary signal, which is low-elevation trends in sand storage, will be monitored by annual (excluding years with HFEs), measurements of the area and volume of fine sediment over long reaches (> 50 km) using multibeam bathymetric surveys, ground-based topographic surveys, underwater video transects, and limited underwater microscope data collection for bed grain size. This task, termed SedTrend, is planned to be performed on a systemwide basis every 5 to 10 years in order to estimate fine sediment budgets over timescales for which the mass balance sediment budgets likely become inconclusive.

In addition to providing this key sediment budget information (that is, the status of the fine sediment "bank account"), these data will also provide information on the location and geometries of backwaters thought to be important habitat for native fish. Currently, it is logistically impossible to survey the bathymetry of the entire river in any given year. Therefore, a different reach of the river will be surveyed each year on a rotating basis. The reaches will correspond to the segments outlined in the downstream quality of water (goal 7) mass balance core-monitoring project, such that upon completion of a repeat survey for a given reach, all components of the sediment budget (the sediment influx at the upstream gage, the sediment efflux at the downstream gage, and the change in storage between the gages) for that reach will have been measured directly. Reach 1, RM 0–30 (upper Marble Canyon); Reach 2, RM 30–61 (lower Marble Canyon); Reach 3, RM 61–87 (eastern Grand Canyon); Reach 4, RM 87–166 (central Grand Canyon); Reach 5, RM 166–226 (western Grand Canyon).

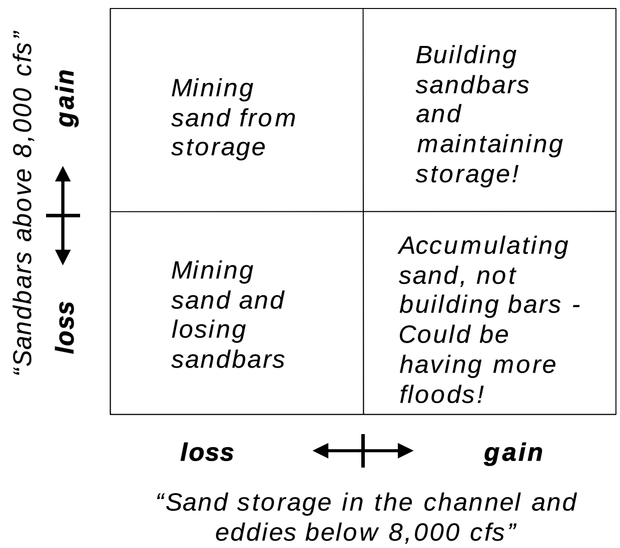

Figure 9. Conceptual plot showing how long-term trends in sand storage detected by the SedTrend monitoring program will inform management for sandbars. In the event that sandbars are increasing in size above the 8,000 cfs stage, the SedTrend monitoring of sand below the 8,000 cfs stage will enable distinction between net depletion, “mining” from storage, and net gain, or “maintenance” of sand. If sandbars above the 8,000 cfs stage are decreasing in size, the SedTrend monitoring will be used to determine whether this is also associated with net decrease in storage or an increase in storage. The later would mean that more high flows could be used to achieve management goals of building sandbars while the former would mean that sandbar goals are unlikely to be met without additional sediment.

These SedTrend surveys will occur in the late spring and will only be completed in years without HFEs; thus, in the absence of HFEs, each reach would be surveyed every 5 years, or if HFEs occurred on average every other year, then each reach would be surveyed on average every 10 years. This 5 to 10 year interval between repeat bathymetric and topographic surveys, coupled with the mass balance flux monitoring, is expected to provide a robust quantification of long-term trends in the fine sediment budget. Because reaches 4 and 5 are much longer than reaches 1 through 3, it is possible that portions of these reaches will not be surveyed. Existing data will be used to identify the portions of these reaches that are most likely to store fine sediment. It is also possible that continued technological advancements and improvements in methods will allow for complete surveys of these reaches in the future.

The monitoring data provided by the SedTrend project will inform managers whether the combined effects of basin hydrology, sediment supply, and dam operations are resulting in accumulation or depletion of sand from storage in the CRE (figure 9). These data will provide guidance on the feasibility of meeting management goals for sand and sandbars and may result in the need to revisit or alter management decisions.

Monitoring High-Elevation Sandbar Deposits and Campsites

High-deviation sandbars will be monitored by infrequent remotely sensed inventory and annual or biennial ground-based measurements. Approximately every 4 years (excluding years with HFEs), the system-wide area of fine sediment above the stage associated with a discharge of 8,000 cfs (that is, approximately 10 percent of the fine sediment in the CRE) will be monitored using orthorectified aerial photography images collected during overflights; the volume of fine sediment may also be monitored if light detection and ranging (lidar) sensors are also deployed. These remote-sensing data may also be used to help monitor the magnitude and trends in campsite area, backwater area and distribution, and the availability of open dry sand on sandbars, as well as for other resource areas such as riparian vegetation monitoring.

A subset of sandbars located throughout the CRE will be monitored every 1–4 years using conventional ground-based surveying methods. This dataset, commonly referred to as the “long term sandbar time series,” is the longest running dataset on the state of sandbars currently available (initiated in 1990). Previous studies have shown that this monitoring effort tracks significant trends in the area of sand above the 8,000 cfs stage (Schmidt and others, 2004). This task is conducted in coordination with recreational experience (goal 9) monitoring of campsite area, and will include measurements of the area and volume of fine sediment above the stage associated with 8,000 cfs.

Monitoring Changes in Coarse-Grained Sediments and Impacts from Tributary Debris Flows

At least 768 tributaries have the potential to contribute coarse-grained sediment to the CRE. The addition of coarse sediment is known to alter beaches and debris fans and can change the way that finer sediment is stored throughout the main channel. Such changes occur as a result of aggregation of main channel rapids, upper pools, and runs above rapids and through deposition of new gravel on existing debris fans and eddies. These geomorphic changes influence the ecosystem’s flow dynamics in and between rapids, and effectively increase the abundance of gravel substrates spatially. Monitoring of changes resulting from continuing tributary inputs of gravel will be conducted as part of the repeat channel mapping, thus enabling detection of long-term trends in coarse sediment storage. Although debris fans will not be mapped during the channel mapping, changes in water surface elevation that result from debris flows will be detected. In the event of large tributary debris flows that significantly alter the navigational characteristics of the main channel, additional field activities may be needed on a contingency basis.

Goal 9: Maintain or improve the quality of recreational experiences for users of the Colorado River ecosystem, within the framework of the GCDAMP ecosystem goals

Statement of Problem

The Colorado River corridor in Glen Canyon and Grand Canyon offers a diverse assortment of recreational opportunities. Immediately below Glen Canyon Dam, the river supports a popular trout fishery, and 24 km (15 miles) downstream of the dam is the start of a 386-km (240-mile) stretch of river that is world-renowned for its whitewater rapids and associated camping and hiking opportunities. Providing for visitor enjoyment by maintaining high-quality recreation experiences along the Colorado River is a mandate of the National Park Service Organic Act, and monitoring dam effects on visitor use values is a requirement of the Grand Canyon Protection Act. The operations of Glen Canyon Dam have the potential to improve or degrade the quality of visitor experiences in the Colorado River ecosystem (CRE) through affecting the condition of fish and their aquatic habitats, flow-related angling opportunities, the size and quality of camping beaches, the quality of the whitewater experience, boater safety, and many other biophysical and social attributes that contribute to the recreational experience. In the Glen Canyon reach, the major concerns of the GCDAMP relate to how dam operations affect the number and size of rainbow trout and the quality of angling opportunities. In Grand Canyon National Park, concerns focus on the size, number, and distribution of camping “beaches” in the river corridor and on how the volume and fluctuations of dam-controlled flows affect overall visitor experience in terms of safety, crowding, camp competition, camp quality, and impacts on visitors’ perceptions of wilderness.

Parameters/Indicators to Be Monitored, Monitoring Signals, and Reporting Variables

In terms of recreational angling, the condition of the sport fishery as reflected in the number, size, and overall health of rainbow trout above Lees Ferry is monitored annually (see goal 4); in the future, these data will be supplemented with survey data on angling success and angler satisfaction collected through routine AZGFD creel surveys. In terms of recreational experience downstream of Lees Ferry, key parameters include the number, size, distribution, and physical attributes of shoreline campsites, which will be assessed through a combination of repeated total station surveys at approximately 35 sites, aerial digital imagery analysis of campsites throughout the CRE, and oblique repeat photographs at a sample of campsites. To assess the overall effects of dam operations on recreational quality and visitor experience attributes, the campsite monitoring program will be supplemented by monitoring key recreational attributes that will be determined through completing periodic surveys of recreational use and values and a recreational attribute trade-off analysis, as recommended by the 2005 recreation PEP (Loomis and others, 2005b.)

Links to Other Program Elements

Recreational experience includes consideration of both biophysical and sociological factors. Campsites are an important indicator of recreational experience because they affect visitor perceptions of enjoyment, wilderness, crowding, and solitude. The size and distribution of campsites also influence types and amounts of human impacts that occur in the CRE. In the absence of engineered environments, humans prefer certain types of campsites (habitat) over others (Stewart and others, 2000, 2003.) Generally speaking, preferred habitats are relatively open and level, free of obstacles, and include expansive views and adequate shade and shelter from the elements. For recreational boaters in Grand Canyon, other important biophysical campsite attributes include quiet stable mooring conditions for boats and relatively easy access from the shoreline to the camp.

Another important sociological attribute for recreational users in wilderness settings is being able to camp out of sight and sound of other parties. For day-use anglers in Glen Canyon, the size, number, and distribution of trout and the quality and accessibility of trout habitats are important, as well as opportunities for quiet and solitude. All of these biophysical attributes, and some sociological attributes, are affected by dam operations. Understanding how these attributes change in response to dam operations requires data from and integration with other elements of the GCDAMP research and monitoring program, including food base (goal 1), fish (goals 2 and 4), terrestrial habitats (goal 6), flow dynamics (goal 7), and sediment (goal 8).

Core Monitoring Information Needs

The 2003 AMP Strategic Plan (GCDAMP, 2003) identifies several core monitoring information needs (CMINs) related to goal 9 that relate to tracking the effects of dam operations on visitor experience quality. Tracking the number, size, and distribution of camping beaches by reach and stage level in Glen and Grand Canyons is one key information need (CMIN 9.3.1). Tracking the effects of dam operations on various other physical and social attributes that affect overall recreational experience quality—such as camp crowding, safety, types and intensity of human impacts, and other factors (CMIN 9.1.1)—is another key information need that has been repeatedly identified as a long-standing gap in the current GCDAMP monitoring program (Kaplinski and others, 2005; Loomis and others, 2005b). Adaptive Management Program stakeholders have also identified the need to track frequency and scheduling of river-related use patterns, including AMP research and monitoring activities.

Summary of Previous Work

Starting in the early 1970s, the National Park Service initiated various monitoring programs to evaluate impacts of visitors on the ecosystem. The effects of dam operations on beaches and the riparian ecosystem became an issue of public concern during the earliest attempts by Grand Canyon National Park managers to evaluate visitor use impacts in the CRE (Dolan and others, 1974; Carothers and Aitchison, 1976; Carothers and others, 1979).

Since initiation of the GCDAMP, the monitoring program for recreation has focused almost exclusively on one aspect of CMIN 9.3.1, specifically the amount (size) of campable area in the CRE. For the past 10 years, monitoring of change in campable area has occurred in conjunction with, and as an extension of, the Northern Arizona University (NAU) sandbar time series monitoring program (one component of goal 8 monitoring). The 1998–2006 campsite area monitoring program has documented a progressive decline in campable area over the past 10 years, with camp area declining faster than sandbar area (Kaplinski and others, 2005); this finding suggests that other factors besides loss of sandbars are contributing to campsite area decline. Vegetation encroachment related to loss of periodic high flows under current dam operations is thought to be a significant additional factor contributing to the progressive loss of campable area in the CRE.

In summer 2005, GCMRC implemented the first PEP review of the recreation monitoring and research programs in the CRE (Loomis and others, 2005b). The review evaluated research and monitoring that had been carried out over the past two decades by the National Park Service as part of their statutory responsibilities, by the Bureau of Reclamation in conjunction with the Glen Canyon Environmental Studies programs (1982–95), and by the GCMRC in support of the stated goals of the GCDAMP. Among other conclusions, the PEP noted that the entire concept of "recreational experience" involves a complex intersection of biophysical and social attributes mediated through management decisions linked to visitor values and expectations. For this reason, the PEP recommended that the GCDAMP invest in additional research to elucidate the relative importance of flows, camping beaches, trout, archaeological sites, social encounter rates, and other biophysical and sociological attributes that can be monitored directly as indicators of recreation experience quality, rather than trying to monitor the overall quality of the recreation experience through annual visitor satisfaction surveys or other indirect means.

Figure 10 illustrates the relationship between physical attributes and recreational experience and highlights the key attributes that are important to monitor in the future as indicators of visitor experience.

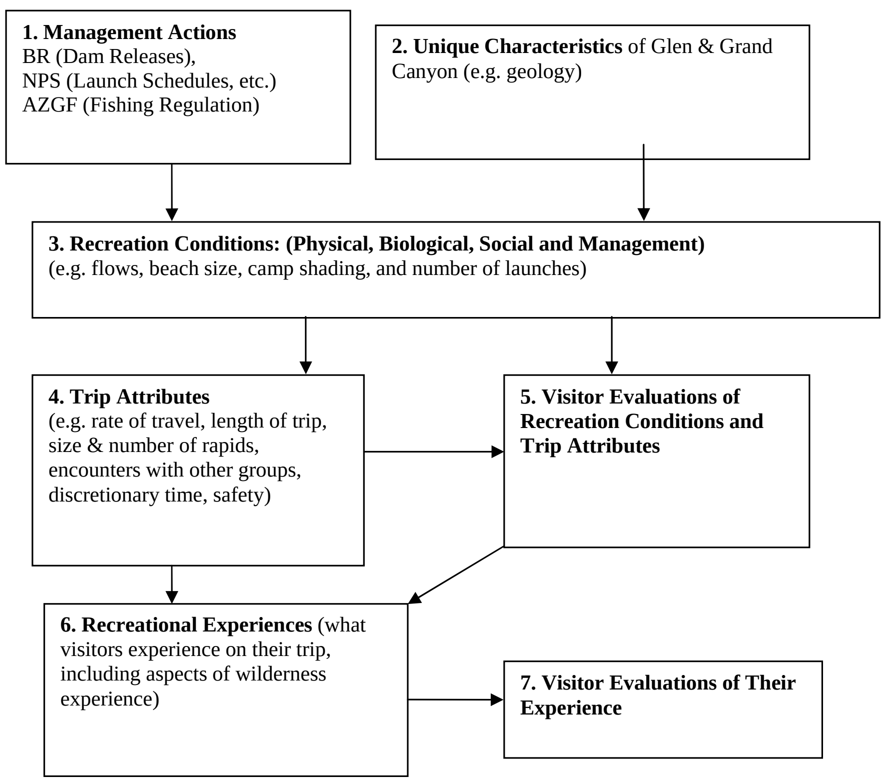

Figure 10. A conceptual model of river recreation to guide monitoring.

Other primary PEP recommendations included the following tasks:

- Refine campsite measurement protocols
- Develop a GIS-base atlas to track systemwide campsite changes and changes in camp distribution through time
- Integrate Adopt-A-Beach images and other photographic records into the future campsite atlas and monitoring program
- Undertake a focused research project to identify the relative importance of flows and various flow-related attributes that contribute to a high-quality recreational experience, and conduct recreational attribute trade-off analyses to ascertain attribute priorities under different flow conditions
- Compile existing safety/incident data and analyze it in relation to flows
- Improve the safety-incident tracking system
- Improve coordination and collaboration between GCMRC and National Park Service recreation monitoring programs to increase efficiency and cost-effectiveness of both programs

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The PEP also recommended that the AMP place more emphasis on monitoring the effects of the dam on recreation economics.

In 2005–06, the National Park Service approved an Environmental Impact Statement (EIS) and issued a Record of Decision (ROD) for a new Grand Canyon National Park Colorado River Management Plan (CRMP). The CRMP focus is different from the GCDAMP; the CRMP focuses on regulating visitor and administrative use levels and managing the effects of that use in the CRE. In the EIS, the National Park Service committed to developing and implementing a visitor use monitoring plan and to managing the river corridor adaptively based on the results of monitoring. One component of the proposed CRMP monitoring plan focuses on monitoring the effects of visitors on campsites and attraction sites. Another component involves tracking rates of on-river and off-river encounters between boating parties under the new regulations.

The specific CRMP monitoring plan and protocols are currently under development but are proposed to include both qualitative and quantitative evaluations of visitor impacts to biological and sociological components of the ecosystem. The National Park Service also tracks and regulates administrative use in the river corridor as part of the CRMP implementation plan. Since 2006, the National Park Service has been working independently of the GCDAMP program to define protocols for CRMP (visitor/administrative use) monitoring and is currently (2009) pilot testing them.

The GCDAMP monitoring program for goal 9 will complement, but does not duplicate, the CRMP program. Developing and testing alternative monitoring protocols for CMINs 9.3.1 and 9.1.1 has been a focus of GCMRC research since the 2005 PEP. Since 2007, the GCMRC has been collaborating with Grand Canyon National Park to develop a GIS atlas documenting the size, distribution, and quality of past and present campsites. This atlas will incorporate historical monitoring data and photographic records documenting changes through time and will allow other components of CMIN 9.3.1 related to the distribution and quality of campsites throughout the CRE to be monitored systematically in the future. So far, the atlas has produced an inventory showing that there are approximately 500 locations in the river corridor that have been used as campsites during the past 35 years, of which approximately 300 are currently still usable as camps.

Summary of Monitoring Project

Geographic Scope

Monitoring related to sport fishing/angling and day rafting recreation are focused in the Glen Canyon reach between Glen Canyon Dam and Lees Ferry; monitoring related to whitewater recreational experiences and changing campsite conditions are focused in Grand Canyon from Lees Ferry to Separation Canyon.

Temporal Scope

The temporal scope of monitoring activities will vary according to the type of monitoring being conducted. Campsite surveys using repeat total station surveys will occur every other year in conjunction with the NAU sandbar monitoring effort (subject to review by the future PEP). Analysis of systemwide changes in campsite distribution will be conducted in conjunction with aerial overflights, coupled with systemwide field inventories once every 5 years. Repeat photographs of 45 popular campsites will be collected annually. A comprehensive analysis of changes in visitor experience quality is proposed to occur once every decade.

Methods

Currently, the GCDAMP monitoring program for recreation focuses primarily on evaluating the effects of dam operations on a single campsite attribute: the amount (size) of campable area in the CRE, as documented through repeat total station surveys of open, level, sandy terrain at a representative (but not random) sample of approximately 35 sandbar campsites (Kaplinski and others, 2005). This monitoring project will continue in the future on a biennial basis at a subset of sandbars and campsites located throughout the CRE using conventional ground-based surveying methods. This monitoring task will be conducted in coordination with Goal 8 core monitoring of the NAU sandbar series and will include measurements of sand areas above the 8,000 cfs stage that are open, flat, and level.

The campsite atlas will serve as the basis for assessing changes in campsite distribution and quality on a systemwide basis; the atlas will also serve as the repository for data derived from monitoring change in campsite attributes. For example, in FY2010–11 we will analyze the amount and density of vegetation at a sample of current and historically used campsites using both aerial imagery and ground-based photographs to quantify the rate of vegetation encroachment and its effects on campsite quality over time.

In terms of monitoring visitor experience, the 2005 PEP recommended conducting a comprehensive recreational attribute tradeoff analysis to determine how different dam operations (flows) affect the various biophysical and social attributes that are important to maintaining a high-quality visitor experience, then monitoring those attributes routinely in lieu of monitoring visitor satisfaction through repeated surveys. Under this plan, visitor surveys would be conducted infrequently (once every ~5 years) to “calibrate” the results of the recreational attribute monitoring effort. Implementation of this project has been deferred repeatedly since 2006, but is still needed and is recommended for implementation within the timeframe of this plan (FY2010–15).

In terms of recreational angling, the AZGFD routinely monitors the size, weight, and number of trout in the Lees Ferry reach to meet the monitoring objectives for goal 4; in addition, GCMRC proposes to re-institute collection of data on recreational angling success and angler satisfaction through repeat creel surveys that the AZGFD formerly routinely conducted as part of their statutory responsibilities.

Third and fourth priority CMINs related to monitoring administrative use levels in the CRE can be readily accomplished by having the National Park Service summarize and report the numbers of research, monitoring, and mitigation trips and research permits issued for work on the Colorado River on an annual basis. (These data are already being compiled routinely for the CRMP.)

Monitoring Program Status/Implementation Schedule

Many recommendations of the 2005 recreation PEP have not been implemented due to perpetual AMP funding constraints; the schedule for their implementation in the future remains uncertain.

Starting in FY2010, both historical and recently acquired monitoring data related to campsites will be made available via the online campsite atlas. In FY2010-2011, GCMRC proposes to continue exploring methods for analyzing remotely sensed data to evaluate campsite changes and will host another PEP focused exclusively on the campsite monitoring elements of the program in 2012, with the intent of having a core monitoring program for campsites in place by the end of FY2012.

Goal 10: Maintain power production capacity and energy generation, and increase where feasible and advisable, within the framework of the GCDAMP ecosystem goals

Statement of Problem

The water level in Lake Powell and the pattern and timing of the release of water through the turbines in Glen Canyon Dam (GCD) directly affect hydropower generation capacity. Power generated at Glen Canyon Dam is marketed mostly in six western states by the Department of Energy's Western Area Power Administration (WAPA). WAPA's primary mission is to sell power from Federal water project power plants under statutory criteria in the Reclamation Project Act of 1939, the Flood Control Act of 1944, and the Colorado River Storage Project (CRSP) Act of 1956.

The adoption of modified low fluctuating flow (MLFF) criteria as a result of the 1996 Record of Decision reduced operational flexibility and the potential value of power generated by the dam. Tracking generation (as impacted by operations for other project purposes), power market rates, necessary power purchases, and Basin Fund cash flow provides the means to assess the impact of Glen Canyon Dam operations in terms of hydropower production and financial impacts to rate payers and the Basin Fund.

Parameters/Indicators to Be Monitored, Monitoring Signals, and Reporting Variables

The specific parameters to be monitored reflect the key variables tracked by WAPA and used in economic models to predict or retroactively assess impacts of various flow regimes on hydropower replacement costs. These include (1) hourly energy generation (System Control and Data Acquisition, SCADA, data), (2) hourly market prices, (3) monthly firming purchases, and (4) monthly Basin Fund balance. More information about each of these variables can be found in the section below titled "Previous Work Towards Core Monitoring."

Core Monitoring Information Needs Summary

The 2003 AMP Strategic Plan identified four CMINs under goal 10. Subsequently, in 2006, the Science Planning Group condensed and reduced the number of hydropower-related CMINs to one, as follows:

CMIN 10.1.1 Determine and track the marketable capacity and energy produced through dam operations in relation to various release scenarios (daily fluctuation limits, upramp and downramp limits, maximum and minimum daily flow limits).

Summary of Previous Work

Despite the importance of hydropower as a regional resource, a formal monitoring program to track the status and trends of this resource and its impact on the Basin Fund has not been undertaken within the context of the GCDAMP. However, the Bureau of Reclamation (Reclamation) and WAPA continuously schedule and monitor power generation to meet anticipated and real-time power demand. This information is available on an hourly time step reported daily, weekly, and monthly from SCADA data.

WAPA and its customers track power source, availability, and market changes on an hourly basis to assess the need, cost, and accessibility for additional power resources to meet contractual obligations or unanticipated demand. Market pricing, resulting costs of purchases, and the impact on Basin Fund cash flow are recorded in the WAPA Energy Tracking Database (ISA). This information is reported monthly and annually and is available through WAPA-CRSP, but is not publically available. Descriptions of these monitored parameters are described in Table 5.

Table 6. Metrics and frequency of data collection for power costs. MW = megawatt, MWH = megawatt hour; SCADA = Supervisory Control and Data Acquisition system, and WAPA = Western Area Power Administration.

Objective	Parameters	Methods	Location(s)	Frequency	Accuracy and precision
Monitor monthly energy generation	MW	SCADA	SCADA Phoenix – Dumped Energy Management System (ISA)	Hourly	N/A
Monitor hourly power market price	$/MWH	WAPA Energy Tracking Database (ISA)	WAPA – Montrose	Hourly	N/A
Monitor monthly firming power purchases	$ and MW purchased	WAPA Energy Tracking Database (ISA)	WAPA-Montrose	Monthly	N/A
Monitor monthly Basin Fund Balance	$	WAPA Energy Tracking Database (ISA)	WAPA-CRSP	Monthly	N/A

Energy generated: The SCADA system that measures generation at Glen Canyon Dam is reported to a database that is accessible by the WAPA Phoenix office. Currently, those data are dumped into the CRSP-Montrose office ISA, and from ISA monthly generation is calculated by summing all the hourly values. Hourly generation totals are not currently reported but can be accessed by WAPA-CRSP or WAPA-Montrose. For the purposes of this project, hourly data are reported.

Hourly market prices: Market prices vary at different purchase points throughout the system. The price that WAPA-Montrose pays for power is pertinent to WAPA and its customers. This value is recorded only for the hours in which WAPA buys or sells power; therefore, the dataset is incomplete. If complete data are needed by WAPA-Montrose, they look at the Dow Jones for a representative point of sale and record that data price. These data can be accessed via the Web and reported to an Excel spreadsheet if access is requested and granted by WAPA-Montrose.

Basin Fund balance: The financial manager for the CRSP office completes an end-of-month cash balance and Basin Fund balance report found on WAPA's Web site. The reports are usually completed by the 15th of the month. These data will be for the previous month's billing on the 2 months previous services.

Monthly firming purchases: These data are found in the WAPA-Montrose ISA database. Purchases made by WAPA for customers are reported by the 10th of the following month, broken out by customer (purchased from).

Summary of Monitoring Project

Geographic Scope

The monitoring project encompasses Glen Canyon Dam.

Temporal Scope

Hourly data will be collected by WAPA and “pulled” into the GCMRC server on a daily basis; monthly data will be delivered to the GCMRC at the conclusion of each month.

Program Status/Implementation Schedule

Currently, the core-monitoring program for goal 10 is under development. Although data on GCD hydropower generation and opportunity costs under MLFF operations are being gathered by Reclamation and WAPA as routine agency functions, these data are not currently accessible to other GCDAMP stakeholders. The need for this information in a readily accessible format has been identified as a program need, and a small amount of funding has been approved by AMWG to serve data generated by Reclamation and WAPA through the GCMRC Web site. Development of computer programs and databases to serve this information is currently underway and close to being finalized. The GCMRC expects to start serving SCADA and ISA data through the GCMRC Web site in 2009.

Goal 11: Preserve, protect, manage, and treat cultural resources for the inspiration and benefit of past, present, and future generations

Statement of Problem

Cultural resources in the Colorado River corridor include archaeological sites, historic structures, traditional cultural properties, and humanly modified landscapes, as well as natural resources that are valued by Native American tribes for their importance in traditional cultural practices. These resources are subject to change over time due to both direct and indirect effects of dam operations, as well as effects independent of dam operations including climate change, weather-induced erosion, and visitor impacts.

The ongoing erosion of archaeological sites in the CRE is of particular concern to GCDAMP stakeholders, especially the National Park Service, because of the presumed effects of dam operations on erosion rates due to changes in sediment supply and sediment redistribution. Erosion at archaeological sites results in deterioration of site stability and increased risk of loss of artifacts and structures. Dam operations may affect rates of erosion and other ecosystem processes by directly eroding or depositing sediment or removing or enhancing stabilizing vegetation (Fairley and others 1994). Indirect dam effects may include deflation or deposition of sediment due to changes in sediment transport rates tied to the creation or loss of sandbars or losses or increases in vegetation or other types of ground-cover in response to ground water level changes or altered disturbance regimes.

Draut and Rubin (2008) have documented the role of aeolian sand in impeding the effects of overland-flow erosion when an appropriately located sand source exists nearby. Their work also demonstrated how enhancing local sand supplies through creation of sandbars under sediment-enriched high flows can potentially result in increased sand transport towards archaeological sites. Dam-induced changes in terrestrial habitats and associated use patterns by small and large mammals (including humans) tied to dam operation effects can also affect the condition of archaeological sites and other types of cultural resources. The interactions of all these ecosystem factors, whether directly or indirectly influenced by dam operations, contribute to changes in the condition of cultural resources in the Colorado River ecosystem.

Parameters/Indicators to Be Monitored, Monitoring Signals, and Reporting Variables

The physical stability of archaeological sites is a primary measure of site condition. Changes in site stability can be linked to effects stemming from variations in dam operations; therefore, GCMRC is currently designing a monitoring program to track status and trends in the physical stability of archaeological sites on a systemwide basis. Specifically, GCMRC is currently developing and testing protocols to accurately measure changes in key indicators of site stability, including surface topography (amount of deposition or erosion of sediment), artifact movement, and soil cover characteristics. We are also quantifying the actual amount of deposition or erosion occurring due to transport of sediment under varying sediment supply and weather conditions. These measurements will complement National Park Service monitoring activities being conducted outside the purview of the Adaptive Management Program (AMP), such as monitoring site condition to comply with Section 110 of the National Historic Preservation Act (NHPA) and monitoring visitor impacts as a Section 106 compliance measure under the new Colorado River Management Plan (CRMP).

Traditional cultural properties and natural resources of traditional importance are being monitored separately by each Native American tribe. Culturally specific monitoring programs are evaluating resource conditions in relation to traditional perceptions of ecosystem "health." These programs include monitoring evidence of human visitation at culturally sensitive locations in the CRE and monitoring overall condition of the riparian and old high water zone ecological communities. Some tribes are also monitoring vegetation cover at select locations in the CRE using transects or other Western science approaches. The specific variables monitored and the protocols used to assess change in resource condition vary by tribe.

Links to Other Program Elements

Archaeological sites and many of the traditional cultural properties along the Colorado River reflect the habitat preferences and resource-dependent activities of past occupants of the CRE. Many of the cultural sites contain a wealth of historical, cultural, geomorphological, and ecological information that can help to inform the GCDAMP and other programs about how the system functioned in the past and can also provide historical reference condition information.

A strong linkage exists between dam operations and effects on cultural resources in the Colorado River ecosystem in Grand Canyon through indirect effects related to the discharge and quality (sediment supply) of water in the Colorado River (U.S. Department of the Interior, 1995; National Research Council, 1996). Nutrient concentrations, salinity, turbidity, and biological components of water released from Glen Canyon Dam directly affect many components of the aquatic-riparian ecosystem below the dam, which in turn can affect rates of sediment transport to and from archaeological sites. Sediment supply, as determined largely by tributary inputs and mainstem Colorado River transport rates, affects the deposition and erosion of alluvial deposits and the overall storage of fine sediment in the CRE, both of which are key to maintaining the stability of archaeological sites in the CRE. Specifically, nearshore sandbars formed and modified by dam-controlled flows provide a potential source of fluvial sediment that can be mobilized and moved inland by wind towards archaeological sites. Exploring the effects of fine sand supply, and the effects of its deposition above the 25,000 cfs stage elevation, is also important to monitoring goals 1,6, 7, 8, and 9.

Core Monitoring Information Needs

The 2003 AMP Strategic Plan (GCDAMP, 2003) identified several core monitoring information needs (CMINs) related to goal 11. In October 2005, the Cultural Resources Ad Hoc Group reached consensus on two revised CMINs for goal 11 and forwarded them to the Science Planning Group of the Technical Work Group for adoption by the program. The core monitoring information needs call for determining "the condition and integrity of prehistoric and historic sites in the Colorado River ecosystem through tracking rates of erosion, visitor impacts, and other relevant variables" and determining "the condition and integrity of traditional cultural properties."

Summary of Previous Work

The National Park Service started monitoring archaeological sites in the Colorado River corridor of Grand Canyon to meet their statutory obligations under the NHPA beginning in 1978. The program evolved over the next 20 years from an informal ad hoc approach (notes and photographs) focused primarily on documenting visitor impacts to a more formalized approach (using standardized forms and photo logs to document qualitative observations) focused on both visitor impacts and erosion of archaeological deposits. In the early 1990s, the program moved into a new phase of monitoring directed toward meeting Section 106 compliance requirements relative to monitoring effects of dam operations; however, monitoring observations continued to be qualitative in nature, rather than quantitative, and the linkage between monitoring observations and dam operations was not clearly established, raising concerns that the monitoring program was not meeting the needs of the GCDAMP (King, 1999; Doelle and others, 2000).

In 2000, a PEP evaluated the National Park Service/GCDAMP cultural resources monitoring program, as well as other aspects of the National Park Service/GCDAMP cultural program (Doelle and others, 2000), and recommended that the monitoring program be redesigned to meet the following objectives:

- Monitor the effects of dam operations on archaeological site condition
- Monitor the efficacy of the treatments being undertaken to mitigate dam effects (that is, check dams to reduce erosion).

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Concurrently, in the mid-1990s, several of the tribes involved in writing and reviewing the Glen Canyon Dam Operation EIS (Bureau of Reclamation, 1995) submitted proposals to the Bureau of Reclamation to undertake their own monitoring programs to evaluate the status of resources in the CRE using tribe-specific approaches and protocols. In 2002, GCMRC attempted to integrate the tribes' monitoring approaches within a broadly conceived Terrestrial Ecosystem Monitoring Program. However, this proved to be difficult because the tribes' interests tended to be focused on specific, culturally important locations on the landscape whereas Western scientists favored using a random sampling approach to assess ecosystem conditions. In 2007, the TWG recommended that funding be provided by Reclamation for the tribes to pursue developing their own approach to monitoring resource condition, and in 2008 additional funding was provided to implement these programs. The tribal monitoring programs continue to be focused on specific places of cultural importance to each tribe.

In 2005, the National Park Service approved an EIS for a new National Park Service Colorado River Management Plan (CRMP). As part of that plan, the National Park Service committed to develop and implement a visitor impact monitoring plan. One component focuses on monitoring the effects of visitors on cultural resources. The specific plan and protocols are under development but are proposed to include qualitative assessments about visitor threats and disturbances on historic property integrity, using guidelines and definitions of the National Park Service's Archaeological Sites Management Information System.

In 2006, GCMRC initiated a cultural monitoring research and development project to follow through on the recommendations of the 2000 PEP. The initial focus has been on developing monitoring protocols for archaeological sites; however, the final program will encompass the full range of cultural resources. As part of this cultural monitoring R&D project, a second review of the 1992–2005 Section 106 archaeological site monitoring program was undertaken. The review panel concluded that the previous monitoring program had succeeded in meeting the National Park Service objective of documenting impacts at archaeological sites, but the panel expressed concerns similar to the previous (2000) PEP about the utility of these monitoring data for meeting GCDAMP needs for information on dam effects, status and trends in resource condition, and efficacy of mitigation actions. Specifically, they noted that the concept of "site condition" needed to be "unpacked" and its components specifically linked to dam operations through a conceptual or numerical model in order to effectively monitor dam operation impacts on cultural resources and objectively track status and trends over the long term (Kintigh and others, 2007).

Since 2006, the GCMRC has been working with cooperators from inside and outside the U.S. Geological Survey to develop and test quantitative monitoring protocols to track changing condition of archaeological sites in the river corridor. The focus of the current R&D effort is on developing protocols to reliably measure effects to the physical stability of archaeological sites tied to dam operations. Using a conceptual framework that links archaeological sites to the broader ecosystem and to the specific ecological processes sustaining that system, GCMRC has evaluated a suite of monitoring tools and protocols to track the effects of ecosystem processes – especially sediment supply and disturbance regimes, both of which are significantly affected by the operations Glen Canyon Dam—on the physical stability of archaeological sites. The proposed protocols are able to quantitatively measure rates and types of surface changes occurring in response to effects of dam operations (Collins and others, 2009; Draut and others, *in prep*.).

Summary of Monitoring Project

Geographic Scope

The project encompasses the Colorado River ecosystem between Glen Canyon Dam and Diamond Creek.

Temporal Scope

TBD – The plan is for sites to be re-monitored on a rotating multiyear schedule.

Methods

Potential monitoring protocols include using repeat lidar surveys of sites to directly measure changes in surface topography, soil crust cover, and artifact movement, in conjunction with using weather stations to track the intermediary effects of weather events on sediment transport to and from shoreline sand deposits and the sites. Given the number and diverse geomorphic settings of archaeological sites in the river corridor, coupled with preliminary data on rates of erosion, we anticipate a monitoring program that relies on a statistically appropriate sample (suitable for characterizing the variability in site types, geomorphic settings, and sediment supply dynamics within the river corridor) to characterize systemwide changes in archaeological site condition.

Program Status/Implementation Schedule

The GCDAMP monitoring program for archaeological sites and traditional cultural properties is currently under development. The current plan calls for testing the protocols in a pilot program (2009–11) then convening a PEP late in 2011 to evaluate the results of this pilot program, with implementation of a final core monitoring project in 2012.

Independently of the GCDAMP program, the National Park Service has developed protocols for CRMP (visitor impact) monitoring and is currently (2009) pilot testing them.

Tribal monitoring programs are currently being implemented on a pilot basis by the individual tribes who value these resources. In the future, the plan is to integrate tribal monitoring efforts with the archaeological site monitoring program where feasible and practical to reduce resource impacts, redundancy, and program costs.

Goal 12: Maintain a high-quality monitoring, research, and adaptive management program

(Coordinated systemwide remote-sensing activities, related to goals 6, 8, 9, 11, and 12)

Statement of Problem

Monitoring any resource in the remote 277-mile-long Grand Canyon is logistically challenging from every standpoint. Many resources are distributed throughout the entire corridor, and environmental factors that affect at least some resources change along the corridor, such that targeted or random sample collection can be scientifically biased or their results ambiguous. Airborne remote-sensing surveys with appropriate sensors can alleviate these collection and sample issues and can, in fact, provide more ground information in less time compared to ground surveys. Even if ground studies could correctly target selected areas for study, the ground surveys would still be as expensive as, and more environmentally invasive than, alternative remote-sensing approaches. From an archival perspective, periodic corridor-wide remotely sensed data provide irreplaceable, historical records of the system, which allow historical analyses for unforeseen research and monitoring issues, but our discussion in this document focuses on applications related to specific, current core monitoring requirements.

Parameters/Indicators to Be Monitored, Monitoring Signals, and Reporting Variables

Different remote-sensing sensors provide different information on various surface characteristics that are directly or indirectly indicative of various ecosystem resources within the corridor. Our tests of various sensors (reviewed in the Summary of Previous Work section) indicated that passive (solar) and active (laser) reflected light sensors were the most viable for resource monitoring in the canyon. These sensors provide reflectance spectral, texture, and elevation data and allow contextual interpretations. The sensors to be employed are discussed in the Planned Monitoring Program section. All of these surface characteristics are used in integrated analyses to identify resource type, area, and volume. The following canyon resources can be monitored using such sensors.

Vegetation

Periodic, systemwide remote sensing on a 4-year interval is proposed for (1) monitoring the gross change in vegetated area along the corridor and within geomorphic reaches since 2002 and 2005 within the limitations of image resolution, and (2) mapping community change at the association-level within a 0.01 hectare minimum mapping unit.

Sandbars and Campsites

Periodic, systemwide remote sensing is proposed for monitoring the area of exposed bare sand above the 8,000 cfs stage. For selected campsites, the proportion of the total area of exposed sand available for camping use will also be monitored. Some visual, contextual interpretations of the remote-sensing data will be required to classify the geomorphology of the sandbars.

Sediment Storage

The primary signal for fine-sediment storage is its volume change within the channel below the 8,000 cfs water stage. The essential data for determining trends in storage volume over periods longer than 5 years are repeat measurements of channel bathymetry. If feasible, systemwide remote sensing will be used to monitor the area and volume of fine and coarse sediment in the main channel.

Shoreline Morphology

Periodic, systemwide remote sensing is proposed for monitoring the distribution and area of debris fans, gravel deposits, bedrock, and backwaters above the 8,000 cfs stage. Some visual, contextual interpretations of the remote-sensing data will be required to accurately determine the areal extent of certain features. These data will be compared to comparable databases derived from 2002 and 2005 remote-sensing data.

Archaeological Sites

Periodic remote sensing is proposed to detect surficial change, to identify source, pattern, and degree of change, and to monitor the trends of natural processes and the effectiveness of mitigation measures. Specific sites for monitoring will be selected by GCMRC, in consultation with the National Park Service and other GCDAMP participants.

Links to Resources

The areal abundance, volume, and distribution of major riparian community types are related to the distribution of native and nonnative vegetation, and affect the quality and quantity of riparian habitats. Sandbars form the substrate for much of the riparian ecosystem, provide a source of windblown sediment that may protect archaeological sites, provide camping beaches for recreational use, and provide low-velocity habitats for native fish (Rubin and others, 2002; Wright and others, 2005). Debris fans provide the basic structure of the CRE in Grand Canyon. They determine the locations where most of the sandbars occur, they strongly affect channel hydraulics and control rapid severity, and they provide aquatic habitats and breeding grounds. Changes in debris fans, which may result from tributary debris flows, and other shoreline characteristics affect both riparian and aquatic habitat conditions. Archaeological sites, although not natural resources, reflect the habitat preferences of past human occupants of the CRE and are shaped by the same ecological processes that affect the ecosystem as a whole.

Core Monitoring Information Needs Summary

The resource core monitoring needs are as follows:

- Determine and track the abundance, composition, distribution, and area of terrestrial native and 3 nonnative vegetation plant species in the CRE (goal 6).
- Determine and track the fine sediment area, volume, and grain size changes at all stages within eddies, below the 5,000 cfs stage elsewhere in the main channel, and above the 5,000 cfs stage for sandbars outside of eddies (goal 8).
- Determine and track, as appropriate, changes in coarse sediment (> 2 mm) abundance and distribution (goal 8).

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- Determine and track the size, frequency, and distribution of camping beaches by reach and stage level in Glen and Grand Canyons (goal 9).
- Determine and track rates of erosion, visitor impacts, and other relevant variables within archaeological sites that pose a threat to cultural resources and possibly track effectiveness of mitigation efforts (goal 11).

The complete list of CMINs is shown in Appendix A.

Summary of Previous Work

Before 2000, all of the remote-sensing data collected for Grand Canyon consisted of aerial analog photography at various scales but generally at a scale of 1:4,800. These data were stored as individual, unrectified image prints. As such, the hardcopy archive was used sparingly or was misused, resulting in image degradation and loss. Lack of and difficulty in accurate registration of the images to actual ground locations was just one reason for their limited use. These data were inventoried and the original film is stored, but digital preservation of the data has been slow and analysis of the historical data has stalled. In 1998, a protocol evaluation panel (Berlin and others, 1998) reviewed GCMRC monitoring efforts and its remote-sensing initiative that lasted 5 years, during which time all available airborne remote-sensing technologies were considered for each monitoring need; the technologies showing promise for recording a monitoring parameter were then field tested. Relevant selection factors included spatial resolution, inherent capability to detect a parameter at the required accuracy, flight altitude and duration, required ground support and post processing, and cost. Sensors that could not meet resource requirements for accuracy, resolution, or sampling interval were excluded from further consideration. This evaluation went well beyond the recommendations developed by PEP review; results of our tests on various remote-sensing technologies were published individually and in a final report on all of the results and recommendations developed during the 5-year study (Davis, 2004).

The relevant, fundamental conclusions from these studies were the following:

- Four-band (blue, green, red, and near-infrared) digital imagery collected at a spatial resolution of 20 cm or better can identify and quantify the gross land-cover units within Grand Canyon—consisting of bare fine- and coarse-grained alluvium, vegetation, water, and bedrock—using spectral and textural information provided by these band data.

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- Four-band data can classify vegetation at the association level, but hyperspectral data obtained at near 1-m spatial resolution is probably required to achieve classification at the community level and to determine the compositions of species in the units.
- Normal, medium-resolution lidar does not currently provide sufficient vertical accuracies (<12 cm at the 95 percent confidence level) to monitor terrestrial sand deposits.
- High-resolution lidar does meet the vertical accuracy requirements for both terrestrial sand deposits and archaeological site monitoring (with a 7–8 cm error at the 95 percent confidence level), but the flight altitude for high-density mapping of archaeological sites is 200 m. However the system is noninvasive, is as accurate as ground lidar, and contains no laser shadows.
- Dual-laser bathymetric Lidar may provide full channel geometry down to a water depth of 18 m, but has not yet been tested within Grand Canyon (it has been successfully tested in Glen Canyon). The system collects data at an altitude of 300 m. Our test of this system near Lees Ferry produced vertical accuracies of 33 cm at the 95 percent confidence level for both terrestrial and bathymetric measurements down to an 18-m water depth. This system is the only method with the potential to map a large fraction of the CRE within 1 week or even within a 5-year period.

Summary of Monitoring Project

Four-band Digital Imagery

Four-band color digital imagery will be collected once every 4 years between Glen Canyon Dam and the Grand Wash Cliffs (277 river miles) for the river corridor as defined by the 250,000 cfs shoreline. Although specifications may change as technology evolves, the 2009 protocol specifies 12-bit data collected at 0.15-m pixel resolution with 0.30-m positional error. These data will be collected using a sensor with a single lens that precludes band-image registration problems. A digital surface model derived from the data will be delivered as 32-bit map tiles with 1-m grid cells and 0.25-m vertical resolution and 0.30-m positional error.

The band imagery requires quality control and possible spatial adjustments for registration with previous databases and for radiometric calibration to provide ground reflectance values. The image data may be delivered as flight lines, to preserve data integrity, and therefore require inter-flight-line adjustments to normalize the effects of variable sun angle and atmospheric scattering. After data are verified and corrected, flight lines will be merged into image mosaics and sectioned into map tiles.

The four-band image mosaics will be digitally analyzed to produce additional, derivative surface characteristics, which are then used to classify the surface into units of vegetation, fine-grained sediment, coarse-grained sediment, bedrock, and water. Additional analyses will separate backwaters and better define debris fans. The area of systemwide camping beaches (indicative of quality but not of camping area quantity) will be derived using the fine-grained sediment unit and camping-beach polygons. That same sediment unit and the digital surface model data will be used to determine the volumes of sandbars systemwide.

The vegetation unit generated from the above land-cover analysis will be used to constrain our analyses of the image data to subdivide (classify) that unit into one of the major vegetation species that occurs in Grand Canyon. We are hoping the 2009 four-band data are the best to date and can provide better vegetation identification and classification than previously, preferably at the community level. However, if that is not the case, we want to explore the alternative, hyperspectral approach discussed next.

Hyperspectral Digital Imagery

Hyperspectral is a term used to describe remote-sensing sensors that provide more than 20 wavelength image bands, although the term generally refers to systems that provide over 100 bands. We propose to use a sensor that provides 357 bands whose wavelengths cover the range from 400 nm to 2,500 nm at 5–10 nm intervals. Such systems are routinely and successfully used by the U.S. Department of Agriculture and U.S. Forest Service for ecosystem mapping and monitoring, including riparian zones. Although the spatial resolution is lower, the significantly larger number of wavelength bands provides greatly increased mapping capability for vegetation, including senescent vegetation, which is extremely difficult to classify with four broad bands that do not include wavelengths beyond 800 nm. Such a system now exists, providing calibrated reflectance data at less than 1 meter spatial resolution flying at an altitude of 2,500 feet. We would like to test this system on selected river reaches that contain all of the major riparian and xeric vegetation species in 2010, during early fall when most species are in bloom. This system can map 10 river miles in less than 1 hour. Although the spatial resolution of the system is lower than desired for other canyon resources, the system can be selectively used to augment the four-band results in areas where there are large stands of diverse vegetation. This may be the only approach to adequately track the compositional changes in the vegetation related to flow release and climate, as well as monitoring the effects of potential tamarisk beetle infestation in the future.

Dual-laser Bathymetric/Terrestrial Lidar

One of the objectives of systemwide remote sensing is to measure changes in sediment storage within the channel below the 5,000 cfs discharge level every 5 to 10 years. This core monitoring objective is discussed in detail in the section in this chapter covering goal 8. It is included here because Lidar is one method that may be capable of simultaneously measuring terrestrial and subaqueous surface elevation throughout the CRE in Grand Canyon. The current protocol described in the section for goal 8 requires 5 consecutive years of acoustic multibeam data collection to map the channel from Lees Ferry to Diamond Creek. It may be possible, using the dual-laser Lidar system, to map much of the CRE within a single year. However, there will be locations where depth or turbidity exceeds the detection level of the system. Those locations could then be captured using the acoustic multibeam system. This combination of techniques would have two advantages: (1) they provide instantaneous full channel geometry of the entire system, and (2) the multibeam surveys would only be performed in Lidar data gaps, which would reduce multibeam's invasive nature, would require less acquisition time, and might be less expensive. Funding for implementing dual-laser Lidar as a core monitoring protocol is not included because more R&D is required before implementation is possible, but we would like to test the Lidar system during 2011 within a mainstem reach that has more representative turbidity than the Lees Ferry reach.

High-Resolution Terrestrial Lidar

This Lidar system (referred to as FLI-MAP) provides the highest ground point density (at least 13-cm spacing) and highest vertical accuracy (7–8 cm) of any system in the world; as a result, it is quite expensive. On the other hand, the system is noninvasive (especially for archaeological sites), acquires data very rapidly, and would be used only in selected areas such as archaeological sites or sandbars that would normally be surveyed by ground crews. Despite the high accuracy of the system on bare ground, it still has problems penetrating dense tamarisk (*Tamarix*) canopies, which is not much of an issue for archaeological sites. However, most sandbars have dense tamarisk groves, which would require ground survey inspection, but only in and around the groves. Thus, a combination of Lidar and ground surveys would significantly reduce ground survey time and possibly cost, if data collection was also coordinated with archaeological site surveys.

Chapter 5. Data Management, Quality Assurance, and Reporting

5.1 Introduction

Reporting, data analysis, modeling, synthesis, and maintaining the integrity of data collected in GCDAMP-sponsored projects is a fundamental mission of the GCMRC. Fulfilling this mission is critical to allow publication and dissemination of information to understand the status and trends of Grand Canyon resources, and how alternative management policies affect those resources. Data management may be parsed into basic conceptual components: planning, implementation, and data assurance. These activities are tailored for each project and refined through continued learning as a result of analysis, modeling, and synthesis. Data repository functions of electronic acquisition, storage, access, and preservation are applied uniformly to all projects. This chapter, which is an expansion of the ideas introduced in chapter 2 on the development of GCMRC's core monitoring programs, presents a discussion of activities within the Data Acquisition Storage and Analysis (DASA) program that support this goal.

5.2 Data Management Overview – Roles and Responsibilities

DASA is a research and support group created to ensure the integrity of data that contribute to management decisions and actions. DASA's remote-sensing scientist, biometrics scientist, database, GIS, and instrumentation staff work with project scientists and data stewards throughout all phases of monitoring to provide end-to-end data management. Data stewards (permanent staff positions) will be established within GCMRC for each core monitoring project; data stewards may work with several monitoring projects in their area of expertise. The following list of roles clarifies how monitoring project tasks are distributed and how DASA interfaces with monitoring projects (fig. 11).

Roles of project scientists, data stewards:

- ~~1)~~ Develop operational plan
- ~~2)~~ Develop data assurance—quality control and assessment procedures
- ~~3)~~ Develop data collection procedures incorporating best practices
- ~~4)~~ Develop metrics for verification, validation, and auditing
- ~~5)~~ Document data collection procedures, forms, and standard operating procedures
- ~~6)~~ Provide training to project technical and field staff
- ~~7)~~ Obtain periodic project reviews (for example, PEP)
- ~~8)~~ Provide oversight of cooperators and contractors
- ~~9)~~ Create and maintain metadata using FGDC Biological Data Profile standards
- ~~10)~~ Scan and upload all field notes and data forms
- ~~11)~~ Upload instrument raw data (ASCII text format where possible)
- ~~12)~~ Upload to GCMRC database using DASA provided tools
- ~~13)~~ Write USGS data reports and journal articles that are approved through the USGS Fundamental Science Practices
- ~~14)~~ Verify that Web access is current

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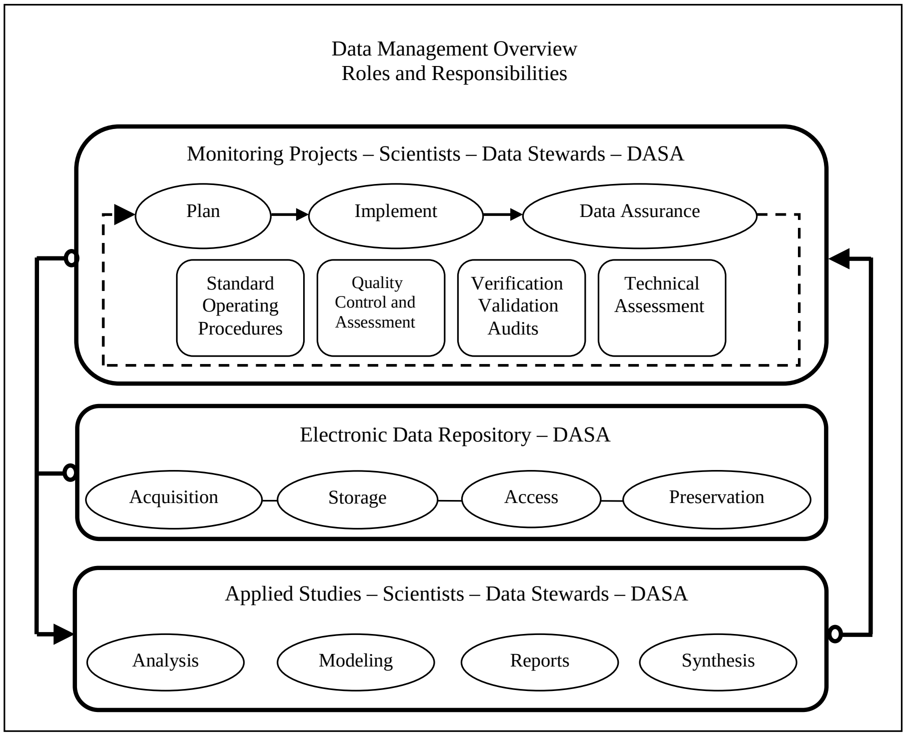

Figure 11. Data management roles and responsibilities overview.

Roles of DASA staff:

- ~~1.~~ Provide data architecture design services
- ~~2.~~ Provide research biometrician services
- ~~3.~~ Provide remote-sensing researcher services
- ~~4.~~ Develop and maintain data management and metadata tools
- ~~5.~~ Develop Web access and visualization tools
- ~~6.~~ Develop GIS ArcServer Web visualization tools and templates
- ~~7.~~ Provide general support and training in database, GIS, and remote sensing
- ~~8.~~ Procure quadrennial overflights and other remote-sensing missions as needed
- ~~9.~~ Provide overflight processing, analysis, and change detection services
- ~~10.~~ Maintain database and GIS datasets
- ~~11.~~ Provide dynamic Web access to tabular and spatial data, plus final reports
- ~~12.~~ Develop archive methods that, wherever possible, are independent of software applications and operating systems
- ~~13.~~ Through cooperation with IT department
  - ~~a.~~ Maintain up-to-date functioning servers and disk arrays
  - ~~b.~~ Oversee tape backups
  - ~~c.~~ Maintain migration path with stable media to assure archive preservation
  - ~~d.~~ Oversee offsite backup and archive storage
- ~~14.~~ Develop modeling and analysis tools
- ~~15.~~ Provide instrumentation and telemetry expertise

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5.3 Data Quality Assurance

A key role of DASA in support of monitoring projects is data quality assurance. Quality assurance is an ongoing data improvement process central to data management, including both quality control and quality assessment. Quality control involves developing field data collection protocols, verifying that the protocols are being followed, and checking the resulting data for errors. Quality control also includes data review, editing, verification, validation, internal consistency checks, and audit procedures. The DASA program will assist in creating specialized tools in the form of automated procedures and manual data QA/QC tools to perform value domain, data type, formatting, bounds, and outlier checks.

Quality assessment is an ongoing process of data resolution, accuracy, precision, and sampling design evaluations aimed at determining if the project is meeting monitoring objectives. Quality assessment also involves developing objectives for data quality during the planning phase and evaluating if the objectives were met through statistical analysis of measurement error and, where possible, collection of multiple data streams through alternative methods as a means of cross checking. Documentation of error assessment methods and results is to be included in reports and as supporting documentation to datasets served through the Web.

5.4 Planning

The GCDAMP has developed a set of goals and CMINs that GCMRC addresses through well-conceived and planned monitoring efforts. Each of these projects undergoes a planning and review phase to ensure that fielded projects will achieve specified monitoring objectives. To assure such rigor, the monitoring project scientist prepares a detailed operational plan that specifies all aspects of the effort. Development and review of the operational plan is facilitated by the DASA biometrician, who may also assist with analysis and modeling as needed by individual monitoring projects. The operational plan must receive and be responsive to both internal and external peer review before funding is released. A general annotated outline of such a plan is provided below to guide monitoring project scientists in the preparation of operational plans.

Executive Summary

- The Executive Summary section should have summarizing subsections titled Need, Benefits, Objectives, Procedures, Personnel, Deliverables, and Budget. It is intended to provide a short overview of the project similar to current work-plan entries.

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Introduction

- The Introduction section should be a broad overview of the need for the monitoring project and should summarize how the information is to be used to inform the adaptive management program.

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Objectives

- The Objectives section should introduce how the set of objectives will meet the need and uses discussed in the Introduction. It should include a list, as detailed as possible, of tasks that will be accomplished and/or metrics that will be produced. Where possible it should describe the precision and accuracy of the metric to be estimated, such as "Estimate the annual survival rate of age-1 rainbow trout in the Lees Ferry reach with coefficient of variation < 20%," rather than "Estimate the mortality rate of juvenile rainbow trout." Such specificity will guide the development of the Data Analysis section later in the document.

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Procedures

- The Procedures section should describe the overall study design to achieve the objectives both tactically and methodologically, including details of sampling frequency and location, sample methods, data collection and recording procedures (consider providing example data-recording sheets with instructions as appendices), and data reduction procedures (for example, how data are summarized electronically for later access and analysis).

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Data Analysis

- The Data Analysis section should describe in exhaustive detail the tactical and statistical procedures to be used to produce the items listed under Objectives. If necessary, the description should include results of preliminary analyses of previous data to justify sample types (random, systematic, etc.) or sample size targets to achieve specified levels of precision and bias. Project scientists should consider how to craft both the Procedures and Data Analysis sections so that portions can be used for the Methods section of annual reports.

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Schedule and Reporting

- The Schedule and Reporting section should describe the schedule and timeline for major milestones in the study, such as field trips, delivery of trip reports and electronic data, and annual report submission.

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Responsibilities

- The Responsibilities section should clarify the roles of key personnel involved with the project. A comprehensive itemization of all major roles is necessary such that reviewers are assured that key tasks will be accomplished.

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Budget

- The Budget section should be sufficiently detailed that reviewers can easily see the cost of major project expenses and are assured that all necessary items are included in the budget.

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5.5 Electronic Data Repository

GCMRC maintains an electronic data repository for archiving and serving project data. Repository workflows are illustrated in figure 12. Operationally, data streams may be thought of as either tabular physical observations or spatial coverage delineating location, and classifying areas and volumes related to the GCMRC CRE base map, which is tied to the GCMRC control network survey. Data streams are analyzed and modeled, producing reports that are also housed in the electronic data repository.

The DASA Data Automation Management System (Msystem) is a newly developed tabular database Web server system that automates much of the traditional manual aspects of data management. The only interaction necessary with the DASA database coordinator is the initial dataset definition, which is defined with a spreadsheet interface. The rest of the Msystem functionality is available to the project data steward without any further interaction with the DASA database coordinator. Msystem provides an interface for project data stewards to upload data, metadata, and final reports, and subsequently to update as necessary with any dataset corrections or updates. The steps listed below outline the path data follow from data structure design to access on the Web.

Msystem Steps:

- Data Planning
  - ~~a.~~o Define dataset (the only step that requires DASA interaction)
  - ~~b.~~o Automatically creates necessary database tables
  - ~~c.~~o Automatically creates Web page for data query access
- Raw Data (uploaded upon return from field – provides data vault function)
  - ~~d.~~o Unedited instrumentation data files
  - ~~e.~~o Datasheets (electronically scanned in the office)
  - ~~f.~~o Field notebooks (electronically scanned in the office)
  - ~~g.~~o Laboratory analyses
- Quality Assured Edited Data (allows full and/or ongoing partial uploads)
  - ~~h.~~o Edited instrumentation data files
  - ~~i.~~o Edited laboratory analyses
- Web Server
  - ~~j.~~o Access to quality assured and in some cases provisional data
  - ~~k.~~o Data steward makes records available after quality assurance SOP

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Geographical Information Systems (GIS) will be a core foundation of the overall core monitoring data management strategy. This allows tabular data and model output to be synthesized with geographic data such as digital elevation models, orthorectified aerial imagery, and feature surveys (campsites, bed formations, etc.). Advanced spatial analysis in support of GCMRC monitoring projects include the following:

- Creation of specialized maps and intuitive data retrieval specific to individual project needs
- Consultation and instruction related to GIS operation and spatial data analysis for GCMRC staff
- Management and dissemination of spatial data

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Acquisition of base layers occurs through various methods such as contractor-supplied aerial imagery, in-house surveying of physical features, digitizing of tabular data and field notes, and output from models and other automated methods. Project scientists and data stewards can then access this centralized GIS data to incorporate and analyze specific project data within a comprehensive geographical context (for example campsite atlas, sampling data from monitoring native fish populations, backwater area and volume estimates, change detection related to varying flow regimes). GIS datasets will be managed, stored, and disseminated from a central repository using ArcSDE and the Oracle relational database management system. This centralized GIS architecture will provide client access to Web-based GIS datasets via the GCMRC Web site via ArcServer, and local access via ArcSDE and ArcMap.

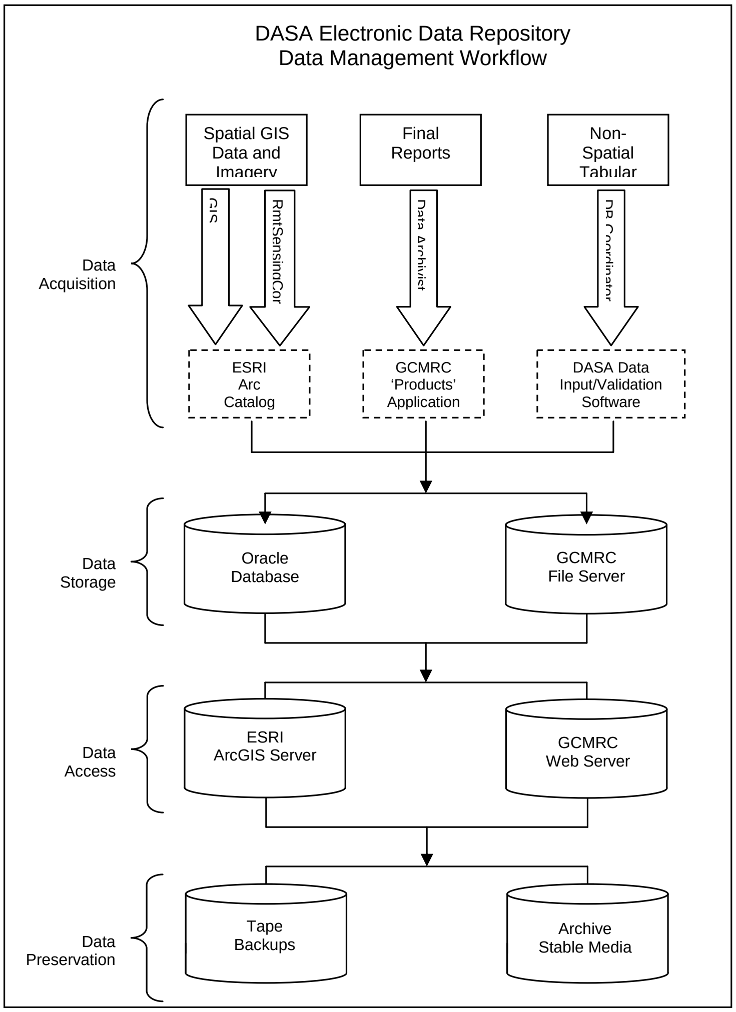

Figure 12. The Grand Canyon Monitoring and Research Center Data Acquisition, Storage, and Analysis program's electronic data repository workflow.

5.6 Analysis and Modeling

Analyses and modeling of monitoring data improve the understanding of status and trend indicators used to inform the GCDAMP decision-making process. Numerous standard and regular analysis and modeling tasks are associated with various monitoring programs.

DASA supports these efforts at a variety of levels:

- Assuring accessible quality assured data
- Building customized data queries for efficient access
- Developing procedural techniques for data mining
- Providing Web access allowing location, time series, and specific parameter retrievals
- Image processing to optimize data fidelity and positional accuracy of aerial overflights
- GIS assessment, analysis, and modeling
- Biometric/statistical support in conceiving and executing data analysis and modeling
- Model development and analytical techniques to further the science capability of the GCMRC

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Recent examples of DASA support for data analysis and modeling include the development of an automated "PIT Tag Synchronization" application. This tool allows the construction of specimen capture histories needed to complete humpback chub assessments using the age-structured mark-recapture model. In the past, this process required several weeks of manual data manipulation by technical experts. However, the tag synchronization tool now performs the task in about 15 minutes and it can be done anytime to provide the most recent capture histories for ASMR modeling.

DASA analysis and modeling activities also function to refine the overall monitoring process by delineating data gaps, providing additional data validation, and discovering data errors that were not caught in the original QA/QC process. The DASA staff has recently collaborated with biologists from GCMRC, the AZGFD, and USFWS to correct historical data anomalies throughout the entire Grand Canyon fish database. This multi-agency effort has resulted in a more reliable database for humpback chub and other species assessments.

5.7 Reporting of Core Monitoring Data, Annual Assessments & Synthesis

Publication of Core Monitoring Data

In accordance with USGS policy, the GCMRC will follow Fundamental Science Practice (FSP) procedures (U.S. Geological Survey Manual 502.1–502.4) for publishing all monitoring data collected through its science program in support of the GCDAMP. To ensure that quality data are collected and reported, the methods for collecting monitoring data are peer reviewed by technical experts and published as methods reports (either as USGS technical reporting series or scientific journal literature) and often through the USGS Data Series reports. For example, Data Series reports have recently been published on water temperature data (Voichick and Wright, 2007) and specific conductance data (Voichick, 2008). Such reports describe the methods used to collect and quality assure monitoring data, typically including a portion of the available data, and they let the reader know where new data will be made available in the future. Another example of quality-of-water (QW) data being published by USGS under the FSP is a compilation of Lake Powell physical QW parameters from the mid-1960s to present (Vernieu, 2009).

All surface water data (river stage and discharge) collected for the Colorado River at USGS streamflow gages below Glen Canyon Dam are published annually by the USGS and made available through the USGS and GCMRC Web sites, following quality assurance procedures described in data series reports. In cases of the streamflow records at several of the tributary (Paria and Little Colorado Rivers) and main channel Colorado River gaging sites, surface records have been published annually as far back as the 1920s. The GCMRC intends to follow similar data publication procedures for non-QW type data collected as part of its core monitoring program below the dam.

Under the core monitoring plan, the various data series and associated methods reports shall be completed as the various monitoring methods are developed in the physical (goals 7 and 8), biological (goals 1–6), sociocultural (goals 9–11,) and data acquisition, storage, and analysis (DASA, goal 12, related to remotely sensed data) programs and are peer reviewed through the previously described PEP workshops.

Although preliminary monitoring data will be reported to the GCDAMP during TWG and AMWG meetings (typically in the form of slide presentations), their ultimate value is derived through their publication as finalized information. When the FSP process is complete, then the final data associated with individual resource goals shall be made more widely available to land and resource management agencies and other interested users through the USGS and GCMRC Internet sites, and they are citable within various types of annual reports.

Annual Reporting Workshop

Another critical element of the core monitoring plan consists of transferring the monitoring information to resource managers in a timely manner and format that makes them relevant and useful in developing GCDAMP recommendations to decision makers. The GCMRC will convene annual workshops with members of the TWG, science cooperators, and other interested parties each January to review progress on projects funded by the GCDAMP. Special emphasis will be made to showcase new information each year from the funded core monitoring projects. During these annual reporting workshops, new monitoring data for each of the resource goals in the GCDAMP's strategic plan will be reviewed following a summary of the related core monitoring information needs included in the strategic plan, as well as the strategic science questions included in the GCMRC's approved 5-year Monitoring and Research Plan. GCMRC will identify how the core monitoring data and associated annual analyses of the data relate to the various information needs and science questions.

These reports will also include the outcome of any related uses (research, synthesis, or management actions undertaken) that have occurred using the core monitoring datasets. The workshops may also set the stage for additional, ongoing discussions and use of the current and historical data during the TWG meetings that ensue throughout the year. The goal is to make core monitoring available to users as expeditiously as possible, consistent with USGS FSP.

Annual Resources Fact Sheets on Status and Trends

As core monitoring data for the various resources of interest to the GCDAMP are annually published, they will also be more formally reported to resource managers, other scientists, and the general public as a series of USGS Fact Sheets. These publications are intended to provide short summaries of status and trends of the resources of interest below Glen Canyon Dam and are developed mostly on the basis of monitoring data and associated analyses required for assessment purposes. Examples of these fact sheets include those recently published by the GCMRC on humpback chub and sediment resources (USGS Fact Sheets 2009-3035, 2007-3113, and 2007-3020). The value of these annual publications is that they are citable science products that summarize published monitoring data (and other related research findings that have been previously published) that can be released widely through Internet distribution at relatively low cost to the GCDAMP. Their format is also typically aimed at the nontechnical audience of resource managers and other interested members of the public and they provide current knowledge of resource state and the efficacy of past management actions. These reports should contain at least one time plot showing the full historic trend, going back as far as possible, of major indicators (abundances, storages, counts, etc.) Graphs and other visual results should be accompanied by a detailed caption (or associated text) describing the key lessons to be derived from the graphic.

SCORE Reports

The GCMRC published USGS Circular 1282 (see Gloss and others, 2005) to provide a decade-scale summary of the status and trends associated with all of the natural and sociocultural resources of concern to the GCDAMP. The 2005 report was informally referred to as the SCORE report, or State of the Colorado River Ecosystem report; it was specifically intended to help managers gain an understanding about how the resources below the dam had responded to new operations associated with the 1996 Record of Decision (modified low fluctuating flows). The effort to produce the SCORE report was substantial. The publication of the SCORE report and similar efforts to report core monitoring and research findings are likely warranted every 5 years to formally document the relationship among dam operations, other factors, and responses of Colorado River ecosystem resources in Grand Canyon. During the periods between publications, the annual fact sheets described above will keep managers updated on changes in resource trends. Over time, the SCORE reports will focus more on integrated analyses, cause and effect, and monitored responses to management actions (both flow and nonflow treatments). These types of new information might be derived from additional related research activities, such as ecosystem modeling, knowledge assessments on individual resources, and syntheses of interdisciplinary resources and interactions.

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Appendix A: Core Monitoring Information Needs

Table A-1. Original AMP goals and Core Monitoring Information Needs, as modified and ranked by the 2005 Science Planning Group (SPG) participants. Column 1 lists the ranked GCDAMP goals from 1 to 12. Column 3 provides the revised wording of the CMINS, as modified by the SPG, and Column 4 shows how SPG managers prioritized the revised CMINs within each goal.

GOAL or CMIN	Revised CMIN wording	SPG Prioritization
GOAL 2 Rank 1	**Maintain or attain viable populations of existing native fish, remove jeopardy from humpback chub and razorback sucker, and prevent adverse modification to their critical habitat.**	
CMIN 2.1.2	Determine and track recruitment (identify life stage), abundance and distribution of humpback chub in the mainstem.	Priority 1
CMIN 2.3.1	Determine and track the parasite loads on humpback chub and other native fish found in the LCR and in the Colorado River ecosystem.	Priority 2
CMIN 2.4.1	Determine and track the abundance and distribution of non-native predatory fish species in the Colorado River.	Priority 3
CMIN 2.6.1	Determine and track the abundance and distribution of flannelmouth sucker, bluehead sucker, and speckled dace populations in the Colorado River ecosystem.	Priority 4
GOAL 11 Rank 2	**Preserve, protect, manage, and treat cultural resources for the inspiration and benefit of past, present and future generations.**	
CMIN 11.1.1	Determine the condition and integrity of prehistoric and historic sites in the Colorado River ecosystem through tracking rates of erosion, visitor impacts, and other relevant variables.	Priority 1
CMIN 11.2.1	Determine the condition and integrity of TCPs in the Colorado River ecosystem.	Priority 1
CMIN 11.2.2	Determine the condition of traditionally important resources and locations using tribal perspectives and values.	Priority 2
GOAL 7 Rank 3	**Establish water temperature, quality, and flow dynamics to achieve the adaptive management program ecosystem goals.**	
CMIN 7.4.2	Determine and track flow releases (gage data and SCADA data; time interval still TBD) from Glen Canyon Dam, under all operating conditions, particularly related to flow duration, upramp, and downramp conditions. (parameters are upramp and downramp rates, volume, daily minimum and max)	Priority 1
CMIN 7.1.1	Determine the water temperature dynamics in the mainstem, tributaries (as appropriate, temperature only in mainstem and LCR), backwaters, and near-shore areas throughout the Colorado River ecosystem.	Priority 2
CMIN 7.2.1	Determine the seasonal and yearly trends in turbidity, conductivity, DO, and pH, (decide below whether selenium is important) changes in the mainstem throughout the Colorado River ecosystem?	Priority 3
CMIN 7.1.2	Determine and track LCR discharge and temperature near mouth (below springs).	Priority 4
GOAL 1 Rank 4	**Protect or improve the aquatic food base so that it will support viable populations of desired species at higher trophic levels.**	
CMIN 1.1.1	Determine and track the composition and biomass of primary producers below Glen Canyon Dam in conjunction with	Priority 1

	measurements of flow, nutrients, water temperature, and light regime.	
CMIN 1.2.1	Determine and track the composition and biomass of benthic invertebrates below Glen Canyon Dam in conjunction with measurements of flow, nutrients, water temperature, and light regime.	Priority 1
CMIN 1.5.1	Determine and track the composition and bio-mass of drift in the Colorado River in conjunction with measurements of flow, nutrients, water temperature, and light regime.	Priority 2
GOAL 6 Rank 5	**Protect or improve the biotic riparian and spring communities including threatened and endangered species and their critical habitat.**	
CMIN 6.1.1	Determine and track the abundance, composition, distribution, and area of the marsh community as measured at 5-year or other appropriate intervals based on life cycles of the species and rates of change for the community.	Priority 1
CMIN 6.6.1	Determine and track the composition, abundance, and distribution of seep and spring communities as measured at 5-year or other appropriate intervals based on life cycles of the species and rates of change for the community.	Priority 2
CMIN 6.2.1	Determine and track the patch number, patch distribution, composition and area of the NHWZ, OHWZ, and sand beach communities as measured at 5-year or other appropriate intervals based on life cycles of the species and rates of change for the community.	Priority 3
CMIN 6.5.1	Determine and track the distribution and abundance of non-native species in the Colorado River ecosystem as measured at 5-year or other appropriate intervals based on life cycles of the species and rates of change for the community.	Priority 4
GOAL 8 Rank 6	**Maintain or attain levels of sediment storage within the main channel and along shorelines to achieve the adaptive management program ecosystem goals.**	
CMIN 8.1.3	Track, as appropriate, the monthly sand and silt/clay -input volumes and grain-size characteristics, by reach, as measured or estimated at the Paria and Little Colorado River stations, other major tributaries like Kanab and Havasu creeks, and “lesser” tributaries?	Priority 1
CMIN 8.2.1	Track, as appropriate, the biennial or annual sandbar area, volume and grain-size changes within and outside of eddies between 5,000 and 25,000 cfs stage, by reach.	Priority 2
CMIN 8.1.2	What are the monthly sand and silt/clay –export volumes and grain-size characteristics, by reach, as measured at Lees Ferry, Lower Marble Canyon, Grand Canyon, and Diamond Creek Stations?	Priority 3
CMIN 8.1.1	Determine and track the biennial sandbar area and fine-sediment volume and grain-size changes within eddies below 5,000 cfs stage, by reach.	Priority 4
CMIN 8.5.1	Track, as appropriate, the biennial sandbar area, volume and grain-size changes above 25,000 cfs stage, by reach.	Priority 5
CMIN 8.6.1	Determine and track the change in coarse sediment abundance and distribution.	
GOAL 9 Rank 7	**Maintain or improve the quality of recreation experiences for users of the Colorado River ecosystem, within the framework of the adaptive management program ecosystem goals.**	
CMIN 9.3.1	Determine and track the size, quality, and distribution of camping beaches by reach and stage level in Glen and Grand Canyons.	Priority 1
CMIN 9.1.1	Determine and track the changes attributable to dam operations in recreational quality, opportunities and use, impacts, serious incidents, and perceptions of users, including the level of satisfaction, in the Colorado River Ecosystem.	Priority 2
CMIN 9.5.1	Determine and track the frequency and scheduling of research and monitoring activity in Glen and Grand Canyons.	Priority 3
CMIN 9.1.2	Determine and track the frequency and scheduling of river-related use patterns.	Priority 4

CMIN 9.2.2	Determine and track accident rates for visitors participating in river-related activities including causes and location (that is, on-river or off-river), equipment type, operator experience, and other factors of these accidents in the Colorado River ecosystem.	Priority 5
GOAL 5 Rank 8	**Maintain or attain viable populations of Kanab amber snail.**	
CMIN 5.1.1	Determine and track the abundance and distribution of Kanab ambersnail at Vaseys Paradise in the lower zone (below 100,000 cfs) and the upper zone (above 100,000 cfs).	Priority 1
CMIN 5.2.1	Determine and track the size and composition of the habitat used by Kanab ambersnail at Vaseys Paradise.	Priority 2
GOAL 10 Rank 9	**Maintain power production capacity and energy generation, and increase where feasible and advisable, within the framework of the adaptive management ecosystem goals.**	
CMIN 10.1.1	Determine and track the marketable capacity and energy produced through dam operations in relation to the various release scenarios(daily fluctuation limit, upramp and downramp limits, list components, maximum flow limit of 25,000 cfs, minimum flow limit of 5,000 cfs).	Priority 1
GOAL 12 Rank 10	**Maintain a high quality monitoring, research and adaptive management program.**	
GOAL 4 Rank 11	**Maintain a naturally reproducing population of rainbow trout above the Paria River, to be extent practicable and consistent with the maintenance of viable populations of native fish.**	
CMIN 4.1.1	Determine annual population estimates for age II+ rainbow trout in the Lees Ferry reach.	Priority 1
CMIN 4.1.4	Determine annual growth rate, standard condition (Kn), and relative weight of rainbow trout in the Lees Ferry reach.	Priority 2
CMIN 4.1.2	Determine annual proportional stock density of rainbow trout in the Lees Ferry reach.	Priority 3
GOAL 3 Rank 12	**Restore populations of extirpated species, as feasible and advisable**	

Appendix B: Description of The TWG Review and Approval Process for Individual Core Monitoring Plans

Appendix ~~B~~C: Description of the Scientific Protocol Evaluation Panel (PEP) Review Process

To acquire independent advice and critical input on proposed monitoring programs for each goal and associated resources, the GCMRC periodically convenes a Protocol Evaluation Panel (PEP) to review the proposed monitoring program. The PEP evaluates the results of the AMP information needs workshop, reviews results of pilot monitoring efforts and relevant research and development activities, and recommends future monitoring protocols and other technical specifications for the monitoring project.

The PEP external review panels are composed of subject experts derived from academia, independent research institutions, government agencies, or private consulting firms. GCMRC solicits potential reviewers from a national (and sometime international) pool of candidates and establishes a list of potential reviewers by discipline during the scoping phases of the project. Membership is determined competitively on the basis of expertise and on willingness and availability to participate within the scheduled time line of a given PEP.

Following the selection of PEP members (3–6 persons per phase/program area), the panel is provided with copies of presentations/reports on assessments of existing data, results of field testing, and critical reviews of trial implementation projects. PEP members then participate in a multiday workshop and/or field expedition where they receive additional information about the work that has been conducted to date, have ample opportunity to review the field conditions and logistical constraints of each program, and can interact informally with the other panel members and previous monitoring project participants. The field trip/workshop is then followed by a 2–3 day panel retreat, where panel members work out their initial ideas and recommendations and formalize them in one or more reports to GCMRC. The panel selects a chair person who becomes the final spokesperson for the PEP and presents the results to GCMRC and the TWG at a later date. Panel members will often meet a second time or convene additional working meetings via conference calls before the PEP report is finalized

A key component of each PEP report consists of recommendations to the GCMRC chief and the science advisors (a group of independent experts in various disciplines that also review the science program annually and may, to some degree, participate in some of the PEP reviews) on what changes in monitoring protocols are warranted. The results of each PEP evaluation are reviewed by the science advisors and then by the TWG, and comments are forwarded to the GCMRC chief for consideration before any new or modified monitoring procedures are implemented by program managers, typically through a competitive RFP-driven process.

For any given resource/program area, there are likely to be at least two, and often three PEP reviews held throughout the development of each core monitoring project: (1) at the initial outset of developing the program, (2) following completion of initial R&D efforts, and/or (3) following completion of a pilot testing phase.

In drafting the original prospectus for the PEP, the GCMRC identified the following issues to be important considerations in the design of future monitoring programs:

1. Articulate Management Objectives/Information Needs, and Current Protocols

It is critical to have a clear and detailed understanding of present stakeholder-derived management objectives and information needs. In addition to describing information needs and objectives, past and presently used monitoring protocols need to be clearly articulated on the basis of existing literature and discussions with present/former project chiefs and PIs who conducted monitoring and research during phases I and II of the Glen Canyon Environmental Studies (GCES, 1983 through 1996), and subsequently. Information on existing protocols, including methods sections of reports and articles that describe various monitoring approaches used in the CRE or other rivers, must be reviewed and made available to external review panels and scoping workshop participants in advance of all PEP workshops or meetings. This information is collected, compiled and distributed by program managers during the scoping phase of the PEP.

2. Define the Range of Optional Alternatives Under Existing Technologies

Alternatives to existing protocols are identified by in-depth GCMRC scoping of monitoring techniques currently used in other long-term programs for river ecosystems. Methodologies used in monitoring of other ecosystems (that is, near coastal marine settings, forests, etc.) are also considered where the protocols might be adapted to a large river.

The PEP scoping process is intended to be wide-ranging, and will glean information from multiple sources such as, reports, journal articles, professional presentations, and displays at professional meetings. Attending national meetings frequented by ecosystem-monitoring experts, and conferences that attract technological innovators by GCMRC staff is encouraged as a means of conducting pre-workshop scoping activities. To increase the effectiveness of the PEP, the limitations and capabilities of new technologies of interest must be screened against information needs by the GCMRC/PEP planning team in advance of the first workshop. New technologies that hold great promise, but are mismatched with stakeholder/GCMRC information needs should be identified and eliminated. This will hopefully eliminate consideration of inappropriate new protocols early in the process. In cases where innovation has led to new approached not recognized by stakeholders, the PEP can act to update managers on areas where new information could be easily obtained. Agencies and private-sector firms identified through the scoping process may be invited to the PEP workshop(s) for demonstration and discussions of new methods and technologies.

Regardless of the diversity of monitoring approaches considered, other topics such as replication, sampling interval and spatial distribution for a long-term monitoring program also need to be evaluated. For instance, information from recent high-flow experiments suggests that monitoring data on grain-size evolution of channel-stored sediment may significantly influence management decision making, but tracking changes in grain-size had not previously been a component of physical-resource monitoring.

3. Evaluation/Selection of Protocols to be Implemented

The PEPs aim to identify which of the past, currently used, or new but untested protocols best meet the objectives of a long-term monitoring program. The program aims to design a river-monitoring program with protocols capable of assessing long-term ecosystem trends, as well as being able to document the impacts of discreet events, such as high-flows from GCD. Protocols must also be able to provide information to stakeholders in a timely manner useful for supporting the adaptive management process (recommendations to the Secretary of Interior). The selected protocols also must work within the unique settings of the CRE, be minimally intrusive to the environment, demonstrate cost effectiveness, stand as scientifically defendable, provide suitable accuracy/precision (depending on level of information need), and be highly repeatable and reproducible regardless of changes in contractors over time. Most importantly, the selected approaches must directly address the management objective-derived stakeholder information needs.

Where existing data occur in the databases of the GCMRC or its former/present cooperators, initial evaluations will be undertaken internally by staff members and scientists already involved in monitoring under existing agreements. However, existing datasets that may foster comparative assessment will only be analyzed after the articulation and scoping steps have been accomplished. Any assessments conducted on existing data will be subjected to internal and external review and will be presented and discussed during initial workshop(s).

The PEP process also recognizes that new information gained from experiments, such as controlled high releases from GCD, as well as evolving information needs, will likely drive additional new needs for monitoring methods of the CRE through time. Therefore, although the PEP may have formal start and end dates, the GCMRC mission will require program managers, stakeholders and the science Advisors to revisit the long-term monitoring strategy (including individual protocols) on a periodic basis. GCMRC proposes that is occur as a 5-year review cycle

GLOSSARY

AMP	Adaptive Management Program
AMWG	Adaptive Management Work Group
ASMR	Age-Structured Mark-Recapture
AZGFD	Arizona Game and Fish Department
CMINs	Core Monitoring Information Needs
CMP	Core Monitoring Plan
CRE	Colorado River ecosystem
CRMP	Colorado River Management Plan
CSV	Comma Separated Values
DASA	Data, Acquisition, Storage, and Analysis
DO	Dissolved oxygen
DOI	Department of Interior
EINs	Experimental Effects Information Needs
EIS	Environmental Impact Statement
ESA	Endangered Species Act
FGDC	Federal Geographic Data Committee
FSP	Fundamental Science Practice
GCD	Glen Canyon Dam
GCDAMP	Glen Canyon Dam Adaptive Management Program
GCES	Glen Canyon Environmental Studies
GCM	Grand Canyon Model
GCMP	General Core Monitoring Plan
GCMRC	Grand Canyon Monitoring and Research Center
GCPA	Grand Canyon Protection Act
GLCA	Glen Canyon National Recreation Area
GRCA	Grand Canyon National Park
HFE	high flow experiment
LCR	Little Colorado River
MRP	Monitoring and Research Plan
MRPP	Multi-response permutation procedure
NAU	Northern Arizona University
NBII	National Biological Information Infrastructure
NHPA	National Historic Preservation Act
NMS	Non-metric multi dimensional scaling
NRC	National Resources Council
PEP	Protocol Evaluation Panel
PIT	Passive integrated transponders
QA/QC	Data quality control and assurance
QW	Quality-of-water
Reclamation	Bureau of Reclamation

RINs	Research Information Needs
ROD	Record of Decision
SINs	Synthesis Information Needs
SPG	Science Planning Group
TEM	Terrestrial Ecosystem Monitoring
TWG	Technical Work Group
UDF	Universal Disk Format
USDOI	U.S. Department of the Interior
USFWS	U.S. Fish and Wildlife Service
USGS	United States Geological Survey

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