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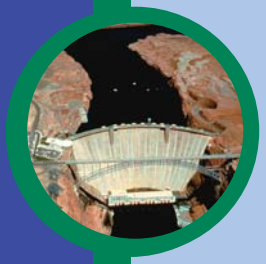
Prepared by the Grand Canyon Monitoring and Research Center

Developed in cooperation with the Glen Canyon Dam Adaptive Management Program



Monitoring and Research Plan to Support Glen Canyon Dam Adaptive Management Program, Fiscal Years 2007–11

Draft
September 13, 2006

U.S. Department of the Interior
U.S. Geological Survey

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CHAPTER 1. Introduction, Purpose, and Organization

Introduction

The Glen Canyon Dam Adaptive Management Program (GCDAMP) was established in 1996 by the Secretary of the Interior to implement the Grand Canyon Protection Act of 1992, the 1995 Operation of Glen Canyon Dam Final Environmental Impact Statement, and the 1996 Record of Decision. Adaptive management in Grand Canyon was envisioned as a new paradigm for addressing the complex environmental problems related to the operation of Glen Canyon Dam through the dynamic interplay of ecosystem science, collaboration, and management. As a result, GCDAMP consists of five major components, including the Adaptive Management Work Group (AMWG), the Secretary of the Interior's Designee, the Technical Work Group (TWG), the U.S. Geological Survey's (USGS) Grand Canyon Monitoring and Research Center (GCMRC), and independent review panels (IRPs). Each entity has a specific role:

1. The **Adaptive Management Work Group** is a Federal Advisory Committee composed of 24 stakeholders that was established to oversee/guide the implementation of the GCDAMP. It reviews and develops alternative dam operations and related conservation measures and provides recommendations to the Secretary of the Interior.

2. The **Secretary of the Interior's Designee** serves as the chair of the AMWG and provides a direct link between the AMWG and the Secretary of the Interior.

3. The **Technical Work Group** translates AMWG policy and goals into information needs, provides questions that serve as the basis for long-term monitoring and research activities, and conveys research results to AMWG members.

4. The **Grand Canyon Monitoring and Research Center** provides credible, objective scientific information on the effects of the operation of Glen Canyon Dam and related factors on natural, cultural, and recreational resources along the Colorado River from Glen Canyon Dam to Lake Mead.

5. The **independent review panels** provide independent assessments of program proposals and accomplishments to ensure scientific objectivity and credibility. For example, a formal group of Science Advisors (SAs) consisting of academic experts in fields germane to studies within the scope of the GCDAMP serves as an IRP.

Science Planning Process

The GCDAMP has adopted a science planning process to develop a credible, objective science program that is responsive to the goals and priority needs identified by the AMWG. Since 1996, the AMWG has used a structured process for specifying their information needs. Through a series of workshops, extensive energy has been expended to develop a hierarchy of goals, objectives, core monitoring information needs (CMINs), and research information needs (RINs). The AMWG also specified 12 goals (hereafter GCDAMP goals, see chapter 2) that provide general guidance for planning, monitoring, and research efforts. However, the list of objectives grew to more than 40 and the various information needs to more than 160, complicating science planning and priority setting.

Given this complexity, the AMWG identified the need for a different approach in 2004 and identified 5 priority questions related to the 12 GCDAMP goals that were to be used to focus science activities. In 2005, to further focus science planning efforts, the GCMRC initiated a Knowledge Assessment Workshop (KAW) that identified areas of scientific uncertainty and specified strategic science questions related to the five priority questions.

For these reasons, the 12 GCDAMP goals are used to organize the science activities articulated in the **Monitoring and Research Plan to Support Glen Canyon Dam Adaptive Management Program, Fiscal Years 2007–11** (hereafter Monitoring and Research Plan or MRP). Monitoring and research activities are focused on AMWG priority questions and the strategic science questions that grew out of the KAW (Appendix A). In some cases, CMINs and RINs are referenced to clarify the intent of both AMWG priority questions and strategic science questions.

The Monitoring and Research Plan has been developed by GCMRC in cooperation with the GCDAMP Science Planning Group (SPG) to specify monitoring and research programs consistent with the strategies and priorities in the both the **Final Draft GCDAMP Strategic Plan** (AMPSP) and the **GCMRC Strategic Science Plan** (SSP). The AMPSP is a long-term plan drafted by GCDAMP participants in cooperation with the GCMRC in August 2001 and refined in 2003, which identifies the Adaptive Management Work Group's vision and mission, principles, goals, management objectives, information needs, and management actions. The SSP was developed by the GCMRC in cooperation with GCDAMP participants to identify strategies for providing science information that are responsive to goals, management objectives, and priority questions of GCDAMP participants, and consistent with the AMPSP.

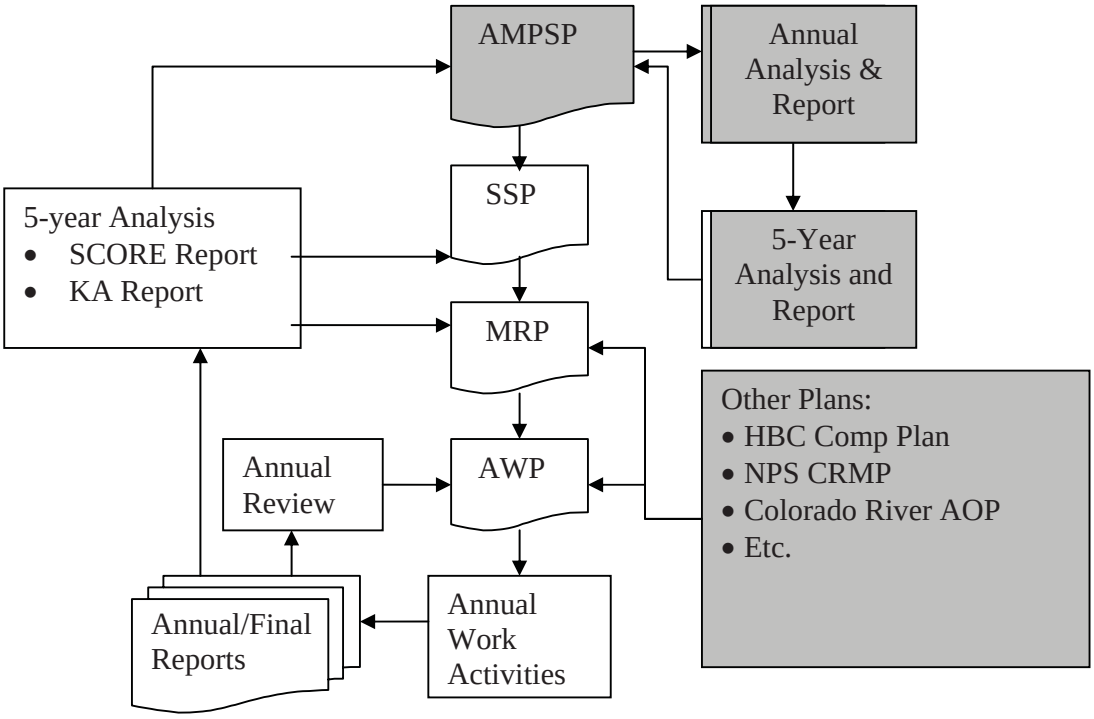

Figure 1.1. Collaborative science planning and implementation process. The Glen Canyon Dam Adaptive Management Program and the Department of the Interior have lead responsibility for the shaded boxes. The Grand Canyon Monitoring and Research Center has lead responsibility for the boxes that are not shaded.

Specific projects to implement the MRP will be described in the **GCMRC Biennial Work Plan** (BWP), which will identify the scope, objectives, and budget for monitoring and research projects consistent with the MRP during a 2-year period. In the meantime, a transitional **Annual Work Plan** (AWP) was developed for fiscal year 2007 (FY07) while consideration is given to the development of the Long-term Experimental Plan (LTEP), a funding plan for a temperature control device (TCD), and development of a recovery program for humpback chub (HBC) in Grand Canyon. The projects identified in the transitional FY07 AMP are summarized in the Monitoring and Research Plan.

To maintain continuity, the transitional FY07 AWP will provide the foundation for the development of the FY08–FY09 BWP. This foundation will be augmented by new information that is anticipated in FY07, which among other things includes (1) the completion of a Long-term Experimental Plan, (2) the implementation of a process for evaluating and selecting core monitoring projects, and (3) the development of a process for implementing ecosystem science approaches.

Figure 1.1 depicts the flow of information in the science planning and implementation process. Annually, the GCMRC will report on accomplishments related to projects included in the BWP and evaluate how science has advanced knowledge relative to GCDAMP goals and management objectives. At 5-year intervals, the GCMRC shall formally synthesize new scientific information and knowledge in the form of an updated State of the Colorado River Ecosystem in Grand Canyon (SCORE) report (Gloss and others, 2005), Knowledge Assessment Report (KAR) (Melis and others, 2006), and other reports, as appropriate. Priority information needs and science questions will be evaluated by scientists and managers to determine what program revisions are needed. This includes the development of revised SSP and MRP documents.

The MRP also incorporates information from appropriate agency and GCDAMP plans such as the National Park Service (NPS) Colorado River Management Plan (CRMP) and the Humpback Chub Comprehensive Plan. GCMRC will attempt to provide science information that is consistent with and supports these plans as appropriate and practical.

GCMRC science planning is designed to be done in conjunction with parallel planning efforts by the GCDAMP to specify or update priority goals/questions, information needs, and management actions and treatments. Concurrent planning will help ensure the science program is properly aligned with current management objectives and priorities. A priority need exists for the GCDAMP and the Department of the Interior (DOI) to define specific desired future conditions for priority GCDAMP resources such as humpback chub (HBC), sandbars, and camping beaches. This information will allow the GCMRC to design more targeted monitoring and research projects that are responsive to management goals.

Purpose

The purpose of the Monitoring and Research Plan is to describe the scope and objectives of a 5-year monitoring and research program to address priority goals, questions, and information needs specified by the GCDAMP. The plan will identify specific priority science needs for FY07; more general needs will be defined for FY08–FY11.

The MRP is designed to be consistent with and implement the GCMRC SSP, which emphasizes four key components:

- Incorporating interdisciplinary, integrated river science
- Building bridges between science and management
- Addressing priority AMWG goals/questions and associated strategic science questions as articulated in the Knowledge Assessment Report (Appendix A)
- Addressing critical monitoring and research needs outside the scope of the GCDAMP

Organization

Chapter 2 of the MRP describes the monitoring and research activities for FY07–FY11 related to the 12 goals included in the GCDAMP Strategic Plan. Within each GCDAMP goal, monitoring and research activities are generally organized into one of three categories:

1. **Core Monitoring Activities**: Scientifically validated protocols or methods to assess the condition and trend of priority GCDAMP resources (HBC, sediment, food base, etc.)
2. **Research and Development Activities:** Research projects aimed at (a) addressing specific hypotheses or information needs related to a priority GCDAMP resource or (b) developing/testing new technologies or monitoring procedures
3. **Long-term Experimental Activities**: A suite of flow and non-flow treatments and management actions designed to improve the condition of target resources (HBC, cultural sites, sediment, etc.) and, through monitoring and research, allow for an understanding of the relationship between treatments/management actions and target resources

In addition to organizing chapter 2 around the 12 GCDAMP goals, the 5 priority questions identified by the AMWG and the related strategic science questions (Appendix A) were used to identify and prioritize monitoring and research activities. As a result, the MRP is focused on AMWG priority questions and related strategic science questions. Other GCDAMP goals and information needs will still be pursued, but with less intensity, until priority issues of concern are resolved and monies can be reprogrammed or obtained through alternate sources.

All monitoring and research activities described in chapter 2 will be designed and carried out in an integrated and interdisciplinary fashion as discussed later in the introduction.

Core Monitoring Activities

> Core Monitoring: 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 (e.g., water year, experimental flows, temperature control, stocking strategy, non-native control, etc.) affecting target resources (Draft GCDAMP Strategic Plan, 2001).

The need for a long-term core monitoring plan for the GCDAMP has been identified as a critical program need since the inception of the program in 1996. However, completion of a long-term core monitoring plan has remained an elusive goal for a variety of reasons. First, the process for the systematic development of monitoring programs generally involves the establishment of a protocol evaluation panel (PEP) for each key resource area, followed by several years of pilot testing of monitoring protocols, then a period of analysis, synthesis, and re-evaluation, culminating in the implementation of long-term monitoring protocols. This process was initiated in 1998 and is in progress for many elements of the program today (e.g., terrestrial ecosystems, archaeological and tribal resources, aquatic food base, recreation, and fisheries). Other factors have hindered rapid progress in the development of a core monitoring plan, including:

- Lack of agreement among GCDAMP stakeholders about scope, purposes, and objectives of core monitoring projects under the GCDAMP
- Lack of agreement among GCDAMP stakeholders and scientists about what defines core monitoring as opposed to other kinds of monitoring, such as monitoring effects of experimental actions or monitoring the effectiveness of management actions
- Lack of agreement about the required levels of precision and accuracy in monitoring data necessary to achieve program goals

A Provisional Core Monitoring Plan (PCMP) (Fairley and others, 2005) was drafted by the GCMRC in cooperation with a GCDAMP Core Monitoring Team. However, the plan only addressed a few highly developed monitoring efforts (so-called "green" projects) and was neither formally adopted by the TWG or the AMWG, nor was it finalized. Nevertheless, the PCMP represents the best guidance currently available for the development of core monitoring projects for FY07–FY11.

The current monitoring projects associated with various GCDAMP resources will be subjected to an evaluation by the GCMRC in cooperation with the TWG. The evaluation of projects for core monitoring suitability is critical because the implementation of core monitoring activities has significant budget implications for the science program that could limit the flexibility of the GCMRC and the GCDAMP to respond to high-priority research needs. Accordingly, all monitoring projects considered for core monitoring status will undergo the following technical evaluation process for determining core monitoring status:

1. **General Core Monitoring Proposal:** In FY07, the GCMRC will draft a General Core Monitoring Proposal that identifies by resource area the general goals, objectives, scope, schedule, and funding level for each proposed core monitoring project. The proposal will be based on AMWG priorities, currently identified information needs, the feasibility of developing monitoring protocols to meet those needs, and other relevant information. The proposal will be provided to the TWG for review.

2. **Information Needs Workshop:** Annually, the GCMRC will conduct a TWG workshop to refine and formulate recommendations concerning specific management goals, information needs, and the scope of all monitoring projects that will be evaluated for core monitoring status in a given fiscal year. 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.

3. **Protocol Evaluation Panel Review:** For each resource goal, the GCMRC will convene a PEP to evaluate the results of the information needs workshop, review the results of past monitoring efforts and relevant research and development activities, and recommend future monitoring protocols and other technical specifications for the monitoring project.

4. **Core Monitoring Program Reports:** Based on the results of the workshop and the PEP evaluation, the GCMRC will prepare a report to the TWG for each project being evaluated for core monitoring status. Core monitoring program reports will provide the TWG sufficient information to evaluate individual programs/projects for core monitoring status. The reports will include the following information:

    - AMWG goal(s) addressed
    - Project title
    - Principal investigator(s)
    - Geographic scope
    - Justification for monitoring effort
    - Project goals, tasks, and schedule by task
    - Key science questions and managers' information needs addressed
    - Linkage 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.
    - Costs of project/program by fiscal year

Those projects approved by the TWG for core monitoring status will receive first consideration for funding each year and will not undergo the same annual competitive review as other projects. However, core monitoring projects will be reviewed during the development of the BWP to incorporate new information, findings, and monitoring techniques that may improve their effectiveness. A more comprehensive review of core monitoring projects will be conducted at 5-year intervals.

The initial focus of the evaluation process described above will be to evaluate for core monitoring status those "green" projects that have undergone a PEP evaluation, have been piloted and results peer reviewed, and that have been implemented for one to several years using methods deemed adequate for long-term monitoring. Projects in this category and their anticipated review schedule include:

- Downstream surface-water parameters (discharge, stage measurements) and specific water-quality parameters related to sediment (e.g., suspended-sediment transport measurements and modeling) (FY07)
- Status of Lees Ferry rainbow trout (FY07)
- Status of humpback chub in the Little Colorado River (to be reviewed through PEP with Colorado River population) (FY08)

In addition, several monitoring projects that have undergone an initial PEP review have subsequently undergone a period of research and development or pilot testing and are now ready for a second PEP review before being implemented as part of the long-term core monitoring plan. Other projects, such as food base and cultural resources, have only recently started their multiyear research and development phase. These projects 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 FY11. The proposed schedule for undertaking core monitoring reviews of these projects is as follows:

- Sand storage monitoring (FY07)
- Terrestrial ecosystem monitoring (FY07)

- Status of humpback chub in the mainstem of the Colorado River (to be reviewed through PEP with LCR population) (FY08)
- Integrated quality of water project (Lake Powell and downstream parameters, including specific conductivity, dissolved oxygen, and temperature) (FY09)
- Kanab ambersnail habitat and population monitoring (FY09)
- Camping beaches monitoring (FY09)
- Cultural site monitoring (archeological, traditional cultural properties) (FY10)
- Aquatic food base (FY10–FY11)

Monitoring of traditional cultural properties (TCPs) and tribal values in the CRE is a component of the GCDAMP; however, the GCMRC faces a number of challenges in determining how to integrate tribal perspectives into core monitoring. This is in part because of differing perceptions about what constitutes appropriate indicators of ecosystem "health" and also because most of the tribes have been reluctant to formally identify their TCPs. Furthermore, in many cases a tribe's resource interests are tied to specific, culturally important places in the river corridor, the locations of which are considered to be proprietary information. Without a clear articulation of the tribes' needs for monitoring data, it is impossible for the GCMRC to develop monitoring projects to meet tribal needs.

The tribes were funded by the GCDAMP in FY06 to define their monitoring projects and associated methods and metrics for evaluating the resources and places of specific tribal interest in the CRE. These projects are scheduled to be brought forward to the TWG for review and discussion in FY07. If the methods and rationales for these proposed monitoring projects are shared with the GCDAMP and subjected to peer review, then they may fit within the GCDAMP science program as currently defined. Otherwise, the information derived from the tribal monitoring effort may be more appropriately incorporated into the GCDAMP decision-making process via ongoing consultation between the tribes, GCDAMP stakeholders, and DOI agencies. The GCMRC will describe the tribal monitoring component of the 5-year science program with more specificity after the tribal monitoring needs are defined and brought forward for TWG review in FY07.

Research and Development Activities

Research and development activities include projects aimed at (a) addressing specific hypotheses or information needs related to a priority GCDAMP resource(s) and (b) developing and testing new technologies or monitoring procedures. Examples of research and development projects included in the MRP are as follows:

1. Link whole-system carbon cycling to food webs in the Colorado River, which will provide the basis for the food base monitoring program
2. Investigate remote passive integrated transponder (PIT) tag reading technology
3. Investigate sonic tag technology
4. Advanced development of downstream flow, temperature, and suspended-sediment models
5. Evaluate quality of historical remote-sensing imagery for change detection
6. Statistical evaluation of HBC habitat preferences

In the MRP, research and development projects will focus on addressing specific information needs and hypotheses related to the AMWG priority strategic science questions and the development and refinement of monitoring protocols.

Long-term Experimental Activities

The Monitoring and Research Plan will be consistent with and implement the Long-term Experimental Plan, or LTEP, to be developed through the GCDAMP in FY07. The LTEP must also be endorsed by the Department of the Interior. It is assumed that the LTEP will reflect the concept of a "hybrid" experimental design embraced by the GCDAMP. The hybrid experimental design incorporates assessments of both management actions and experimental treatments. Management actions are those activities that provide a demonstrated resource response that no longer require further research. For example, control methods developed for coldwater fish in the 2003–6 research program have been proven effective at reducing the abundance and distribution of rainbow trout within treatment reaches near the confluence of the Little Colorado River (LCR). As such, further GCMRC research on this activity is not included in the MRP. Future implementation of this action should be carried out primarily by the appropriate land and resource management agencies.

A component of the LTEP will include research to test various hypotheses associated with different experimental flows from GCD, such as evaluating the effects of different ramping rates on downstream resources, evaluating alternative triggers for steady flows, or assessing the effects of short-duration flow spikes on aquatic productivity or drift. One area of emphasis will be further research on the use of beach/habitat-building flows (BHBF), or controlled floods, to build sandbars that support several GCDAMP goals such as providing camping beaches, fish habitat, and riparian habitat. BHBFs are triggered by predetermined target levels of natural deposits of sediment in the mainstem Colorado River below the Paria and Little Colorado Rivers. In the FY07–FY11 period, GCMRC anticipates two additional BHBF tests. Estimated costs for the

monitoring and research associated with the BHBF tests are $1 to $1.5 million per test.

In 2005, the GCDAMP recommended the establishment of an experimental fund to pay for experimental research projects so they can be conducted without financially impacting other ongoing aspects of the science program. The current balance of the experimental fund at the end of the FY06 is anticipated to be approximately $400,000. An additional $500,000 will be set aside by the GCMRC annually in an account at the Bureau of Reclamation (Reclamation) to fund the BHBF tests and other research related to experimental efforts.[1] Deposits to the experimental account will cease when the balance reaches $2.5 million.

Consistent with the available funds, the GCMRC will develop a LTEP work plan in consultation with the GCDAMP. Experimental research will be coordinated with ongoing monitoring and research projects to maximize cost effectiveness.

NOTE: Several flow and non-flow experiments for FY07–FY11 are currently being evaluated by the GCMRC and the GCDAMP. Once this evaluation is complete and a LTEP is finalized, the agreed upon experimental actions will be incorporated into the MRP. The LTEP will be implemented following approval by the Secretary of the Interior and completion of appropriate environmental compliance requirements (e.g., National Environmental Policy Act, Endangered Species Act). The GCMRC will provide scientific information to support the environmental compliance process, as requested.

Integrated and Interdisciplinary Science

The GCMRC will provide increased emphasis on using an integrated, interdisciplinary science approach over the next 5 years. An integrated and interdisciplinary approach is the only practical way to appropriately link the physical, biological, and sociocultural components of the CRE. In order to provide a framework for appropriately integrating scientific activities, the MRP is structured around overarching strategic science questions (Appendix A). The integrated, interdisciplinary science approach to be developed in FY07 will emphasize four areas, which are discussed in greater detail below. By focusing on integrated science questions that emphasize priorities, it should be possible to completely address key questions in no more than 5 years.

[1] The Grand Canyon Monitoring and Research Center will set aside funds for experimental research projects under Project ADM 12.E1.07 (FY07–FY08 Carry Forward Fund for Experiment Phase II), which is described in the fiscal year 2007 Annual Work Plan.

Staffing and Organizational Capacity

In FY06, the GCMRC staff was realigned to create a Deputy GCMRC Chief position that is responsible for managing and supervising day-to-day operations at the GCMRC and assuring that integrated/interdisciplinary methods and procedures are used in the science program. In addition, in FY08, the GCMRC proposes to recruit a part-time/visiting ecosystem scientist/ecologist to work with GCMRC staff and cooperators to pursue specific integrated, interdisciplinary, ecosystem-science strategies. Possible strategies include the application of the CRE conceptual model to science planning and project design, and the evaluation and implementation of decision-support tools to improve the application of science information in the GCDAMP process (see below). The efficacy of hiring the visiting scientist will be reviewed based on the Science Advisors' proposed FY07 evaluation and recommendations related to opportunities for incorporating an ecosystem science approach into the current science program (see below).

Conceptual Ecosystem Model Enhancement

In 1998, Walters and others (2000) conducted a workshop to assist scientists and managers in development of a conceptual model of the CRE affected by GCD operations. The model proved to be useful for helping to understand the relationship among various ecosystem component, identifying knowledge gaps, and predicting the response of some ecosystem components to policy change. However, it lacked the capability to predict the effects of policy decisions on several key areas such as long-term sediment storage, fisheries response to habitat restoration, and socioeconomic effects. Expanded design, development, and use of the conceptual ecosystem model is needed to increase its utility in ecosystem science planning and management processes, and to provide information that is relevant to each high-priority AMWG goal/question.

In FY07–FY08, the GCMRC will work with the Science Advisors to identify and incorporate more robust integrated, interdisciplinary science approaches into its overall program effort. The Science Advisors' review will address practical approaches and opportunities to improve the ability of the GCMRC to address priority GCDAMP information needs using an integrated, interdisciplinary science approach. A specific objective of the SAs' review will be to evaluate the redesign and expansion of the conceptual CRE model. A preliminary list of priority expansions of the CRE model include:

- Expanding the fishery elements to address coldwater and warmwater fish predation on HBC young-of-year (YoY), HBC habitat use, etc.
- Modeling outcomes of non-flow management activities (e.g., operation of a temperature control device, mechanical removal of nonnative fish, translocation efforts for HBC, tributary triggers for BHBFs)

- Linking Lake Powell and downstream temperature simulations to fine sediment, food web, and fisheries sub-models
- Expanding the model to provide a broader landscape perspective by incorporating Lake Powell, the Little Colorado and Paria Rivers, and terrestrial habitats in the CRE
- Enhancing the use of climatic input data and simulations
- Recreational use and campsite size, abundance, and distribution
- Cultural site change and protection strategies (archaeological sites, TCPs)
- Financial impact simulations coupled to the flow/dam operations sub-models

Sediment Dynamics

Sediment and sand supplies are critical ecosystem components important to the long-term maintenance of several priority GCDAMP resources. For example, high-elevation sandbars provide camping beaches, support riparian habitat and associated wildlife, and are a source of aeolian sand that affords protection for some archaeological sites in close proximity to the river. Sandbars also provide backwater habitats that are warmer than main channel habitats and may be important to the growth and survival of humpback chub and other native fishes. As part of the experimental program, two BHBF experiments are planned for the FY07–FY11 period to enhance sand dynamics and related resources, provided sediment triggers are reached. A focus of these experiments and the BHBF work plan will be to determine the relationships between creation and maintenance of sandbars and these GCDAMP resources.

Temperature Control Device Evaluation and Planning

> It is essential that adopting the use of a TCD as a management policy be accompanied by a commitment to a comprehensive long-term level of research and monitoring that provides timely results in evaluating its value as a management tool (GCDAMP Science Advisors, 2003).

The design and possible construction of a TCD for GCD has been identified as a priority activity for the GCDAMP in the FY07–FY11 period. The objective of the TCD would be to allow for regulation of temperatures and other water-quality parameters (e.g., dissolved oxygen) of water released from GCD. The primary goal would be to create mainstem water temperature conditions that promote natural reproduction and recruitment of humpback chub in the mainstem of the Colorado River. Other potential effects of a TCD may include:

- Increased aquatic productivity
- Increased distribution and abundance of native fishes
- Increased trout productivity in the Lees Ferry reach and associated improvements in the trout fishery

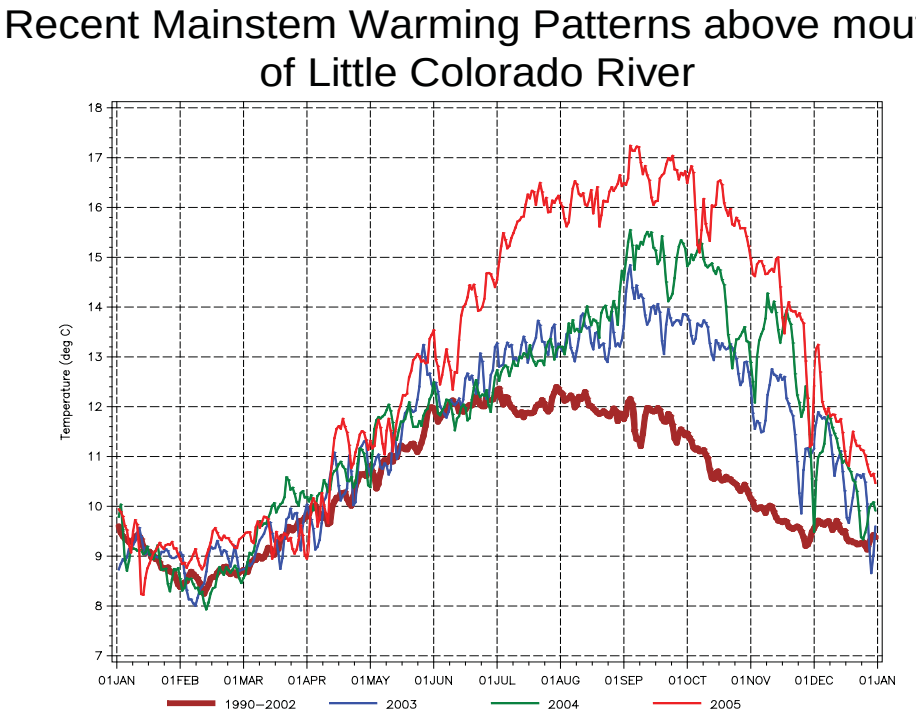

Figure 1.2. Recent mainstem warming patterns above the mouth of the Little Colorado River. The natural warming of the river is expected to occur at least through water year 2006 and provides a unique opportunity to study the effects of warmer water on Colorado River ecosystem resources before the possible construction of a temperature control device.

- Increased satisfaction with the river recreation experience
- Increased flexibility to generate hydropower at very low reservoir elevations

The primary risk associated with a TCD involves the proliferation of warmwater nonnative fishes that may compete with or prey upon native fishes. (Warmwater nonnative fishes are considered a threat to the humpback chub and other native fishes in the Colorado River ecosystem.)

Since 2003, the Colorado River water temperatures below GCD have been increasing (Figure 1.2) owing to prolonged drought conditions and lower water levels in Lake Powell. The low water levels have resulted in warmer water passing through the dam than would have occurred under higher reservoir elevations. These warm water releases are correlated with a number of changes in the fisheries, including:

1. Evidence of mainstem spawning of HBC, which is indicated by the presence of YoY HBC at river mile 30 on the Colorado River
2. Increased numbers of juvenile HBC in comparison to recent years
3. A decline in the rainbow trout population in the Lees Ferry reach possibly owing to reductions in dissolved oxygen associated with the warmer GCD releases
4. Increased observations of warmwater nonnative fishes that may prey upon or compete with native fishes

The GCMRC proposes the following studies and activities to evaluate the effects of natural river warming and to assist in the decisions related to funding and design of a TCD:

1. Develop and test water temperature model to better predict the effects of GCD operations on downstream water temperature and associated shoreline habitats
2. Synthesize water-quality data for Lake Powell and link Lake Powell to the Colorado River quality-of-water models
3. Synthesize and evaluate currently available water temperature data focused on the Colorado River near the confluence of the LCR
4. Develop and test a nonnative fish management plan that will (a) assess the implications and expected response of both the native and nonnative fisheries communities to warmer water and (b) identify methods of control that will be tested/refined (FY07–FY11)
5. Continue to gather and evaluate baseline data on the effects of natural warming of river temperatures on the distribution, abundance, and reproductive success of native and nonnative fishes (FY07–FY11)
6. Work with the U.S. Fish and Wildlife Service (FWS) to develop a HBC Genetics Management Plan and a related plan for one or more refuges for HBC to support efforts to avert the catastrophic decline of HBC populations associated with the proliferation of nonnative fishes
7. Organize and conduct a workshop to develop a comprehensive science plan to address the operation of a TCD

Critical Monitoring and Research Needs Outside of the GCDAMP

The uses of GCDAMP funds are currently focused on addressing the impacts of dam operations on resources in the immediate Colorado River corridor downstream of Glen Canyon Dam to Lake Mead. As a result, some potentially significant external threats to CRE resources that are relevant to the GCDAMP mission and goals are not being addressed. USGS will seek funding outside the GCDAMP to address three critical needs: (1) Little Colorado River threats, (2) Lake Powell water quality, and (3) effects of climate change and drought in the Colorado River Basin.

Little Colorado River Threats

The lower reach of the LCR located just above its confluence with the main Colorado River is critical spawning and rearing habitat for virtually the entire endangered HBC population in Grand Canyon. However, only the lower few miles of the LCR watershed are being addressed by the GCDAMP. Possible spills of hazardous materials and the potential for water-quality contamination in upstream areas of the LCR watershed have been identified by the FWS as a significant threat to the endangered HBC. The FWS has identified the need to develop a hazardous material spill response plan to help avert the catastrophic loss of the HBC population.

The GCMRC proposes the following activities to support this need:

- Enhance the existing stream gage in the lower LCR to include water-quaility sampling consistent with the existing mainstem quality-of-water program, which would improve the capacity to detect changes in water quality resulting from contamination in the upper watershed
- Synthesize existing historical hydrology, sediment, water-quality, and land-use information in the LCR Basin in relation to habitat requirements of humpback chub in the lower reach of the LCR
- Assess the risk of water contamination from various sources in the LCR

Lake Powell Water Quality

A primary determinant of water quality in the Colorado River below Glen Canyon Dam is the water released from Lake Powell. In addition, the water-quality characteristics and dynamics of Lake Powell have significant implications for the design and operation of a TCD that will allow for regulating the temperature and other water-quality characteristics of releases from GCD. While extensive physical and biological data on Lake Powell water quality have been collected for over two decades, the data have not been synthesized or subjected to extensive analysis and advanced modeling to simulate both temperature and dissolved oxygen characteristics for GCD operations and resulting releases. Under this activity, historical Lake Powell data would be synthesized to identify trends in quality of water. In addition, trends in dam operations, basin hydrology, and climate variability will be linked with biological data both in the reservoir and downstream of GCD (aquatic productivity and both nonnative and native fish trends). Information from this activity will support efforts to model both Lake Powell quality of water and downstream release characteristics associated with projected use and testing of a TCD. These assessments could significantly advance knowledge of potential future water quality in Lake Powell and the appropriate design and operation of the TCD. This study will be carried out in partnership with the Bureau of Reclamation.

Effects of Climate Change and Drought

Long-term drought and climate change have significant implications for decisions about future water management and hydropower production in the Colorado River Basin and the conservation of natural resources in Grand Canyon. Run-off in 2000–4 in the upper Colorado River Basin was the lowest in the period of record; Lake Powell is currently (2006) less than 50% full. Water managers increasingly need predictive capability for climate change and related drought forecasting over annual-to-decadal time spans. However, the causal mechanisms of drought are not presently well enough understood to make accurate predictions to meet the needs of managers at even seasonal-to-annual scales. In addition, continued climate change and long-term drought will have potentially significant implications for several identified strategies for the operation of GCD to attain a variety of GCDAMP goals (e.g., native fishes, sediment, cultural resources, and recreation).

Under this research initiative, basin-scale climate studies will be conducted on how new emerging climate information could be used by water and other resource managers in the GCDAMP program. The specific focus will be on: (1) how climate forecast information could be used in decisions related to the operation of GCD and other Colorado River Storage Project operations, and (2) the role of climate variability and hydrological variance (upper basin runoff versus the flood frequency of major tributaries below GCD) in ecosystem responses and their relationship to operation of GCD. This study will be carried out in cooperation with the National Oceanic and Atmospheric Administration and the Bureau of Reclamation.

CHAPTER 2. Proposed FY07–FY11 Monitoring and Research Plan Activities

Proposed science activities for FY07–FY11 are summarized in table 2.1. These activities are categorized as core monitoring, research and development, and long-term experimental. All proposed science activities are related to both GCDAMP goals and AMWG priorities.

The following section summarizes the core monitoring, long-term experimental, and research and development activities for GCDAMP goals 1–11. General activities are described for goal 12. This chapter also discusses by goal efforts to link and integrate monitoring and research activities across goals, illustrating how specific science elements of individual goals are integrated across several goals. Strategic science questions that will be addressed are a product of the Strategic Science Plan and 2005 Knowledge Assessment Workshop (KAW).

Table 2.1. Summary of core monitoring, research and development, and experimental activities described in the Monitoring and Research Plan to Support Glen Canyon Dam Adaptive Management Program, Fiscal Years 2007–11. Several long-term experimental activities currently under discussion are not reflected in the table; additional experimental activities will be specified pending the finalization of the Long-term Experimental Plan. Activities address Glen Canyon Dam Adaptive Management Program (GCDAMP) goals 1–12 in relation to science questions and information needs. Priority and related strategic science questions are paraphrased from the Draft GCMRC Strategic Science Plan (Appendix A). Information needs are paraphrased from the GCDAMP Strategic Plan. Abbreviations are as follows: SSQ=strategic science question, CMIN=core monitoring information need, RIN=research information need, and SA=GCDAMP Science Advisors summary questions.

GCDAMP goal	Priority science questions and information needs (Questions from Strategic Science Plan and Monitoring and Research Plan in italics)	Core monitoring activities	Experimental activities	Research and development activities
1. Food base	AMWG Priority:1, 3, and 5 *SSQ 1-5. What are the important pathways that link lower trophic levels with fish and how will they link to dam operations?* *SSQ 1-6. Are fish populations, trends, or indicators from fish, such as growth, condition, and body composition, correlated with patterns in invertebrate flux?* *SSQ 5-2. Is invertebrate flux affected by water quality (e.g., temperature, nutrient concentrations, turbidity) and dam operations?*	FY09: Aquatic food base monitoring program will be reviewed and evaluated for core monitoring status FY10–FY11: Implement aquatic food base core monitoring	FY08–FY11: Evaluate effects of experimental flows on food web	FY06–FY09: Determine carbon budget to understand how energy is exchanged among organisms in the Colorado River ; develop monitoring techniques and metrics for key organisms FY07: Diet, drift, and predation data analysis
2. Humpback chub (HBC) and other native fishes (A.)	AMWG Priority:1, 3, and 5 *SSQ 1-1. To what extent are adult populations of native fish controlled by production of young fish from tributaries, spawning and incubation in the mainstem, survival of young-of-year (YoY) and juvenile stages in the mainstem, or by changes in growth and maturation in the adult population as influenced by mainstem conditions?* *SSQ 1-4. Can long-term decreases in abundance rainbow trout be sustained with a reduced level of effort of mechanical removal or will recolonization from tributaries and from downstream and upstream of the removal reach require that mechanical removal be an ongoing management action? This question also applies to future removal programs targeting other nonnative species.* CMIN 2.1.2 Determine and track abundance and distribution of all size classes of HBC in the LCR and the mainstem.	FY07–FY08: Monitor status and trends of HBC in Little Colorado River (LCR) and mainstem using existing protocols FY08: HBC monitoring program will be reviewed and evaluated for core monitoring status in protocol evaluation panel (PEP) FY09–FY11: Implement HBC core monitoring	FY08–FY11: Evaluate effects of experimental flows on HBC and other native fishes	FY06 and ongoing: Stock assessment FY07–FY08: Gear efficiency/sampling evaluation FY07–FY11: Statistical review of existing HBC monitoring protocols and habitat data FY07–FY11: Evaluate protocols for warmwater and coldwater nonnative fish monitoring, removal, and control; effects on native fish

Table 2.1. Summary of core monitoring, research and development, and experimental activities described in the Monitoring and Research Plan to Support Glen Canyon Dam Adaptive Management Program, Fiscal Years 2007–11. Several long-term experimental activities currently under discussion are not reflected in the table; additional experimental activities will be specified pending the finalization of the Long-term Experimental Plan. Activities address Glen Canyon Dam Adaptive Management Program (GCDAMP) goals 1–12 in relation to science questions and information needs. Priority and related strategic science questions are paraphrased from the Draft GCMRC Strategic Science Plan (Appendix A). Information needs are paraphrased from the GCDAMP Strategic Plan. Abbreviations are as follows: SSQ=strategic science question, CMIN=core monitoring information need, RIN=research information need, and SA=GCDAMP Science Advisors summary questions. —Continued

GCDAMP goal	Priority science questions and information needs (Questions from Strategic Science Plan and Monitoring and Research Plan in italics)	Core monitoring activities	Experimental activities	Research and development activities
2. Humpback chub and other native fishes (B.)	AMWG Priority:1, 3, and 5 *SSQ 1-2. Does a decrease in the abundance of rainbow trout and other coldwater and warmwater nonnatives in Marble and eastern Grand Canyons result in an improvement in the recruitment rate of juvenile humpback chub to the adult population?* *SSQ 1-4. Can long-term decreases in abundance of rainbow trout in Marble and eastern Grand Canyons be sustained with a reduced level of effort of mechanical removal or will recolonization from tributaries and from downstream and upstream of the removal reach require that mechanical removal be an ongoing management action?* *SSQ 5-6. Do the potential benefits of improved rearing habitat (warmer, more stable, more backwater and vegetated shorelines, more food) outweigh negative impacts due to increases in nonnative fish abundance?* CMIN 2.4.1 Determine and track the abundance and distribution of nonnative predatory fish species in the CRE and their impacts on native fish. RIN 2.4.1: What are the most effective strategies and control methods to limit nonnative fish predation and competition on native fish? RIN 2.4.3: To what degree, which species, and where in the system are exotic fish a detriment to the existence of native fish through predation or competition?	FY07–FY08: Continue mainstem monitoring of fish community		FY07–FY10: Develop and test nonnative fish management plan FY07–FY11: Develop abundance estimation framework that allows scientists to better estimate nonnative fish numbers in mechanical removal reaches FY07–FY10: Develop bioenergetic model to predict changes in fish communities in response to environmental changes
2. Humpback chub and other native fishes (C.)	AMWG Priority:1, 3, and 5 *SSQ 1-1. To what extent are adult populations of native fish controlled by production of young fish from tributaries, spawning and incubation in the mainstem, survival of YoY and juvenile stages in the mainstem, or by changes in growth and maturation in the adult population as influenced by mainstem conditions?* *SSQ 1-7. Which tributary and mainstem habitats are most important to native fishes and how can these habitats best be made useable and maintained?* SA 1. What are the most limiting factors to successful HBC adult recruitment in the mainstem: spawning success, predation on YoY and juveniles, habitat (water, temperature), pathogens, adult maturation, food availability, competition?			FY07–FY10: Review data and literature on HBC in upper basin to see if HBC habitat can be identified, protected, and re-created below GCD

Table 2.1. Summary of core monitoring, research and development, and experimental activities described in the Monitoring and Research Plan to Support Glen Canyon Dam Adaptive Management Program, Fiscal Years 2007–11. Several long-term experimental activities currently under discussion are not reflected in the table; additional experimental activities will be specified pending the finalization of the Long-term Experimental Plan. Activities address Glen Canyon Dam Adaptive Management Program (GCDAMP) goals 1–12 in relation to science questions and information needs. Priority and related strategic science questions are paraphrased from the Draft GCMRC Strategic Science Plan (Appendix A). Information needs are paraphrased from the GCDAMP Strategic Plan. Abbreviations are as follows: SSQ=strategic science question, CMIN=core monitoring information need, RIN=research information need, and SA=GCDAMP Science Advisors summary questions.—Continued

GCDAMP goal	Priority science questions and information needs (Questions from Strategic Science Plan and Monitoring and Research Plan in italics)	Core monitoring activities	Experimental activities	Research and development activities
2. Humpback chub and other native fishes (D.)	AMWG Priority:1, 3, and 5 *SSQ 1-8. How can native and nonnative fishes best be monitored while minimizing impacts from capture and handling or sampling?*			FY07–FY09: Develop alternative, noninvasive HBC monitoring gear to reduce stress on fish (e.g., DIDSON camera, remote PIT tag reading, and sonic tags) FY07–FY09. Evaluate the effects of trammel net sampling
3. Extirpated species		No projects	FY07–FY11: Evaluation and planning of temperature control device	No projects
4. Rainbow trout (RBT)	AMWG Priority: 3 *SSQ 3-6: What Glen Canyon Dam operations (ramping rates, daily flow range, etc.) maximize trout fishing opportunities and catchability?* CMIN 4.1.2 Determine annual proportional stock density of rainbow trout in the Lees Ferry reach. CMIN 4.1.4 Determine annual standard condition (Kn) and relative weight of rainbow trout in the Lees Ferry reach.	FY07–FY11: Monitor status and trends of Lees Ferry BRT population FY07: Review/evaluate RBT monitoring for core monitoring status FY08–FY11: Implement RBT core monitoring	FY07: Evaluate effects of modified low fluctuating flow (MLFF) operations on RBT FY08–FY11: Evaluate effects of experimental flows on RBT	
5. Kanab ambersnail (KAS)	AMWG Priority: 3 CMIN 5.1.1 Determine and track the abundance and distribution of KAS at Vasey's Paradise. CMIN 5.2.1 Determine and track the size and composition of the habitat used by KAS at Vasey's Paradise.	FY07: KAS habitat monitoring; evaluate for core monitoring status in conjunction with U.S. Fish and Wildlife Service species status review	FY08–FY11: Evaluate effects of experimental flows, especially beach/habitat-building flows (BHBF), on KAS	FY07: Evaluation of alternative survey methods of KAS habitat

Table 2.1. Summary of core monitoring, research and development, and experimental activities described in the Monitoring and Research Plan to Support Glen Canyon Dam Adaptive Management Program, Fiscal Years 2007–11. Several long-term experimental activities currently under discussion are not reflected in the table; additional experimental activities will be specified pending the finalization of the Long-term Experimental Plan. Activities address Glen Canyon Dam Adaptive Management Program (GCDAMP) goals 1–12 in relation to science questions and information needs. Priority and related strategic science questions are paraphrased from the Draft GCMRC Strategic Science Plan (Appendix A). Information needs are paraphrased from the GCDAMP Strategic Plan. Abbreviations are as follows: SSQ=strategic science question, CMIN=core monitoring information need, RIN=research information need, and SA=GCDAMP Science Advisors summary questions.—Continued

GCDAMP goal	Priority science questions and information needs (Questions from Strategic Science Plan and Monitoring and Research Plan in italics)	Core monitoring activities	Experimental activities	Research and development activities
6. Springs /riparian	AMWG Priority: 4 *SSQ 2-1. Do dam controlled flows affect (increase or decrease) rates of erosion and vegetation growth at archaeological sites and TCP sites, and if so, how?* *SSQ 3-2. How important are backwaters and vegetated shoreline habitats to the overall growth and survival of YoY and juvenile native fish? Does the long-term benefit of increasing these habitats outweigh short-term potential costs?* CMIN 6.1.1., 6.6.1., 6.2.1., 6.5.1. Determine and track the abundance, composition, distribution, and area of terrestrial native and nonnative vegetation species in the CRE.	FY07: Conduct a PEP to advice development of vegetation core monitoring FY08–FY11: Implement vegetation core monitoring	FY08–FY11: Evaluate allochthonous contribution during experimental flows	FY07: Terrestrial monitoring FY07 and ongoing: Terrestrial mapping FY07–FY11: Vegetation synthesis project
7. Quality-of-water	AMWG Priority:1, 3, and 5 *SSQ 3-5. How is invertebrate flux affected by water quality (e.g., temperature, nutrient concentrations, turbidity) and dam operations?* *SSQ 5-1. How do dam release temperatures, flows (average and fluctuating component), meteorology, canyon orientation and geometry, and reach morphology interact to determine mainstem and near shore water temperatures throughout the CRE)?* *SSQ 5-3. To what extent do temperature and fluctuations in flow limit spawning and incubation success for native fish?* CMIN 7.3.1. What are the status and trends of water quality releases from Glen Canyon Dam?	FY07–FY09: Lake Powell monitoring using existing protocols FY09: Lake Powell monitoring PEP FY07–FY11: Downstream integrated quality-of-water monitoring (including suspended-sediment flux) FY10–FY11: Implement Lake Powell core monitoring	FY08–FY11: Collect water-quality and suspended-sediment data in support in support of experimental flow research efforts	FY08–FY10: Lake Powell synthesis and modeling FY07–FY11: Advanced development of downstream flow, temperature, and suspended-sediment models

Table 2.1. Summary of core monitoring, research and development, and experimental activities described in the Monitoring and Research Plan to Support Glen Canyon Dam Adaptive Management Program, Fiscal Years 2007–11. Several long-term experimental activities currently under discussion are not reflected in the table; additional experimental activities will be specified pending the finalization of the Long-term Experimental Plan. Activities address Glen Canyon Dam Adaptive Management Program (GCDAMP) goals 1–12 in relation to science questions and information needs. Priority and related strategic science questions are paraphrased from the Draft GCMRC Strategic Science Plan (Appendix A). Information needs are paraphrased from the GCDAMP Strategic Plan. Abbreviations are as follows: SSQ=strategic science question, CMIN=core monitoring information need, RIN=research information need, and SA=GCDAMP Science Advisors summary questions.—Continued

GCDAMP goal	Priority science questions and information needs (Questions from Strategic Science Plan and Monitoring and Research Plan in italics)	Core monitoring activities	Experimental activities	Research and development activities
8. Sediment (sandbars and debris fans/rapids)	AMWG Priority: 1,2,3, and 4 *SSQ 4-1. Is there a "Flow-Only" operation (i.e. a strategy for dam releases, including managing tributary inputs with BHBFs, without sediment augmentation) that will restore and maintain sandbar habitats over decadal time scales?*	FY07–FY11: Implementation of recommendations from the final SEDS-PEP (summer 2006) FY07: Detection of trends in sandbars through biennial measurements of sand-storage changes as reflected in campsite area monitoring (see goal 9, below)	FY08–FY11: Evaluate the effects of BHBFs and alternative ramping rates on sandbars and sediment	FY07–FY11: Map change in nearshore habitat resulting from 2004 BHBF; convert exiting overflight analog images to digital to facilitate research
9. Recreation (A)	AMWG Priority: 3 and 4 *SSQ 3-9. How do varying flows positively or negatively affect campsite attributes that are important to visitor experience?* 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.	FY07–FY11: Monitor change in sandbar campable area, topography, and volume (see above, project linked to sandbar monitoring)	FY08–FY11: Evaluate effects of experimental flows and ramping rates on campsites	FY07–FY08: Complete campsite inventory and GIS atlas FY07–FY08: Evaluate use of field data vs. remotely sensed data for campable area monitoring FY09: Evaluate vegetation encroachment on campsites; revisit Weeden survey data

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GCDAMP goal	Priority science questions and information needs (Questions from Strategic Science Plan and Monitoring and Research Plan in italics)	Core monitoring activities	Experimental activities	Research and development activities
9. Recreation (B)	AMWG Priority: 3 *SSQ 3-7. How do dam controlled flows affect visitors' recreational experiences, and what is/are the optimal flows for maintaining a high quality recreational experience in the CRE?* *SSQ 3-8. What are the drivers for recreational experiences in the CRE, and how important are flows relative to other drivers in shaping recreational experience outcomes?* *SSQ 3-10. How can safety and navigability be reliably measured relative to flows?* *SSQ 3-11. How do varying flows positively or negatively affect visitor safety, health and navigability of the rapids?* *SSQ 3-12. How do varying flows positively or negatively affect group encounter rates, campsite competition, and other social parameters that are known to be important variables of visitor experience?*		FY08–FY11: Evaluate effects of experimental flows and ramping rates on visitor safety and visitor health	FY07 or FY08: Compile and analyze existing safety data FY08–FY09: Evaluate relative importance and potential effects of different flows on recreation experience qualities FY10–FY11: Update regional recreation economic surveys
10. Hydropower	AMWG Priority: 3 *SSQ 3-3. What are annual hydropower replacement costs of the MLFF since 1996?* *SSQ 3-4. What are the projected hydropower costs associated with the various alternative flow regimes being discussed for future experimental science (as defined in the next phase of experimental design)?* 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, maximum flow limit of 25,000 cfs minimum flow limit of 5,000 cfs).	FY07–FY11: Monitor power generation and market values under current and future dam operations	FY08–FY11: Evaluate economic implications of experimental flows (with focus on hydropower and the Basin Fund)	

Table 2.1. Summary of core monitoring, research and development, and experimental activities described in the Monitoring and Research Plan to Support Glen Canyon Dam Adaptive Management Program, Fiscal Years 2007–11. Several long-term experimental activities currently under discussion are not reflected in the table; additional experimental activities will be specified pending the finalization of the Long-term Experimental Plan. Activities address Glen Canyon Dam Adaptive Management Program (GCDAMP) goals 1–12 in relation to science questions and information needs. Priority and related strategic science questions are paraphrased from the Draft GCMRC Strategic Science Plan (Appendix A). Information needs are paraphrased from the GCDAMP Strategic Plan. Abbreviations are as follows: SSQ=strategic science question, CMIN=core monitoring information need, RIN=research information need, and SA=GCDAMP Science Advisors summary questions.—Continued

GCDAMP goal	Priority science questions and information needs (Questions from Strategic Science Plan and Monitoring and Research Plan in italics)	Core monitoring activities	Experimental activities	Research and development activities
11. Cultural	AMWG Priority:2, 3, and 4 *SSQ 2-1. Do dam controlled flows affect (increase or decrease) rates of erosion and vegetation growth at archaeological sites and TCP sites in the CRE, and if so, how?* *SSQ 2-4. How effective are various treatments (e.g., check dams, vegetation management, etc.) in slowing rates of erosion at archaeological sites over the long term?* *SSQ 2-7. Are dam controlled flows affecting TCPs and other tribally-valued resources, and if so, in what respects?* CMIN 11.1.1 Determine the condition and integrity of archaeological sites and TCPs in the CRE through tracking rates of erosion, visitor impacts, and other relevant variables. (SPG revised CMIN) CMIN 11:2.1 Determine the condition of traditionally important resources and locations using tribal perspectives and values. (SPG revised CMIN)	FY10: Cultural PEP II	FY08–FY11: Evaluate effects of experimental flows on sediment supply and deposition at archaeological sites and traditional cultural properties (TCPs)	FY07: Research and development towards core monitoring (development of protocols for archaeological sites and TCPs) FY07: Implement Technical Work Group (TWG) approved tribal monitoring projects FY08–FY10: Integrated archaeological site monitoring pilot project FY09–FY10: Expand pilot study to evaluate geomorphic changes in the CRE using remotely sensed imagery FY08–FY10: Develop geomorphic model of archaeological site vulnerability
12. High-quality monitoring, research, and adaptive management program (A.) Data acquisition, storage, and analysis	AMWG Priority:1,2, 3, 4, and 5	FY07–FY11: Remote sensing activities related to the preparation, acquisition, and storage of 2009 terrestrial resource monitoring data	No projects	FY07–FY11: Convert existing analog images (especially overflight imagery) and reports t o digital (see also goal 8) FY07–FY11: Shoreline habitat and change detection mapping (see goals 2 and 8)

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

Strategic Science Questions and Information Needs

Food availability and quality are often important determinants of fish density and condition. For this reason, the Monitoring and Research Plan seeks to address discreet scientific questions, information needs, and objectives related to these conditions in an effort to advance goal 1. Specifically, adaptive Management Work Group (AMWG) priority questions from the Knowledge Assessment Report were used to frame key strategic science questions for GCDAMP goal 1. The strategic science questions that emerged as the focus of monitoring and research activities for goal 1 are listed below:

1. **SSQ 1-5.** What are the important pathways, and the rate of flux among them, that link lower trophic levels with fish?
2. **SSQ 1-6.** Are trends in the abundance of fish populations, or indicators from fish such as growth, condition, and body composition (e.g., lipids), correlated with patterns in invertebrate flux?
3. **SSQ 5-2.** How is invertebrate flux affected by water quality (e.g., temperature, nutrient concentrations, turbidity) and dam operations?

Monitoring and Research Activities

Food base monitoring and research activities for FY07–FY11 carry forward two elements of the overall Monitoring and Research Plan, core monitoring and research and development. Individual food base monitoring and research activities are discussed in terms of both the specific objectives the are designed to achieve and the individual element of the plan they are support.

Core Monitoring Activities

Monitoring the Aquatic Food Base

The aquatic protocol evaluation panel (Anders and others, 2001) recommended that "the food base program needs to be critically reviewed because the current level of understanding about the linkages between lower trophic levels and food availability of native fishes is not adequate to interpret food base data in relation to the management goal." There are two main reasons for this uncertainty: (1) the feeding habits of many fishes have never been studied and (2) the relative contribution of algae and allochthonous carbon to invertebrate, and ultimately fish, production is unclear. In other words, we do not have a good understanding of what constitutes the food base for many fishes and aquatic invertebrates. The new food base research initiative is focused on understanding the linkages that connect lower trophic levels with fish (i.e., what are invertebrates eating, what are fish eating), quantifying the availability of basal and invertebrate food resources, and documenting the feeding habits of fish throughout the system. Equipped with this knowledge, in FY09 we intend to develop a monitoring program that is focused on the most important components and drivers of the food base. Activities in this category address SSQ 1-5 and SSQ 5-2.

FY09–FY11. Evaluation and Implementation of New Protocols for Monitoring the Aquatic Food Base

Insights from the new food base research initiative (see below) will form the basis for new food base monitoring protocols that will be evaluated and implemented in FY09–FY11. A competitive solicitation process will be used to select cooperators to implement the new monitoring protocols.

Research and Development Activities

Trophic Linkages

Managers of native and nonnative fishes need to understand the amounts and quality of aquatic food resources that are available to fishes to help direct management actions. In particular, managers need to understand how different flow regimens affect the aquatic food base. Results from previous food base research provide some indication of the food items that are most often consumed by rainbow trout and humpback chub (HBC), but there is very little data on what constitutes the food base for other fish that are common in the Colorado River ecosystem. Further, the relative contribution of allochthonous and autochthonous carbon to invertebrate, and ultimately fish, production remains unclear. Yet, an understanding of what sources of carbon contribute to invertebrate and fish production is critical to making informed management decisions because the supply of autochthonous carbon is strongly affected by dam operations while the supply of allochthonous carbon is not. Activities in this category address SSQ 1-5, SSQ 1-6, and SSQ 5-2.

FY05–FY09. Aquatic Food Base (Project BIO 1.R1.07)

This project was initiated in 2005, and field work began in spring 2006, to identify energy pathways and quantify basal resources through multiple approaches. The project incorporates stable isotope and diet analysis of invertebrates and fish to identify trophic pathways. Flux along trophic pathways will be quantified by calculating invertebrate densities and estimating production and growth, and also estimating rates of food consumption by fish using bioenergetic approaches. Whole stream metabolism, terrestrial litter inputs from the riparian corridor, and allocthonous inputs from tributary flooding events will be measured to assess basal resources. Lastly, these data will be incorporated into a bioenergetics model for the aquatic ecosystem. Although the focus of the project is on carbon cycling, flux of dissolved and particulate nitrogen and phosphorus is also being studied. Results from this work, scheduled to end in FY09, will contribute to the development of a core monitoring program for the Grand Canyon food base in subsequent years.

FY07. Diet, Drift, and Predation Analysis (Project BIO 1.R3.07)

Rainbow and brown trout diet, food resource availability, and incidence of piscivory were areas of investigation associated with the effort to remove trout from the Little Colorado River inflow reach of the Colorado River in Grand Canyon. Some of the tasks associated with these projects have been completed, including field work, laboratory analysis of samples, and data entry. However, the data from these projects have not been assessed for data omission, data entry errors, nor have the data been completely compiled into a database. Only preliminary analysis has been conducted to date and results have not been documented. This project is a 1-year effort for FY07 and will lead to the completion of the database, including quality control, and synthesis of the data in the form of reports and manuscripts. Completion and synthesis of the database provides value to the GCDAMP by increasing understanding of trout diets along downstream reaches of the Colorado River, information that is valuable to managers as they evaluate the information generated by the first project for this goal, above.

Integration

Physical Sciences

Five of the seven study reaches in the whole-system carbon cycling project are FIST (fine-grained integrated sediment transport) and integrated water-quality monitoring sites, which will facilitate integration of the physical environment data with the standing mass, distribution, and production of basal resources and invertebrates, further supporting a long-term core monitoring program. The temperature model that is being developed by the Physical Science and Modeling Program will be a valuable tool for estimating systemwide growth rates of algae and invertebrates (temperature is the most important determinant of invertebrate growth rates). Sampling of organic inputs during recent tributary flood events, including a moderate sized Paria River flood, indicates that organic matter constitutes between 3%–6% of total transported material with the other remainder being sand, silt, and clay. If this relationship holds up, the food base project will be able to estimate organic inputs from tributary floods events based on estimates of sediments inputs obtained by the Physical Science and Modeling Program.

Fisheries

Ongoing fisheries monitoring data on the distribution and relative density of common native and nonnative fishes will be used to determine rates of energy flow to fishes in the system. Where possible, cooperating scientists will also rely on existing fisheries monitoring efforts to obtain the fish stomachs and tissue samples required for gut content and stable isotope analysis, respectively. The analysis of trout diets and other data collected during the mechanical removal effort will provide valuable information on the temporal variability of basal resources and food habits of fish that are outside the scope of the food base research initiative. Further, completing the stomach content analysis of samples taken during the mechanical removal project will help managers evaluate what rainbow trout in the removal reach have been eating and how this may or may not impact humpback chub entering and exiting the Little Colorado River.

GCDAMP Goal 2: 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

Strategic Science Questions and Information Needs

The Monitoring and Research Plan (MRP) for FY07–FY11 seeks to address discreet scientific questions, information needs, and objectives that support maintenance of viable populations of native fish. Adaptive Management Work Group (AMWG) priority questions from the Knowledge Assessment Report were used to frame key strategic science questions for GCDAMP goal 2. The strategic science questions that emerged as the focus of monitoring and research activities for goal 2 are listed below. Relevant Science Planning Group (SPG) prioritized core monitoring information needs (CMINs), and a summary question posed by the Science Advisors (SA 1) are identified.

1. **SSQ 1-1.** To what extent are adult populations of native fish controlled by production of young fish from tributaries, spawning, and incubation in the mainstem, survival of YoY and juvenile stages in the mainstem, or by changes in growth and maturation in the adult population as influenced by mainstem conditions?
2. **SSQ 1-2.** Does a decrease in the abundance of rainbow trout and other cold and warm water non-natives in Marble and eastern Grand Canyons result in an improvement in the recruitment rate of juvenile humpback chub to the adult population?
3. **SSQ 1-4.** Can long-term decreases in abundance of rainbow trout in Marble and eastern Grand Canyons be sustained with a reduced level of effort of mechanical removal or will re-colonization from tributaries and from downstream and upstream of the removal reach require that mechanical removal be an ongoing management action? This question also applies to future removal programs targeting other nonnative species.
4. **SSQ 1-7.** Which tributary and mainstem habitats are most important to native fishes and how can these habitats best be made useable and maintained?
5. **SSQ 1-8.** How can native and nonnative fishes best be monitored while minimizing impacts from capture and handling or sampling?
6. **SSQ 5-6.** Do the potential benefits of improved rearing habitat (warmer, more stable, more backwater and vegetated shorelines, more food) outweigh negative impacts due to increases in nonnative fish abundance?
7. **SA 1.** What are the most limiting factors to successful HBC adult recruitment in the mainstem: spawning success, predation on YoY and juveniles, habitat (water, temperature), pathogens, adult maturation, food availability, competition?
8. **CMIN 2.1.2.** Determine and track recruitment (identify life stage), abundance and distribution of HBC in the LCR.
9. **CMIN 2.4.1.** Determine and track the abundance and distribution of nonnative predatory fish species in the Colorado River.
10. **RIN 2.4.1.** What are the most effective strategies and control methods to limit nonnative fish predation and competition on native fish?
11. **RIN 2.4.3.** To what degree, which species, and where in the system are exotic fish a detriment to the existence of native fish through predation or competition?

Note: Razorback sucker are not currently regularly observed in Grand Canyon. Ongoing monitoring for native and nonnative fishes may capture this species if it is present or returns to the system.

Monitoring and Research Activities

Monitoring and research activities to support goal 2 range from monitoring efforts designed to provide decision makers with status and trends information on both native and nonnative fishes to efforts to understand the habitat preferences of humpback chub and the effects of modified low fluctuating flow operations on rainbow trout. Individually, activities can generally be characterized as core monitoring, research and development, or experimental in keeping with the structure of the Monitoring and Research Plan; however, when considered together, the activities described below are designed to complement one another and strategically address the myriad factors related to reaching goal 2. Many of the activities described below will be undertaken in partnership with GCDAMP stakeholders, especially the U.S. Fish and Wildlife Service and the Arizona Game and Fish Department.

Core Monitoring Activities

Monitoring of Native and Nonnative Fishes

Monitoring the status and trends of the fish community of the Colorado River in Grand Canyon is integral to assessing the impacts of dam operations on these species. This assessment is led by the GCMRC working with GCDAMP partners, especially the U.S. Fish and Wildlife Service and the Arizona Game and Fish Department, to provide managers with fish status and trend information that they can use to support management decisions. Different flow regimens and non-flow actions (especially the mechanical removal of nonnative fishes near the Little Colorado River inflow) have been implemented in recent years. Continued monitoring is needed to help evaluate whether these actions have been beneficial or detrimental to native and nonnative fishes. Because of its federally endangered status, the humpback chub is often the focus of Grand Canyon fish monitoring efforts. Current monitoring will be maintained in FY07 and FY08, building on the current long-term data set for humpback chub and other fish species. The current monitoring results will also be used to inform the development of core monitoring for humpback chub, the subject of a protocol evaluation panel (PEP) scheduled for FY08. The recommendations from this PEP will be implemented in FY09 and beyond. The primary questions and information needs addressed by these activities are SSQ 1-1, SSQ 1-2, and CMIN 2.1.2.

FY07–FY08. Little Colorado River Humpback Chub Monitoring Lower 15 km (Project BIO 2.R1.07)

This monitoring of the known spawning tributary of humpback chub in Grand Canyon will be led by the U.S. Fish and Wildlife Service. Sampling is conducted with hoop nets during four annual trips, two in the spring and two in the fall, as a continuation of the Little Colorado River (LCR) humpback chub stock assessment program initiated in the fall of 2000. These trips will occur in March, April, September, and October. This effort will provide spring and fall abundance estimates of HBC in the Little Colorado River. Tags deployed during fall and spring LCR trips will potentially be available for later recapture during mainstem activities. In addition to the short-term estimates and inferences that these sampling trips will support, this monitoring provides continued data collection in support of the ASMR open population model for humpback chub.

FY07–FY08. Little Colorado River Humpback Chub Monitoring Lower 1,200 m (Project BIO 2.R2.07)

This monitoring maintains a data set that has been conducted annually, with few exceptions, since the 1980s. Humpback chub are monitored with hoop nets near the mouth of the Little Colorado River (LCR). It is led by the Arizona Game and Fish Department (AZGFD).

FY07–FY08. Humpback Chub Monitoring Above Chute Falls (Project BIO 2.R3.07)

This project, led by the U.S. Fish and Wildlife Service, monitors the population of humpback chub found above Chute Falls (river km 16.2), a frequent, if inconsistent, barrier to upstream fish movement in the Little Colorado River. Humpback chub have been translocated above the falls in 2003, 2004, and 2005 and presented evidence of spawning (production of young fish) in 2005. Untagged adult fish were captured in 2006 indicating that limited movement above the falls is possible.

FY07–FY08. Monitoring Mainstem Fishes (includes below Diamond Creek) (Project BIO 2.R4.07)

This project combines elements of multiple projects from previous years, including sampling of the fish community in the Colorado River mainstem between Lees Ferry and Diamond Creek and from Diamond Creek to Pearce Ferry. The timing has been developed to coincide with three of the four lower 15 km LCR sampling events so that concurrent sampling is accomplished, consistent with reviewer recommendations. While humpback chub sampling is the focus of this work, information on other native and nonnative fishes is also gathered. The full mainstem sampling events will be conducted once in the spring and once in the fall to provide biannual snapshots of the fish community. The mainstem monitoring will also detect changes in nonnative fish populations that will be used to inform future nonnative control efforts.

Mechanical Removal of Nonnative Fish

One of the biotic factors thought to be limiting to native fishes is nonnative fish, which are thought to compete with native fish for food and prey on young native fish. This threat has been addressed during fiscal years 2003–6 with the mechanical removal of rainbow trout and other nonnative fish

using boat electrofishing. With warming of the Colorado River in the Grand Canyon the nonnative fish species posing the greatest threat to natives may change to species more adapted to warmer water. A comprehensive nonnative control plan will be prepared to address this threat. The plan will address how nonnative species posing the greatest threat to natives are identified and potentially controlled. Questions and information needs addressed by these projects are SSQ 1-4, SSQ 5-6, CMIN 2.4.1, RIN 2.4.1, and RIN 2.4.3.

FY07–FY10. Nonnative Control Planning and Nonnative Control Pilot Testing (Project BIO 2.R5.07 and Project BIO 2.R6.07)

The threats from nonnative species will be addressed in a comprehensive nonnative species control plan to be developed in fiscal years 2007–10. This time period will also be utilized to implement pilot projects, assess their value, and then refine the techniques. The DIDSON camera may be deployed along with some gear types to evaluate its efficacy.

Modeling Populations

As managers and scientists strive to manage and conserve the natural resources of the Grand Canyon, it is important to characterize the population size of the resident humpback chub population and the trend of the population over years. The GCMRC has been taking the lead in estimating the population size and trend and will continue to lead this effort in the future. Characterization and modeling of the population is dependent on some of the other projects described above, especially ongoing monitoring. Associated projects include development of a bioenergetic model of the Grand Canyon fish community to help predict anticipated changes in the fish communities in response to environmental changes, and development of abundance estimation procedures for nonnative fishes. Utilization and analysis of data collected in the field informs decisions regarding sampling design and gear selection. Questions and information needs addressed by these projects are SSQ 1-2, SSQ 1-4, SSQ 5-6, CMIN 2.4.1, and RIN 2.4.3.

FY07–FY11. Stock Assessment of Native Fish in Grand Canyon (model development) (Project BIO 2.R7.07)

To provide HBC status and trend information, the GCMRC mark-recapture database will be annually updated with most recent data collected during routine monitoring efforts. Following this update, the HBC mark-recapture database will be reanalyzed using (where appropriate) both open and closed mark-recapture based abundance estimators to provide the most current information on humpback chub status and trend. In particular we will rely on ASMR models and other appropriate models to determine trends in HBC abundance and recruitment trends. Finally, we will evaluate the applicability of similar techniques as described above to assessing stocks of flannelmouth sucker and bluehead sucker.

FY07–FY11. Abundance Estimation Procedures (Project BIO 2.R8.07)

Currently, the traditional Zippin abundance estimator is used to estimate the abundance of nonnative fish (primarily rainbow trout) in the mechanical removal reaches of the Colorado River. Though accepted and widely applied, this estimator makes the strict assumption that the vulnerability of fish among depletion passes is constant. Because large changes in turbidity are commonly observed within and among removal trips, this assumption is questionable. A more contemporary Bayesian estimation framework allows relaxation of this assumption if the relationship between a covariate (e.g., turbidity or sediment concentration) and vulnerability can be estimated. Additionally, this framework may allow more efficient use of the available data by allowing model-based aggregation of site specific estimates. Program BUGS (Bayesian Inference using the Gibbs sampler) will be used to fit models to our removal data.

FY07–FY10. Bioenergetic Modeling (Project: BIO 2.R9.07)

We will construct an ecopath model (http://www.ecopath.org/) using data available from previous studies conducted in Grand Canyon as well as the relevant scientific literature. Of particular importance will be the diet data collected associated with the mechanical removal project.

Monitoring Technology Research

The native fish population of the Grand Canyon, especially humpback chub, is handled regularly as part of efforts to understand the population size status and trends and also during mechanical removal. Electroshocking and netting of fish can cause stress to, and reduce the growth of, these animals, especially when they are handled repeatedly (e.g., Paukert and others, 2005). Potential negative effects of capture and study, especially of endangered fishes, have lead researchers to seek less invasive methods for evaluating the populations including alternative gears and remote monitoring technologies as part of the effort to define the most appropriate gear to be used to study Grand Canyon fishes. Tagging technologies that could reduce repeated handling of fishes need to be evaluated for their effectiveness in Grand Canyon. Acoustic imaging technologies show promise for describing distribution/habitat selection of native fishes. Research of some alternative monitoring technologies will be conducted beginning in FY07. The question addressed by these projects is SSQ 1-8.

FY07–FY09. Trammel Net Effects (Project BIO 2.R12.07)

Trammel nets have been used extensively to capture native fishes in the Colorado River, but have also been implicated in the injury of fish. This project provides partial support to a Northern Arizona University graduate student to investigate the impacts of these nets on fish. The results of the student's research will be used to evaluate this gear type for future studies of native fishes in Grand Canyon.

FY07–FY09. Remote PIT Tag Reading (Project BIO 2.R13.07)

Fisheries researchers in Grand Canyon (and around the world) inject fish with a unique electronic identifying code in a passive integrated transponder, or PIT, tag. The standard method for reading these tags is to check for the presence of a PIT tag upon capture of an individual fish, but remote PIT tag reading technologies are being developed. Experimentation with the use of remote antennae to read PIT tags will be conducted. The study area will focus, at least initially, on the LCR confluence with the Colorado River.

FY07–FY09. Test Sonic Tags (Project BIO 2.R14.07)

Experimentation with sonic tags will be led by GCMRC and AZGFD personnel, working closely with the product's manufacturer. Initial efforts will focus on capturing nonnative fish that will be implanted with these tags and released to see if the equipment is effective in the Colorado River.

FY07–FY09. Test DIDSON Camera (Project BIO 2.R15.07)

The DIDSON camera is owned by the Bureau of Reclamation (Reclamation), and is housed in Denver, Colo. The camera uses acoustic technology to produce an underwater image. It is especially effective in low light and turbid conditions as are common in the Colorado River. The camera's operator will be accompanied by GCMRC personnel on a river trip to test what habitat types can be sampled most effectively and to determine if fish aggregations can be identified.

Research and Development Activities

Habitat

The published assumptions regarding which habitats are optimum and available for different life stages of HBC need to be tested, but they could potentially serve to direct long-term monitoring and population modeling efforts, and the selection of flow regimens. To the extent possible, the characteristics of habitats (physical, water quality), particularly in the mainstem Colorado River, that are most important to native fishes need to be identified. Habitat characteristics needed by young-of-year (YoY) and juvenile HBC are most important to identify and protect because of the endangered status of this species. The questions addressed by this project are SSQ 1-1, SSQ 1-7, and SA 1.

FY07–FY10. Native Fishes Habitat Data Analysis (Project BIO 2.R11.07)

The GCMRC will review existing data and available literature and information from the upper basin regarding HBC habitat usage and preferences to see if such habitats can be identified from available data. A multivariate statistical method for linking environmental variables to fish populations will be tested for potential value in defining important habitat characteristics, including river flows, water-quality characteristics, and physical habitat.

Long-term Experimental Activities

Evaluating Effects of Experimental Flows on Fish

The habitats used by native fishes have been the subject of substantial research, but the research remains scattered in many different references. One of the shortcomings of this research is a lack of quantification of existing habitat types and how those habitat types change over time. In order to address this information need, GCMRC staff and cooperators will undertake efforts to detect changes in the abundance and distribution of different shoreline habitat types, especially sandbars and backwaters, in the Colorado River (Project DASA 12.D6.07). In terms of fish, knowledge of the distribution, abundance, and change potential of these habitats in the mainstem will help scientists evaluate the potential of the mainstem to support young HBC under various flow regimes. This project will build on the baseline data set of shoreline habitat for six habitat types at the 8,000 cfs elevation developed from 2000 data. Three other remote-sensing data sets from 2002–5 data will be used to extend the time series for a 5-year period. Using data taken in a variety of years will support this experimental effort to extend the data set to include higher elevation habitats up to 45,000 cfs. Higher elevation information will allow for better correlation of existing fish collection information with a variety of flows.

Integration

The food base research is closely associated with the fish community in Glen and Grand Canyons because most of the native and nonnative fish species depend on primary and secondary production for sustenance. The current food base study includes a component that integrates carbon flow through the system, including fishes. Monitoring of the native and nonnative fish populations will provide additional information for evaluating the results of the food base study; for example, the results of flux in fish populations can be correlated with flux of the food base to help critically evaluate the importance of primary and secondary production for fishes.

Monitoring and characterization of the fish community of Grand Canyon will be integrated with monitoring and modeling of physical habitat and water-quality parameters, especially in relation to various Glen Canyon Dam release regimens. Additional details of integration strategies and products are provided above and in the FY07 Annual Work Plan.

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

Goal 3 is not currently a Glen Canyon Dam Adaptive Management Program (GCDAMP) priority goal; however, the goal is part of the National Park Service (NPS) and U.S. Fish and Wildlife Service (FWS) long-term resource management objectives. If goal 3 becomes a higher priority for the GCDAMP in the future, initial efforts will be to investigate the feasibility of reintroducing the target extirpated species.

The knowledge gained from Grand Canyon Monitoring and Research Center monitoring and research efforts on key ecosystem drivers—the operation of the Glen Canyon Dam, riparian zone health and function, and water quality—will be useful to assess the steps necessary to reintroduce specified extirpated native fish, mammals, and amphibians into the river ecosystem. As the Colorado River ecosystem improves and changes the NPS, FWS, and the Arizona Game and Fish Department will, in cooperation with the GCDAMP, prioritize any reintroduction efforts.

GCDAMP 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

Strategic Science Questions and Information Needs

Monitoring of the rainbow trout population above the Paria River is an important activity for understanding the population status and trends and evaluating whether the observed status and trends are meeting goal 4. Therefore, monitoring of this population is to continue during FY07–FY11. Monitoring data will be used to support a protocol evaluation panel (PEP), which is scheduled for FY07. The fate of trout eggs and very young fish in response to dam operations will be the subject of continuing research in FY07 and FY08. The primary science questions and information needs addressed by both projects are as follows:

1. **SSQ 3-6.** What GCD operations (ramping rates, daily flow range, etc.) maximize trout fishing opportunities and catchability?
2. **CMIN 4.1.2.** Determine annual proportional stock density of rainbow trout in the Lees Ferry reach.
3. **CMIN 4.1.4.** Determine annual standard condition (Kn) and relative weight of rainbow trout in the Lees Ferry reach.
4. **RIN 4.1.1.** What is the target proportional stock density (i.e., trade-off between numbers and size) for rainbow trout in the Lees Ferry reach?

Monitoring and Research

Core Monitoring Activities

The monitoring of the rainbow trout population above the Paria River will continue to document population changes and condition factors. Current monitoring results and those from previous years will be used to inform the FY07 PEP, which, in turn, will be used as guidance for core monitoring of rainbow trout population above the Paria River.

FY07. Status and Trends of Lees Ferry Trout (Project BIO 4.M1.07)

The fishery is sampled by electrofishing to estimate biological parameters used to assess the status and trends of the fishery. Electrofishing provides information on size composition, relative abundance (catch per minute as a surrogate for population size), and condition (length weight relationships). Samples are collected for whirling disease examination. The project addresses SSQ 3-6, CMIN 4.1.2., and CMIN 4.1.4.

FY07. Rainbow Trout Redds and Larvae (Project BIO 4.E1.07)

Analysis of redd (nest) production, egg production, and larval survival will be continued in FY07 to determine population responses to flows, and also to inform the PEP process. Information from this project and monitoring helps managers and peer reviewers trying to address RIN 4.1.1, as well as the SSQ 3-6, CMIN 4.1.2, and CMIN 4.1.4.

Research and Development Activities

The aquatic food base research project described under goal 1 will support efforts to determine the amount and quality of food available for trout.

Long-term Experimental Activities

The project will monitor fish population and habitat responses to various experimental flow regimens. The results of such monitoring will contribute to understanding what flow regimens best support and maintain the rainbow trout present below Glen Canyon Dam.

Integration

The aquatic food base research project described under goal 1 helps provide evaluation of the amount and quality of food available for trout.

GCDAMP Goal 5: Maintain or attain viable populations of Kanab ambersnail

Strategic Science Questions and Information Needs

Managers and scientists continue to investigate the highly variable population of Kanab ambersnail (KAS) in Grand Canyon. Population size and habitat measurements reveal that both snail numbers and habitat availability can vary dramatically, therefore the natural, acceptable population and habitat size variability remains undefined. Understanding what amount of variability is natural (i.e., what is acceptable for managers), will be one of the prime questions addressed by the U.S. Fish and Wildlife Service (FWS) as part of their status review of this species in 2006 and 2007. Another important question for FWS to consider will be the taxonomic status of the Vasey's Paradise population. This population has been included in populations that are the subject of genetics research being concluded in 2007 at the University of Arizona under contract with the GCMRC. The GCMRC will be closely involved in providing science support to the FWS during their review.

GCMRC in cooperation with partner agencies will continue to address the following core monitoring information needs (CMINs) for the Kanab ambersnail:

1. **CMIN 5.1.1.** Determine and track the abundance and distribution of Kanab ambersnail at Vasey's Paradise in the lower zone (below 100,000 cfs) and the upper zone (above 100,000 cfs).

2. **CMIN 5.2.1.** Determine and track the size and composition of the habitat used by Kanab ambersnail at Vasey's Paradise.

Monitoring and Research Activities

Core Monitoring Activities

Population and habitat monitoring methods for Kanab ambersnail continue to be defined and refined. Working closely with the Arizona Game and Fish Department (AZGFD) and the National Park Service (NPS), the GCMRC is providing logistics support and data analysis for ongoing monitoring. The species status review being conducted by the FWS in 2006 and 2007 will provide important guidance for determining what constitutes core monitoring for this species. This guidance will be subject to review by GCDAMP committees and the National Park Service when determining their core monitoring needs. Monitoring activities address CMIN 5.1.1 and CMIN 5.2.1.

FY07–FY11. Monitoring Kanab Ambersnail (Project: BIO 5.R1.07)

Habitat surveys at Vasey's Paradise include surveying the total area of the habitat and surveying individual patches of vegetation within the habitat. Areas are determined using traditional land-survey methods. Habitat surveys are conducted in the spring and fall of each year. Within each designated patch, the cover and heights of dominant plant species are recorded as are variables associated with soil moisture. Snail densities are determined by randomly sampling areas within vegetation

patches. Snail densities are extremely variable seasonally and among vegetation patches. Consequently, confidence intervals around subsequent population estimates are large and considered to be statistically unreliable, so more emphasis is needed with regard to sampling emphasis and approaches. The project addresses CMIN 5.1.1 and CMIN 5.2.1.

Research and Development Activities

Testing Alternative Methods

Surveying in Vasey's Paradise to determine the extent of the habitat can be invasive. Remote technologies that include oblique orthorectified imagery and land-based LiDAR may be two methods that can be used to determine area cover and heights of dominant plants without the need for a person to step into the habitat. Alternative methods will be tested beginning in FY07 to assess potential survey and monitoring approaches for incorporation into long-term monitoring. Depending on the results of these tests, conducted in conjunction with monitoring, additional projects could be identified in future fiscal years.

Genetic Research

Current genetics research of the *Oxyloma* species has been supported by GCDAMP funds through the GCMRC. The results of the research effort are expected in 2007 and are expected to contribute to the species status review.

Long-term Experimental Activities

Experimental Flows Population Monitoring and Habitat Salvage

In November 2004, the GCMRC and the AZGFD temporarily removed habitat patches that were determined to be subject to scouring before the 2004 experimental beach/habitat-building flows (BHBF). These patches were moved above the inundation level and then returned to their original locations. The habitat survived the temporary removal and provided a means to reduce habitat loss under high-elevation flow scenarios. Population response to this action suggests that removal and replacement of habitat patches can be conducted during the period of low flows before and following high-flow tests, respectively. To assure confidence in this result, monitoring of this technique and especially its safety for the KAS population, should accompany future BHBFs.

Integration

The Kanab ambersnail monitoring trips are conducted in conjunction with river trips that sample backwater habitats for small-bodied fishes with seines. This arrangement allows researchers to monitor two very different species and habitats with a single river trip.

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

Strategic Science Questions and Information Needs

The riparian and spring vegetation communities of Grand Canyon are a component of many other resources, including vertebrate habitats, organic inputs into the river, sediment transport, recreation sites, and cultural resources. Understanding how dam operations and other factors, especially climate, affect the vegetation communities requires definition of the existing vegetation communities and how they change. The projects planned under this goal are designed to document and model the vegetation communities and how they change with the eventual goal of developing some remote monitoring and modeling capabilities to inform management needs.

Monitoring and research activities related to goal 2 are designed to address the following strategic science questions (SSQs) and core monitoring information needs (CMINs):

1. **SSQ 2-1.** Do dam controlled flows affect (increase or decrease) rates of erosion and vegetation growth at archaeological sites and TCP sites, and if so, how?
2. **SSQ 4-2.** How important are backwater and vegetated shoreline habitats to the overall growth and survival of YOY and juvenile native fish? Does the long-term benefit of increasing these habitats outweigh short-term potential costs (displacement and possible mortality of young humpback chub) associated with high flows?
3. **CMINs 6.1.1, 6.2.1., 6.5.1, and 6.6.1.** Determine and track the abundance, composition, distribution, and area of terrestrial native and nonnative vegetation in the CRE.

Monitoring and Research Activities

Core Monitoring Activities

Riparian vegetation monitoring requires systemwide assessment of vegetation change at the broad scale (e.g., new high-water zone) as well as at the local scale (e.g., plot data at 25,000 cfs). While knowing how much vegetation in the river corridor exists is useful, it is equally useful to know how the species that make up the vegetation may be changing. Changes in riparian vegetation are associated with dam operations (Stevens and others, 1995; Kearsley and others, 2006) and can include the propagation of exotic species like tamarisk (Porter, 2002). Yearly transects can detect changes among herbaceous species, including invasives, while remotely sensed data collected at a 5-year intervals can assess changes in overstory wood species that change more slowly. Monitoring in this way provides data across temporal and spatial scales. In FY07, this work is being developed as a core monitoring project and will be reviewed by a protocol evaluation panel (PEP). Monitoring activities address SSQ 2-1, CMIN 6.1.1, CMIN 6.2.1, CMIN 6.5.1, and CMIN 6.6.1.

FY07–FY08. Vegetation Mapping (Project BIO 6.R1.07)

FY07–FY11. Vegetation Transects (Project BIO 6.R2.07)

These two field-based projects are designed to compliment one another. Annual monitoring that uses vegetation transects (Project BIO 6.R2.07) associated with specific stage elevations records species diversity, richness, and cover. The

changes in vegetation parameters that this monitoring detects is relevant to perennial and annual herbaceous species like bunch grasses, marsh species, and invasive species that can change on an annual basis. Vegetation mapping (Project BIO 6.R1.07) utilizes the overflight digital imagery (a product of the Data Acquisition, Storage, and Analysis Program) to quantify larger scale area changes (e.g., expansion of arrowweed patches, or extent and type of vegetated shoreline). Analysis of change detection in the vegetation mapping project would incorporate the annual transect survey results to help explain patterns of change that may occur over a 5-year time frame. The two projects compliment each other because they provide information about changes in riparian habitat at different ecological scales that may affect other riparian community constituents like invertebrate biomass and riparian bird abundance.

Research and Development Activities

Our understanding of how riparian vegetation changes as a result of dam operations is well developed for marsh species (see Stevens and others, 1995). The authors related decadal changes in operations, geomorphic reach, and distance from the dam to area cover and species composition. Our knowledge regarding this community was reaffirmed in the Knowledge Assessment Workshop, which is summarized in Melis and others (2006). However, as one moves upslope from the channel, our understanding of how operations influence vegetation change is less conclusive. As a result of the vegetation transects completed from 2000 to 2004, we do know that dam operations affect vegetation cover, richness, and diversity up to the 35,000 cfs river stage elevation, while the local environment appears to affect vegetation above this elevation. We do not know, however, how short duration high flows (discharges greater than 31, 000 cfs), may change riparian vegetation. These questions will be considered within the scope of the vegetation synthesis.

FY07–FY11. Vegetation Synthesis (Project BIO 6.R3.07)

The vegetation synthesis will use previous mapping and monitoring results to test mechanisms that affect riparian vegetation establishment and expansion, including rates of change and potential colonization sites. The synthesis seeks to address knowledge gaps identified by the Knowledge Assessment. For example, the Knowledge Assessment revealed that there was some certainty about the relationship of marsh community development and flows for the Colorado River ecosystem, but that this certainty decreased as one progresses upslope. Additionally, the Knowledge Assessment found the need for an understanding of the integrated role of riparian vegetation with other resources (e.g., aquatic and cultural resources). A synthesis is a step toward filling these needs and will be implemented in two parts. Part I (FY07–FY09) will address local processes and systemwide change and Part II (FY09–FY11) will integrate faunal and cultural components. This project addresses SSQ 1-5 and SSQ 3-2.

Long-term Experimental Activities

Experiments associated with riparian vegetation will be curtailed until Part I of the vegetation synthesis is completed in FY09. A potential experiment associated with riparian vegetation that could be subsequently implemented would be to remove vegetation that is subject to inundation during high flows, including low-growing limbs, to determine the effect of reduced vegetation on sediment transport and deposition, and to observe colonization rates in understory and open-beach areas. The colonization rates would examine how native versus introduced species compete and occupy newly available space. The results would be used to test hypotheses generated in the synthesis. In the interim, annual monitoring that is correlated with stage variation will be conducted to provide a general picture of vegetation response to changes in operations associated with long-term experimental planning from FY07–FY11.

Integration

Riparian vegetation is a critical interface between aquatic and terrestrial environments around the world. In the Colorado River ecosystem, the vegetation itself serves as a host for invertebrates, provides breeding and foraging habitat for birds, provides cover in the heat of the day, and may be harvested for cultural uses. Changes in the composition or structure of riparian vegetation like the expansion of an exotic species may alter these interactions. Riparian vegetation regulates nutrient exchange between the land and water. For example, leaf litter is a terrestrial carbon source that may influence in-stream invertebrate production. The relative importance of terrestrial carbon in the aquatic food web is being, in part, addressed through the food base initiative. The linkage could be further defined through studies that focus on terrestrial productivity and processes. Again, changes in abundance or kind of riparian carbon sources may influence aquatic productivity processes. In addition, an understanding of how vegetation influences cultural resources is needed, which was noted in the Knowledge Assessment. Through a combination of monitoring, synthesis, and field research, the Biology Program will improve the understanding of the role riparian vegetation plays in influencing other resources.

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

Strategic Science Questions and Information Needs

Recognizing the importance of the qualities of water released from Glen Canyon Dam (GCD), the GCMRC seeks to better understand how water-quality conditions in Lake Powell affect and interact with downstream quality of water and aquatic resources below the dam. This will be addressed with an integrated program of monitoring and modeling both in Lake Powell and downstream.

In 2004, the Adaptive Management Work Group (AMWG) identified several priority questions, one of which relates directly to downstream quality of water, particularly water temperature below Glen Canyon Dam:

AMWG Priority 3: What is the best flow regime?

In addition, during the 2005 Knowledge Assessment Workshop, biological scientists also identified uncertainty related to options for achieving fishery and food web objectives related to downstream water quality and temperature. As a result, the scientists formulated several key strategic science questions for GCDAMP goal 7 around those uncertainties. The most critical strategic science questions that emerged as the focus of monitoring and research activities for goal 7 are as follows:

1. **SSQ 3-5.** How is invertebrate flux affected by water quality (e.g., temperature, nutrient concentrations, turbidity) and dam operations?
2. **SSQ 5-1.** How do dam release temperatures, flows (average and fluctuating component), meteorology, canyon orientation and geometry, and reach morphology interact to determine mainstem and near shore water temperatures throughout the CRE?
3. **SSQ 5-3.** To what extent do temperature and fluctuations in flow limit spawning and incubation success for native fish?

As part of the GCDAMP strategic plan, several core monitoring information needs (CMINs) for measurements of downstream flow and water temperature, as well as the quality of water leaving GCD, were identified. The key CMINS related to goal 7 are as follows:

1. **CMIN 7.1.1.** Determine the water temperature dynamics in the mainstem, tributaries (as appropriate), backwaters, and nearshore areas throughout the Colorado River ecosystem.
2. **CMIN 7.2.1.** Determine the seasonal and yearly trends in turbidity, water temperature, conductivity, DO, and pH, changes in the mainstem throughout the Colorado River ecosystem.
3. **CMIN 7.3.1.** What are the status and trends of water quality releases from Glen Canyon Dam?

Monitoring of stage and discharge below Glen Canyon Dam provides a means for determining when dam operations are in compliance with the 1996 Record of Decision, as well as when departures occur under emergency criteria. Owing to the fact that suspended-sediment measurements are usually considered to be a component of the quality-of-water monitoring project, the CMINs associated with goal 8 for sediment are also tied to monitoring of downstream quality of water (see goal 8, this report).

Monitoring and Research Activities

Monitoring and research activities related to goal 7 are carried out by the integrated quality-of-water (IQW) project and involve Lake Powell, the tailwater of Glen Canyon Dam, and the water downstream of Glen Canyon Dam. All of the activities related to goal 7 carry forward one or more of the three elements of the overall Monitoring and Research Plan, including core monitoring, research and development, and long-term experimentation. For this reason, individual monitoring and research activities are discussed in terms of the element of the plan they are designed to support.

Core Monitoring Activities

Upstream Quality of Water Monitoring of Lake Powell and Glen Canyon Dam Tailwater

Processes within Lake Powell, climate changes in the upper Colorado River Basin, the structure of the GCD, and various aspects of dam operations affect the quality of water released from GCD to the Colorado River ecosystem (CRE) in Grand Canyon. Temperature, dissolved oxygen concentrations, nutrient concentrations, biological composition, and other characteristics of GCD releases can have a profound effect on the aquatic ecosystem below the dam. Activities in this category are designed to address strategic science questions SSQ 3-5, SSQ 5-1, and SSQ 5-3.

FY07–FY11. Quality of Water Monitoring of Lake Powell and the Glen Canyon Dam Tailwater (Project BIO 7.R1.07)

Water quality, including temperature, in Lake Powell makes a fundamental contribution to the aquatic environment downstream of Glen Canyon Dam. This monitoring project maintains a 40-year long database of water-quality information that managers can use to help understand the aquatic environment that is available to organisms downstream. These data are currently being combined with other data to support downstream thermal modeling. A data report that includes status and trends of parameters and identification of recurring patterns will be produced by the GCMRC in FY07. This report will inform further analysis that is anticipated in future years of reservoir processes, climatic versus operational effects, and suitability of the released water for downstream resources. The results of the ongoing monitoring will be a fundamental resource for an expert protocol evaluation panel (PEP) anticipated in FY09. The PEP will look critically at the current protocols and recommend any necessary changes.

Downstream Quality of Water Monitoring

Suspended-sediment transport data for both sand and finer particles are analyzed and used to update managers about the status of suspended-sediment flux between the two major tributaries (influx) and export to upper Lake Mead (efflux). The measurements and modeling estimates for tributary sand influx and main channel efflux are used to support experimental flow triggers related to testing of beach/habitat-building flows (BHBFs) and to evaluate research flows, such as alternative fluctuating operations and stable flows. Temperature, flow, and stage data are also made available for use by scientists in assessing habitat characteristics for aquatic organisms. This effort addresses SSQ5-1.

FY07–FY11. Downstream Integrated Quality-of-Water Monitoring (below Glen Canyon Dam) (Project PHY 7.M1.07)

The downstream integrated quality-of-water monitoring project focuses primarily on monitoring, but also has the capacity to support research related to experimental flows, including BHBFs. There are several general components to the monitoring strategy for goal 7, relating to the downstream integrated quality-of-water project:

- Monitor and report real-time data of release pattern of Glen Canyon Dam (stage and discharge, as measured at the Colorado River gage near Lees Ferry and key points downstream)
- Monitor and report real-time quality-of-water data for downstream segments of the Colorado River ecosystem that focus on managers' needs and supports modeling efforts below Glen Canyon Dam (temperature, specific conductivity, and other characteristics in the main channel and selected tributaries)
- Monitor and report estimates for (measurements and modeling) sand and silt/clay volumes (with grain sizes) delivered by major and lesser tributaries below Glen Canyon Dam (ecosystem's influx of fine sediments)
- Monitor and report estimates for (measurements and modeling) sand and silt/clay volumes (and grain sizes) transported by the Colorado River downstream below Glen Canyon Dam (ecosystem's efflux of fine sediments)
- Monitoring to support experimental flows, including collecting, as need arises, additional similar data in support of experimental flows released from Glen Canyon Dam

Research and Development Activities

Advanced Development of Downstream Flow, Temperature, and Sediment Modeling

FY07–FY08. Monitoring Support Linked with Integrated Quality-of-Water Monitoring (Project PHY 7.R1.07)

Several modeling efforts and related research activities are planned for the 2007–11 monitoring and research period:

- Ongoing development and verification of thermal and sediment-transport models below GCD as well as user interfaces and World Wide Web access to data
- Applications of sediment and thermal modeling simulations for science planning support
- Interdisciplinary cooperation between scientists modeling water quality and food web researchers working on the development of nutrient monitoring and mass balance
- Evaluation of use of hydroacoustic instrumentation for continuous monitoring of organic drift in the Lees Ferry reach

As part of science efforts between 2007 and 2011, the GCMRC shall continue development of a downstream model for temperature (initiated in 2006). Temperature monitoring along the main channel is proposed to be expanded to include continuous measurements in selected nearshore environments, such as backwaters (return-current channel) within Marble and eastern Grand Canyons. These data are intended to support ongoing development of a downstream thermal model for the main channel and associated nearshore habitats of importance to aquatic organisms and fish.

During 2007 and 2008, GCMRC scientists and cooperators conducting research on nutrient dynamics related to the ecosystem's aquatic productivity and the quality-of-water project are scheduled to continue collaborative efforts to define future monitoring activities. One objective of the food web research is to help the GCMRC identify elements of downstream monitoring that might be of interest to managers. Strategies for expanding downstream quality-of-water measurements and integrating new protocols with existing measurements shall be explored during the remainder of the food web research. Use of acoustic backscattering data for estimating drifting organic matter that leaves the Lees Ferry reach has been attempted as a pilot study in 2005. Preliminary evaluation of this approach shows promise and is the motivation for more detailed field activities between the IQW staff and aquatic scientists within the GCRMC in FY07 and beyond.

Long-term Experimental Activities

Experimental Flow Support

The IQW project will collect, as need arises, additional similar quality-of-water and suspended-sediment data in support of experimental flows released from GCD, including future BHBF tests.

Depending upon the suite of experimental flows included in the long-term experimental design, additional experimental studies, such as alternative fluctuating flows, might also be the focus of field measurements and modeling simulations to address the above science questions related to fine sediment dynamics, conservation of sandbars, etc.

The experimental design for future BHBF studies has not been fully determined, but is likely to focus on replication of a high-flow release of similar duration to the experiment conducted in 2004 (41,000 to 45,000 cfs for approximately 2 days) under similarly sand-enriched conditions from the Paria and Little Colorado Rivers. The logic for replication of additional BHBFs under sand-enriched conditions similar to the antecedent conditions that preceded the 2004 experiment is described in the next section related to goal 8 (sediment).

Additional flow and sediment studies are most likely to focus on alternative fluctuating flows, possible stable flows, or even thermally modify releases from GCD by the end of the monitoring and research period.

Integration

The potential for interdisciplinary studies between other resource areas and the IQW project is great owing to the fact that it results in high-resolution data streams for temperature, conductivity, and suspended-sediment data throughout the CRE. Integration will be necessary to answer most of the strategic science questions associated with AMWG priority 5. For example, dissolved oxygen data measured in the tailwater below the dam and in Lake Powell are of special interest to fisheries biologist and managers in the Lees Ferry reach. Temperature and suspended-sediment data are particularly important to scientists working on problems of fishery habitat use and productivity above and below the Lees Ferry reach. River discharge and associated downstream stage data are important for understanding nutrient spiraling and habitat conditions throughout the main channel of the ecosystem. The evolving state of the fine-sediment mass balance throughout the ecosystem influences efforts to restore and maintain beaches of interest to managers and scientists for their roles in both the aquatic and terrestrial environments. Continued in-situ preservation of cultural resource sites depends upon nearshore beach habitats

being sufficiently nourished by new tributary sand supplies (presumably, through effective BHBF implementation) to contribute to wind transported sand into arroyos and other geomorphic setting where archaeological sites have eroded.

During the monitoring and research period of FY07–FY11, new efforts shall be made to bridge or link core monitoring within the downstream IQW project to food web, fishery, recreation, and archaeological science projects. Special emphasis shall also be made within the monitoring project to collect temperature data that directly supports increased modeling capabilities for predicting downstream water temperature in the main channel and near-shore habitats. These nearshore data shall be collected specifically within the context of seasonal field activities conducted within the fishery and food web research trips and at sites where those science efforts are already being focused.

The primary objective toward promoting use of the IQW core monitoring data to achieve greater integrated science shall be to not only collect these data, but then to make them readily accessible to other cooperating scientists and managers so that they can be used and integrated into focused research and development, as well as experimental research efforts. Historical temperature, flow, and sediment data shall be used also in updating and advancing the Grand Canyon conceptual model, previously developed in the late 1990s. Conceptual modeling workshops held during the 2007–11 period shall have access to quality-of-water data from both Lake Powell and downstream IQW efforts.

Sand beach mapping and change detection studies, scheduled for 2007 and beyond, shall also have the advantage of using the continuous fine-sediment mass balance core monitoring data for use in evaluating sandbar area, volume and grain size changes that are identified over the period 1999–2009, when airborne, remote-sensing missions capture imagery of ecosystem shorelines. By having these core monitoring data for fine-sediment flux, scientists and managers may better evaluate the relationship between dam operations (including BHBF tests) and physical habitat responses associated with sandbars throughout the river corridor.

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

Strategic Science Questions and Information Needs

Recognizing that maintaining or attaining a sufficient level of sandbars and related habitats is a long-term goal, the Monitoring and Research Plan seeks to address discreet scientific questions, information needs, and objectives required to achieve this larger goal. In 2004, the Adaptive Management Work Group (AMWG) identified several priority questions, including priority question 4 which relates directly to sediment: What is the impact of sediment loss and what should we do about it?

In addition, during the 2005 Knowledge Assessment Workshop, sediment scientists also identified uncertainty related to options for achieving sandbar conservation objectives and posed key strategic science questions for GCDAMP goal 8 around those uncertainties. The most critical strategic science question that emerged as the focus of monitoring and research activities for goal 8 is:

- **SSQ 4-1.** Is there a "Flow-Only" operation (i.e. a strategy for dam releases, including managing tributary inputs with BHBFs, without sediment augmentation) that will restore and maintain sandbar habitats over decadal time scales?

Also identified as part of the GCDAMP Strategic Plan are several core monitoring information needs (CMINs), which are briefly summarized in table 2.2.

Monitoring and Research Activities

Monitoring and research activities are categorized below into three activities: core monitoring, research and development linked to monitoring and modeling, and long-term flow experimentation. In the case of goal 8, monitoring activities for detecting changes in sand storage throughout the river ecosystem were extensively reviewed through the protocols evaluation panel (SEDS-PEP) process during the period 1998–2006. The SEDS-PEP review process for sediment monitoring was concluded in August 2006 with a final meeting and report to the GCMRC. Recommendations for future monitoring shall be integrated into the science planning process during 2007, as planning for the FY08–FY09 Biennial Work Plan occurs. As a result of the timing associated with this ongoing process, only general elements of long-term sediment monitoring are discussed in this section of the Monitoring and Research Plan.

Core Monitoring Activities

Core monitoring activities will focus on:

- Monitoring and reporting biennial field measurements (site-specific conventional surveys) on status of sandbar area, volumes, and grain size characteristics at a selected sub-sample of sandbars within specified geomorphic reaches
- Monitoring and reporting remotely sensed measurements of sandbar areas systemwide, as derived from multispectral, orthorectified, digital imagery flown once every 4 years
- Monitoring and reporting changes in the distribution and abundance of shoreline types pertaining to terrestrial and aquatic habitats of interest to managers, such as backwaters, camping areas, cultural preservation sites using data derived from multispectral, orthorectified, digital imagery flown once every 4 years
- Monitoring and reporting changes in the geomorphic impacts along the Colorado River ecosystem that result from tributary debris flows and stream floods

Monitoring Changes in Sediment Storage

External Peer Review of Sediment Protocols in 2006–7

The external review of sediment protocols to take place from 2006–7 will be followed by planning for sandbar monitoring toward implementation in 2008–11 and beyond. Recommendations from external peer reviewers on options for monitoring of sediment storage throughout the ecosystem shall be incorporated into a GCMRC-led core monitoring workshop with the Technical Work Group (TWG) during 2007. The purpose of the 2007 workshop is to ensure that stakeholder information needs related to sediment resources are specifically considered during planning for future monitoring. The GCDAMP' approved core monitoring information needs for sediment are summarized in table 2.2.

Of these information needs for sediment, the Science Planning Group recently identified a prioritization for sediment monitoring that identified measurements and modeling estimates of sediment inputs from major tributaries as the most important monitoring activity (see goal 7, this report). The measurement of changes in high-elevation sandbars along the main channel of the ecosystem was the next most important activity. Because retention of tributary sand inputs has been identified by scientists and managers as a precursor for experimental beach/habitat-building flows (BHBF) intended to restore and maintain sandbars, sand export from the upper reaches of the ecosystem is also a monitoring priority in support of research aimed at evaluating sediment triggers for future high-flow tests.

Owing to the fact that fine-sediment deposits (beaches within eddies) are closely related to the distribution of coarse-grained sediment deposits (tributary debris fans), core monitoring for changes in gravel deposits is also needed at decade-scale periods to fully evaluate changes in sand beaches, whitewater rapids, and related geomorphic settings and habitats.

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

Core Monitoring activities related to coarse sediment in the ecosystem are to be determined during FY07, following external peer review and report on recommendations from the SEDS-PEP panel meeting (August 2006). Future core monitoring efforts for both fine and coarse-grained sediment deposits shall be planned on the basis of: managers' core information needs (table 2.2), results from recent research and development (2000–6 study results), external peer review, and planning with the Technical Work Group.

Over 700 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

Environment	Discharge range	Goal 8 Core Monitoring Information Need(s)	
Tributaries	N/A	Monthly sand and silt/clay input volumes and grain-size characteristics from the Paria and Little Colorado Rivers and other major tributaries like Kanab and Havasu creeks, and "lesser" tributaries	
Main channel	< 5,000	Biennial fine-sediment volume and grain-size changes by reach	Monthly sand and silt/clay loads and grain-size characteristics at Lees Ferry, lower Marble Canyon, Grand Canyon, and Diamond Creek
Channel margins (not eddies)	5,000 – 25,000	Biennial sandbar area, volume and grain-size changes by reach	
Eddies	< 5,000	Biennial sandbar area, volume and grain-size changes by reach	
	5,000 – 25,000	Annual sandbar area, volume and grain-size changes by reach	
	> 25,000	Biennial sandbar area, volume and grain-size changes by reach	
Throughout the CR ecosystem	N/A	Changes in coarse sediment (> 2 mm) abundance and distribution	

Table 2.2 Overview of core monitoring information needs related to GCDAMP goal 8.

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 shall be conducted on a systemwide basis through the use of remotely sensed imagery once during 2007–11, using imagery obtained in 2005 and 2009. Additional field activities may be scheduled for purposes of ground truthing in support of change detection. In the event of larger tributary debris flows that significantly alter navigational characteristics of the main channel, additional field activities may needed on a contingency basis. Monitoring data from this project shall be reported to managers at biennial science symposia and TWG meetings (on a period basis) and will be available for integration into other resource area efforts, such as food web, cultural/recreational, and fisheries projects.

Research and Development Activities

Development of Core Monitoring Protocols for Sediment

From 2000 through 2006, research and development efforts were proposed, funded competitively through solicitations, and completed by a consortium of sediment scientists from the U.S. Geological Survey, Northern Arizona University and Utah State University. The results of these long-term studies were reviewed in summer 2006 by an expert panel of sediment scientists who were charged with evaluating the results of the studies, as well as developing science-based recommendations for what protocols are appropriate for use in core monitoring of sandbar changes throughout the CRE. Additionally, the review panel also critically evaluated the results of a major sediment modeling initiative programmed by the GCMRC between 2001 and 2006. While the sediment protocols evaluation panel's (SED-PEP) draft report includes recommendations for additional research studies and focused evaluations, the main goal of the GCMRC is to incorporate the panel's review recommendations into a core monitoring plan for goal 8 (sediment) information needs in FY08 and beyond. The proposed schedule for core monitoring is likely to be tied to a biennial strategy of field measurements, as well as change-detection mapping and evaluation tied to airborne remote-sensing overflights (digital imagery) collected once every 4 years. The next such mission is proposed in FY09.

Strategy for Ongoing Development of Sediment Transport Models

Initial written comments received from the 2006 SED-PEP related to proposed FY07 modeling activities indicate the need for additional testing and review of the sand transport modeling project. This former research project (2002–6), funded through competitive solicitation in FY01, was focused on simulating the short-term (i.e., weeks to months) fate of tributary inputs using a pseudo-one-dimensional model, as well as modeling the effects of single BHBF on eddy storage. Comments from the SED-PEP indicate substantial concern regarding the adequacy of the existing sediment transport models for the Colorado River ecosystem. Therefore, the original FY07 modeling work plan (referred to in goal 7, this report) has undergone modification to include further testing of the models by their developers, as well as additional review. A second important recommendation from the PEP related to sand transport modeling was the need to develop a model for simulating the long-term fate (i.e., years to decades) of sandbar deposits. A long-term model would be an invaluable tool for evaluating various "flow only" alternatives (presumably centered around repeated use of BHBFs) for restoring sandbars over decadal time scales (i.e., answering the strategic sediment question above). Thus, the additional sand transport model review will occur in FY07 in combination with a workshop designed to formulate a strategy for development of this long-term model, which could be implemented in FY08–FY09.

Long-term Experimental Activities

Generally, the experimental science support objective for goal 8 is tied to evaluation of "flow only" options for sandbar restoration and maintenance through use of beach/habitat-building flows. For this reason, in support of the evaluation of experimental flows from Glen Canyon Dam, GCMRC program staff will collect, as need arises, additional sand storage data throughout the main channel of the CRE.

Two specific types of experimental sediment activities are anticipated during the FY08–FY11 period of monitoring and research are described below.

Experimentally Replicate the 2004 Beach/Habitat-Building Flow Test

Sediment research results from the 2004 experimental high flow suggested that short-duration dam releases in the range of 41,000 to 45,000 cfs that are release in the same season or year that significant sand is delivered to the Colorado River by larger tributaries can result in a net positive change in sandbar resources. Following this result, sediment scientists have recommended that replication of the sediment enriched test during winter or spring months could answer the question about whether repeated implementation of such releases following sediment inputs might be a sustainable means of restoration and maintenance of sandbars and related ecosystem habitats. The logic associated with such an experimental strategy for sandbar restoration is shown in fig. 2.1.

In the event that results from a repeat of the sediment test conducted in 2004 (similar with respect to sand enrichment regardless of seasonal timing) are not net positive, then future tests might need to occur when more highly constrained dam

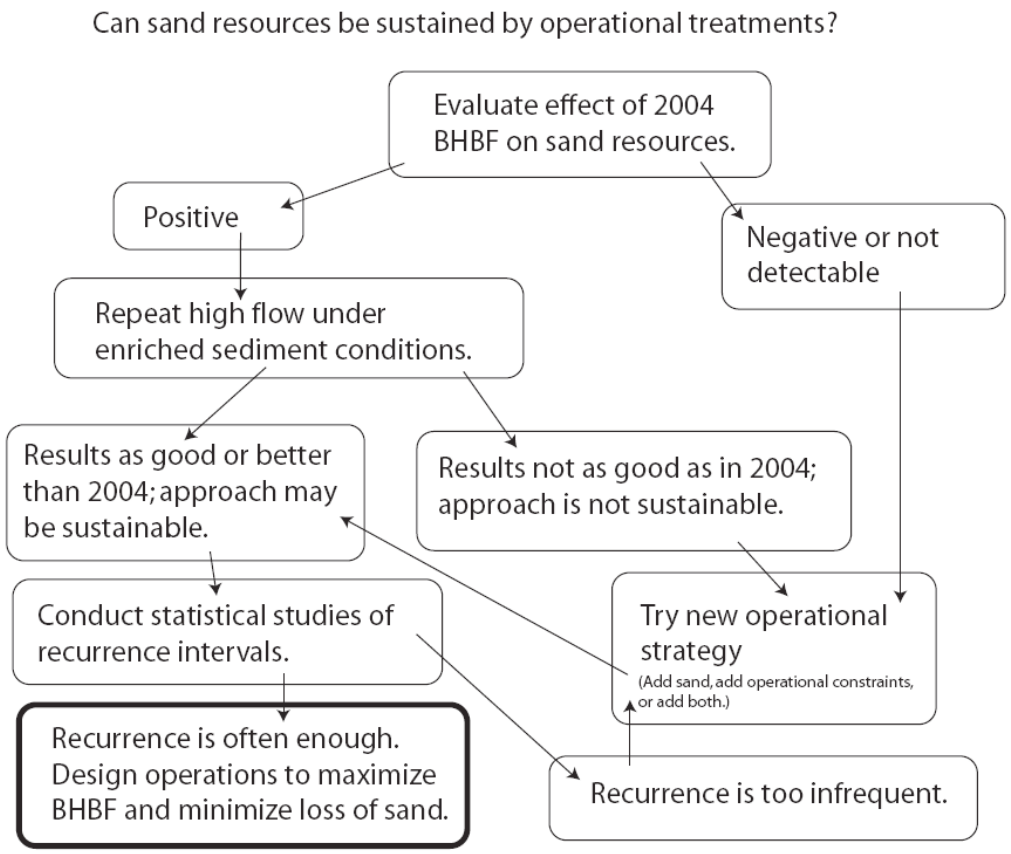

Figure 2.1 Flow chart showing the proposed experimental strategy for evaluating whether a "flow only" operational strategy for restoration and maintenance of sand bars below Glen Canyon Dam can be successfully implemented through repeated implementation of beach/habitat-building flows during years when tributaries produce average to above-average sand inputs to the Colorado River ecosystem.

releases allow downstream tributary sand inputs to accumulate over time or when sand can be imported from upstream sources (or perhaps some combination of both).

The strategy of attempting to replicate the net positive sand mass balance documented as the result of the 2004 high flow experiment is intended to directly answer the primary strategic science question for sediment (SSQ 4.1) listed above. If replication of the 2004 test suggests that the "flow only" operational strategy for sandbar restoration is sustainable through repeated implementation following tributary sand inputs, then additional monitoring and research (perhaps combined with flow and sediment modeling) might be undertaken to determine an optimal recurrence interval for BHBFs that is required to achieve future desired conditions for sandbar resources throughout the ecosystem.

Experimentally Evaluate Alternative Ramping Rates

The stability of sandbars and their fate following BHBFs under patterns of diurnal fluctuating releases is another important topic of concern for the GCDAMP. One of the critical elements of daily fluctuating operations linked with sandbar stability is the hourly rates at which flows are increased and decreased. This operational parameter relates to sandbar stability, particularly with regard to the down-ramp rate of dam releases that affect the rate at which perched water within sandbars is able to drain from beach sands as the river stage drops toward the daily low flow. Alternative ramping rates, particularly increased rates for the down ramping, are therefore identified as a priority for further experimental flow research to determine if down ramping at more than the currently allowed rate of 1,500 cfs/hour significantly increases sandbar erosion rates between episodes of beach building and sandbar restoration.

Data relating to SSQ 4 -1 shall be collected through a focused strategy of monitoring measurements made before and after future BHBFs using methods developed for sandbar monitoring during the 2000–5 era or research and development. Measurements shall focus on areas identified as representative for eddy and sandbar responses within Glen, Marble, and Grand Canyons as reported in recent synthesis research reports. Resolving the answer to strategic science question 4-1, assumes that at least one more sand-enriched BHBF test occurs in the future research period of 2007–11 (to be compared with data from the 2004 high flow experiment).

Data relating to alternative ramping rates could be collected through a focused strategy of experimental field measurements, modeling, and laboratory studies of alternative fluctuating flows during the research period 2008–11. This research represents a return to the types of studies that were conducted during the 1990–94 environmental impact statement era using methods developed for sandbar monitoring during the 2000–5 era or research and development. New methods shall also be used to further refine the information on

how alternative ramping rates and daily stage ranges (relative to the Record of Decision) influence sandbar stability and related habitats below the dam. Sandbar measurements shall focus on areas identified as representative for eddy and sandbar responses within Glen, Marble, and Grand Canyons, as reported in recent synthesis research reports. Ongoing monitoring data on suspended-sediment transport shall also be evaluated to determine how alternative fluctuating flow operations influence downstream sand transport (export).

Integration

Initiated in 2003, monthly integrated science meetings are convened by the GCMRC to explore and identify methods for linking past and present monitoring and research activities to one another. At these meetings, staff and cooperating scientists discuss strategic science questions that have been identified by stakeholders and evaluate monitoring and research progress that is being made by individual projects in the program. Future integration efforts are generally identified and are then considered during the annual science planning process that is conducted jointly between GCMRC Program Managers and the Technical Work Group to develop budgets and work plans.

Another major effort by the GCMRC to better support integrated science activities has been to work within and between individual projects to ensure that databases resulting from the science efforts are documented in terms of metadata as they enter the GCMRC Oracle database. This initiative is an ongoing task of the GCMRC's Data Acquisition, Storage and Analysis (DASA) Program and is intended to allow for integrated analyses of spatial data as integrated studies are identified.

Sand storage monitoring and research efforts shall continue to be integrated into monitoring and research related to recreation camping site areas, terrestrial vegetation, preservation of archaeological sites, and nearshore habitats and substrate distributions related to fish and food web dynamics in the aquatic ecosystem. Most importantly, the changes in sand storage that are measured through monitoring and mapping efforts shall be used to verify results of the fine-sediment mass flux element of the downstream integrated quality-of-water project, as well as to verify sand transport and sandbar modeling results.

Changes in the distribution, abundance and morphology of gravel deposits that are derived from coarse-grained monitoring shall be related to recreational whitewater boating (navigation) experience, terrestrial and aquatic substrate, campsite areas, nearshore habitats (backwaters), as well as the abundance and distribution of sand storage throughout the ecosystem (changes in eddy storage).

An example of an integrated project related to sediment resources is the integrated analysis of mapping shoreline habitat changes project (Project DASA 12.D6.07). During FY07, the GCMRC staff and its science cooperators shall undertake efforts at mapping changes in the distribution and abundance of sandbars and related nearshore habitats throughout the CRE. This effort shall be undertaken as an experimental support activity associated with the collection of May 2005 digital, remotely sensed imagery (systemwide data were also collected in 2002 and 2004) and is directly related to conservation measures identified with the November 2004 high flow experiment.

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

Strategic Science Questions and Information Needs

Maintaining or improving the quality of the recreational experience is a multifaceted and complex goal. For example, dam operations affect a myriad of physical and biological attributes that have direct or indirect effects on river-based recreation, and a specific flow regime may have both positive and negative effects on different attributes of the overall recreation experience. As a result, the Monitoring and Research Plan seeks to address discreet scientific questions, information needs, and objectives required to achieve goal 9.

In 2004, the Adaptive Management Work Group (AMWG) identified several priority questions. Priority 3 relates directly to goal 9:

AMWG Priority 3: What is the best flow regime?

In addition, a number of strategic science questions related to the effects of flows on recreation emerged from the Knowledge Assessment Workshop (KAW) conducted in July 2005. The strategic science questions that emerged from the KAW are primarily targeted at improving our understanding of how flows affect biophysical conditions and social attributes that are important to the quality of recreation experiences in the Colorado River ecosystem (CRE). The most critical strategic science questions that emerged as the focus of monitoring and research activities for goal 9 are the following:

1. **SSQ 3-6.** What GCD operations (ramping rates, daily flow range, etc.) maximize trout fishing opportunities and catchability?
2. **SSQ 3-7.** How do dam controlled flows affect visitors' recreational experiences, and what is/are the optimal flows for maintaining a high quality recreational experience in the CRE?
3. **SSQ 3-8.** What are the drivers for recreational experiences in the CRE, and how important are flows relative to other drivers in shaping recreational experience outcomes?
4. **SSQ 3-9.** How do varying flows positively or negatively affect campsite attributes that are important to visitor experience?
5. **SSQ 3-10.** How can safety and navigability be reliably measured relative to flows?
6. **SSQ 3-11.** How do varying flows positively or negatively affect visitor safety, health, and navigability of the rapids?
7. **SSQ 3-12.** How do varying flows regimes positively or negatively affect group encounter rates, campsite competition, and other social parameters that are known to be important variables of visitor experience?

The GCDAMP identified several core monitoring information needs under each of the five recreation management objectives. The Science Planning Group (SPG) subsequently refined and prioritized the core monitoring information needs (CMINs) for the purposes of defining the most important monitoring needs of each goal in order to allocate future funding. The latter process resulted in the following ranking of CMINs for recreation:

1. **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.
2. **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.
3. **CMIN 9.5.1** Determine and track the frequency and scheduling of research and monitoring activity in Glen and Grand Canyons

4. **CMIN 9.1.2** Determine and track the frequency and scheduling of river-related use patterns.

5. **CMIN 9.2.2** Determine and track accident rates for visitors participating in river-related activities including causes and location (i.e. on-river or off-river), equipment type, operator experience, and other factors of these accidents in the Colorado River ecosystem.

Note: In June 2005, a protocol evaluation panel (PEP) reviewed the entire GCDAMP recreation program and produced a final report (Loomis and others, 2005), which included numerous recommendations for improving GCMRC's recreation monitoring and research program. The recreation PEP recognized that most of the recommended monitoring and research programs had the potential to benefit both the GCDAMP and the National Park Service (NPS) Colorado River Management Plan (CRMP). In addition to the strategic science questions, the recommendations provided in the PEP report form the foundation for the FY07–FY11 recreation program described below.

Monitoring and Research Activities

Monitoring and research activities related to recreation for FY07–FY11 encompass all three elements of the overall Monitoring and Research Plan, including core monitoring, research and development, and experimental activities.

Core Monitoring Activities

Status and Trends in Campsite Area

A key concern of recreational rafters in Grand Canyon is the diminishing number and size of campsites along the Colorado River. In FY07–FY11, The GCMRC will continue to monitor changes in campable area at the Northern Arizona University (NAU) sandbar study sites, while concurrently exploring alternative and additional methods to evaluate changes in campable area throughout the CRE.

FY07–FY11. Sandbar and Campable Area Monitoring (Project REC.9.R1.07)

In FY07–FY11, the GCMRC will continue to monitor campable area at the NAU sandbar study sites, using conventional survey methods as in the past (Kaplinksi and others, 2005), but with more emphasis on differentiating optimal campable area (level and flat sandy areas) from suboptimal campable area (sloping, lightly vegetated, and/or rockier terrain). A major thrust of the FY07–FY11 monitoring program will be to more closely integrate the campable area monitoring work with that of the NAU sandbar monitoring program so that the latter program can inform the former with respect to the effects of changing sandbar area and morphology on campable area.

Concurrently, in FY07, the GCMRC will explore options for using remote-sensing data to evaluate changes in campable area in the future through a focused research and development effort (see Project REC 9.R2.07 and Project REC 9.2.R3.07 below).

Status and Trends in Recreational Angling

A key interest of recreational anglers in lower Glen Canyon is the quality of the rainbow trout fishery (specifically size, number, and health of fish), which is directly related to the available food supply. In FY07–FY11, the condition of the Lees Ferry trout fishery will be monitored through routine stock assessment procedures conducted by Arizona Game and Fish Department (AZGFD) (see goal 4, this report). In addition, the GCMRC proposes to work with AZGFD biologists to upgrade the quality and consistency of angler satisfaction data being collected through intermittent AZGFD-sponsored creel surveys.

In addition to trout condition and numbers, anglers have previously expressed concern about fishing conditions ("fishability") and boating access upstream from Lees Ferry, and they also have concerns about safety issues (primarily for waders and independent shoreline fishermen) because of fluctuating flows. All of these issues have direct relevance to the goal of maintaining a high-quality recreation experience. The role of fluctuating flows in affecting fishability and boater safety will be evaluated as part of the long-term experiment (see discussion under ramping rate experiments), while effects of flows on other recreational experience attributes will be evaluated as part of a focused research effort in FY08–FY09 designed to improve our current understanding about how flows effect recreational experience (see Project 9.R5.08 below).

Research and Development Activities

The 2005 recreation PEP recommended that the GCMRC initiate several foundational research studies to provide a baseline of information against which the effects of future experiments and management actions can be evaluated and compared. Furthermore, they recommended that the GCMRC invest in studies that would provide data that could be used to better predict the effects of experiments and management flows on recreation in lieu of investing in long-term visitor satisfaction monitoring programs. The following research programs will be implemented in FY07–FY11 in response to the 2005 PEP recommendations:

FY07–FY08. Compile Campsite Inventory and GIS Atlas (Project REC 9.R3.07)

The last comprehensive campsite inventory was completed more than 20 years ago after the 1983 uncontrolled release from Glen Canyon Dam. Since that time, many of the camps identified during that survey have fallen into disuse or disappeared entirely because of sandbar changes and vegetation encroachment, while some new ones have emerged. A new inventory is needed to evaluate changes in the CRE during the past two decades and to provide an up-to-date baseline for designing future studies. In FY07–08, an up-to-date inventory and GIS atlas of all previous and currently available campsites in the CRE will be compiled. The atlas will include information on campsite characteristics and attributes that are known to be important to visitors (e.g., physical size, estimated size of group that can be reasonably accommodated, frequency of use, amount of open sand versus vegetation, availability of shade, mooring attributes, etc.). This baseline inventory will define the population of campsites from which samples can be drawn to characterize systemwide changes, and it will serve as a basis for evaluating recreation impacts on other CRE resources of concern such as archaeological sites.

FY07. Evaluate Campable Area Monitoring Results Using Measured Field Data vs. Remotely Sensed Data (Project REC 9.R2.07)

A formal comparison of campable area monitoring results derived through field measurements and GIS-based analysis of remotely sensed imagery and topography will be completed in FY07. A pilot effort conducted in FY05 demonstrated that estimates derived from remotely sensed data consistently over-estimated campable area compared with measurements derived from field surveys; therefore, one desired outcome of the proposed study will be the development of an algorithm to allow future comparisons of previously collected campable area data (derived from field surveys) with future data derived via remotely sensed imagery. Depending on the study results, it may be possible to transition the campable area monitoring program to one based largely, or exclusively, on remotely sensed imagery.

FY07. Compile and Analyze Existing Safety Data (Project REC 9.R4.07)

Using graduate student labor, existing safety data maintained in various NPS databases and in published and unpublished reports will be compiled and evaluated as a prelude to conducting safety and navigability evaluations under experimental flows. This project is targeted for implementation in FY07 contingent on the availability of funding. If funding is not available in FY07, the project will be deferred to FY08.

FY08–FY09. Evaluate the Relative Importance of and Trade-offs to Recreation-related Attributes Affected by Flows on Recreation Experience (Project: REC 9.R5.08)

The quality of a recreation experience is determined by multiple interacting physical, biological, and social factors, many of which are affected by flows (e.g., the size, quality and distribution of campsites; the size, navigability, and "thrill-factor" of the rapids; the rate of boat movement down river with consequent implications for social encounters and crowding; and the size, abundance, and condition of rainbow trout). Flows affect these recreational attributes in varying and sometimes conflicting ways. The purpose of this study is to determine the relative importance of the various recreation-related physical, biological, and social attributes and conditions that are affected by flows and to analyze the trade-offs to recreational experience quality that are created by implementing various flow regimes.

FY09. 1973 Weeden Survey Revisited

The 1973 Weeden survey was the first attempt to comprehensively inventory and document campsites in the CRE. This effort produced hundreds of photographs and aerial imagery maps of campsites in the CRE. The NPS is currently working on relocating the photo points used to obtain the images. In FY07–FY08, using CRMP funding and both volunteer and professional photographers, the NPS will duplicate the aerial imagery and related campsite data from the 1973 Weeden survey. In FY09, this data will be integrated into the campsite atlas, and a formal analysis of differences between the photographic images from the Weeden survey and identical images collected in 2007–8 will be undertaken to provide a diachronic perspective on campsites change in the CRE during the past 35+ years.

FY09. Quantify Vegetation Encroachment at Campsites

Vegetation encroachment rates and the relative significance of vegetation encroachment in diminishing campable area will be evaluated by comparing vegetated areas at a stratified sample of heavily used and infrequently used camps using remotely sensed imagery and analyzing these data in a GIS environment.

FY10–FY11. Update Regional Recreation Economic Studies

By FY10, existing economic baseline studies will be 20 to 25 years old (!), so in FY10–FY11, economic valuation studies for CRE-based recreation will be repeated.

Long-term Experimental Activities

Several specific studies will be initiated in conjunction with the experimental flows of FY08–FY11 to evaluate effects of various experimental flows on recreation. These studies will

evaluate effects of beach/habitat-building flows (BHBF) and ramping rate experiments on beach morphology, beach size, and distribution (e.g. campable area), as well as post-BHBF effects to the Lees Ferry trout fishery and angling experience. In addition, GCMRC will partner with NPS to evaluate effects of high, low, steady, and fluctuating flows on human health and safety.

Evaluate Effects of Ramping Rates and BHBFs on Campsites

Changes in campable area within the CRE are the result of a variety of flow-related factors, including changes is sediment deposits, modification of sandbar topography, and vegetation encroachment. This project will focus on evaluating the roles of different ramping rates and effects of BHBFs on these three critical attributes.

Evaluate Effects of BHBFs, Low Steady Flows, and Fluctuating Flows on Navigability and Safety

Safety issues associated with high and low flows and varying ramping rates were a primary concern of the public during the scoping phase of the Glen Canyon Dam environmental impact statement process. This project will build upon previous studies undertaken during past experimental flows to assess how changes in flow volume and ramping rates affect the numbers and types of river-based incidents that potentially affect the safety of recreational anglers and whitewater boaters in the CRE. The proposed safety data compilation study (Project REC.9.R4.07) will provide a foundation for this experimental study.

Evaluate Effects of Steady Flows vs. Fluctuating Flows on Visitor Health

Issues associated with human health were identified by river guides in relation to the low summer steady flows (LSSF) experiment of 2000, when many boating parties in Grand Canyon were affected by a waterborne virus. Although possibly a coincidence, the Norwalk viral outbreak of summer 2000 raised the possibility that certain flow regimes are more conducive to spreading human pathogens than others. This project will evaluate human health risks associated with specific experimental flows. Specifically, the study will attempt to determine if steady flows or highly fluctuating flows have a measurable effect on sanitary conditions at heavily used camping beaches. This project will be implemented through a cooperative partnership with the National Park Service.

Integration

Physical Science Program

Changes in campable area are largely, but not exclusively, because of changes in sandbar area and volume. Other factors that may be contributing to campsite area decline in the CRE include changes in bar morphology (e.g., steeping of slopes under certain flow regimes). To evaluate the role of sandbar morphology in affecting campable area requires comparisons of topographic data derived from the sand storage monitoring program against prior campable area survey results. The sand storage monitoring program will be undergoing a PEP review in FY06, and the definition of future core monitoring protocols for tracking sediment storage in the CRE will be determined on the basis of the PEP review. Although the specific protocols for sand storage monitoring have not been defined, campable area monitoring will continue to rely on and be integrated with data derived from the Physical Science and Modeling Program to a large degree.

In addition, flow-stage modeling based on the improved STARS model will be useful for defining stage relations at camps for which survey data are not currently available. The analysis and storage of campsite data and the creation and maintenance of the GIS atlas will require direct involvement from members of GCMRC's Data Acquisition, Storage, and Analysis Program.

Biological Sciences

Monitoring of trout condition is a critical proxy measurement for angler satisfaction in lower Glen Canyon. GCMRC and AZGFD will work together to define additional angler satisfaction measurements that can be collected through periodic AZGFD creel surveys.

Although sand supply is a critical factor affecting campable area in the CRE, another significant process that may be contributing to campsite loss is vegetation encroachment. Evaluating the role of vegetation encroachment on campable area will require using remotely sensed vegetation data collected during the 2000, 2002, and 2005 remote-sensing missions and the results of the ongoing vegetation mapping effort (Project BIO 6.R1.07) in combination with the data developed for the GIS campsite atlas (Project REC 9.R3.07.)

NPS Colorado River Management Plan

As discussed in the PEP review of the GCDAMP recreation program, there is considerable overlap in information needs for the CRMP and the GCDAMP. However, while closely intertwined, the interests and emphases of these two programs are not identical: the CRMP is primarily focused on evaluating effects of NPS visitor management decisions on river-based visitor experience qualities and associated physical and biological resource values, while the GCDAMP is concerned primarily with monitoring and researching effects of dam operations on CRE resources, including the visitor-use values associated with those resources. The GCDAMP recreation program has historically focused on the effects of dam operations (flows) on physical and biological attributes important to recreation (e.g., camping beaches, trout); although,

multiple reviews of the GCDAMP have identified the need for more emphasis to be placed on social/experiential and economic effects of dam-controlled flows. Also, the geographic scope of the GCDAMP is considerably more restricted than that of the CRMP. The CRMP addresses issues associated with visitor use of side canyons and other attraction sites accessed from the river but located outside the mainstem river corridor, whereas the focus of the GCDAMP is on the Colorado River ecosystem.

The NPS has been allotted $500,000 per year for the next 5 years to design and implement monitoring and research programs relevant to the information needs of the CRMP. To the extent that these programs overlap with those of the GCDAMP, it will be beneficial for the GCMRC and the NPS to develop coordinated, integrated, and jointly funded projects to satisfy multiple needs simultaneously. However, since some CRMP-driven needs for information lie outside the scope of the GCDAMP, not all CRMP funding will apply to resources of mutual concern. Projects that are likely to be jointly funded and co-managed in the next 5 years include the campsite inventory and GIS atlas, the safety data compilation, evaluation of ramping rates and steady flows on visitor health, and the duplication of the Weeden survey photographs.

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

Strategic Science Questions and Information Needs

The third priority question identified by the Adaptive Management Work Group (AMWG) at their August 2004 meeting was: "What are the best flows?" This question has obvious direct implications for hydropower in terms of not only evaluating the best flows from the perspective of optimizing hydropower generation, but also in terms of evaluating the potential costs of implementing flows that optimize benefits to other resources, such as endangered fish and sediment. Power-production capacity and the related economic activities are tied to a range of variables. For this reason, the Monitoring and Research Plan focuses on discrete scientific questions, information needs, and objectives. The 2005 Knowledge Assessment Workshop (KAW) identified two key strategic science questions related to goal 10, which are as follows:

1. **SSQ 3-3.** What are the hydropower replacements costs of the MLFF (annually, since 1996)?

2. **SSQ 3-4.** What are the projected costs associated with the various alternative flow regimes being discussed for future experimental science (as defined in the next phase experimental design)?

The GCDAMP Science Planning Group (SPG) reviewed, revised, and prioritized the core monitoring information needs (CMINs) in the GCDAMP Strategic Plan. The SPG redefined the primary core monitoring information need for goal 10 as follows:

1. **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, maximum flow limit of 25,000 cfs, minimum flow limit of 5,000 cfs).

Monitoring and Research Activities

Core Monitoring Activities

Data on Glen Canyon Dam hydropower generation and opportunity costs under modified low fluctuating flow (MLLF) operations have been identified as information needs by the GCDAMP. These parameters are routinely monitored by the Bureau of Reclamation (Reclamation) and Western Area Power Administration (WAPA), but the data are not readily accessible to most GCDAMP stakeholders. To meet the need for core monitoring information related to power generation and replacement costs, WAPA will provide data on power generation and marketable capacity valuations. These data will be provided to the GCMRC on a daily or monthly basis depending on the parameter. These data will then be made available through the GCMRC Web site.

FY07–FY11 (New). Monitor Power Generation and Market Values Under Current and Future Dam Operations (Project HYD 10.M1.07)

Reclamation tracks hourly hydropower generation capacity and WAPA and its customers track power source availability and market changes on an hourly basis in assessing the need, cost, and accessibility for additional power resources to meet contractual obligations or unanticipated demand. Market pricing, resulting cost of power purchases, and the impact on Basin Fund cash flow are recorded in the WAPA Energy Tracking Database (ISA) and reported monthly. In FY07, the GCMRC will work with Reclamation and WAPA to serve and archive these existing hydropower and replacement-cost data through the GCMRC Web site in order to address this current program information need shortfall.

Long-term Experimental Activities

Experimental flow studies are currently (FY06) being discussed that would evaluate alternative ramping rates and daily fluctuating ranges. These studies would initially focus on the influence of such alternative operations on downstream sandbar stability and related habitats, and eventually on other related ecosystem processes, but effects on costs to power generation capacity must also be considered.

Economic implications of various flow regimes, in terms of energy generation capacity and power replacement costs, are important variables to consider when selecting future flow regimes, yet with few exceptions (e.g., low summer steady flow experiment of 2000), independent, peer-reviewed data and analyses on costs and revenues associated with various dam operations have not been readily available for the GCDAMP to factor into their recommendations to Department of the Interior.

In preparation to conducting future experimental flows, an economic analysis of predicted hydropower opportunity costs under various alternative experimental scenarios is being undertaken in FY06. This study will evaluate the economic implications of various experimental flows being considered by the GCDAMP in terms of energy generation capacity and replacement costs. WAPA and Colorado River Energy Distributors Association (CREDA) are providing input on the models and assumptions used to generate the results and will provide the hydropower production cost and power sales data that will be factored into the analyses.

FY10–FY11. Evaluate Economic Implications of Experimental Flows

Once the experiment is initiated, the GCMRC will track costs associated with the approved experiment using the monitoring program described above. The evaluation of economic implications will focus primarily on hydropower replacement costs and associated impacts to the Basin Fund. In FY10–FY11, the GCMRC will conduct an independent analysis to determine whether the predictions were accurate or not, and to determine where and why they may have deviated from expected outcomes.

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

Strategic Science Questions and Information Needs

In August 2004, the Adaptive Management Work Group (AMWG) identified the following questions as the second highest priority of the GCDAMP: "Which cultural resources, including TCPs (traditional cultural properties), are within the Area of Potential Affect from dam operations, which should we treat, and how do we best protect them? What are the status and trends of cultural resources and what are the agents of deterioration?" Since that time, the Bureau of Reclamation (Reclamation) and the National Park Service (NPS) have agreed to develop a treatment plan for 161 archaeological sites of the 323 sites potentially affected by dam operations in the Colorado River ecosystem (CRE). The sites subject to treatment have been determined by NPS to be actively deteriorating because of a variety of impacting agents. With immediate treatment needs now being addressed by Reclamation and NPS, the GCMRC monitoring and research activities will focus on assessing the overall status and trends of cultural resources in the CRE, the relative contributions of the various agents of deterioration in affecting cultural resource condition, and the long-term effectiveness of the implemented treatment measures.

To focus monitoring and research activities for cultural resources even more, the Monitoring and Research Plan is placing its attention on three key strategic science questions, which are as follows:

1. **SSQ 2-1.** Do dam controlled flows increase or decrease rates of erosion at arch sites and TCP sites, and if so, how?

2. **SSQ 2-2.** How do flows impact Old High Water zone terraces in the CRE, and what kinds of important information about the historical ecology and human history of the CRE are being lost due toongoing erosion of the Holocene sedimentary deposits?

3. **SSQ 2-3.** If flows contribute to arch site/TCP erosion, what are the optimal flows for minimizing impacts to these cultural resources?

4. **SSQ 2-4.** How effective are various treatments (e.g., check dams, vegetation management, etc.) in slowing rates of erosion at archaeological sites over the long term?

5. **SSQ 2-7.** Are dam controlled flows affecting TCPs and other tribally-valued resources in the CRE, and if so, in what respects are they being affected, and are those effects considered positive or negative by the tribes who value these resources?

The GCDAMP also identified several core monitoring information needs (CMINs) under goal 11. The GCDAMP Science Planning Group (SPG) subsequently refined and prioritized the CMINs for cultural resources for the purposes of defining the most important monitoring needs under each GCDAMP goal in order to allocate future funding. The latter process resulted in the following ranking of CMINS for cultural resources:

1. **CMIN 11.1.1 (SPG revised)** 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. Determine the condition and integrity of TCPs in the Colorado River ecosystem.

2. **CMIN 11.2.1 (SPG revised).** Determine the condition of traditionally important resources and locations using tribal perspectives and values.

Monitoring and Research Activities

Core Monitoring Activities

Past research indicates that dam-controlled flows influence archaeological site condition in a variety of ways. Several hypotheses have been advanced to account for the role of dam operations in archaeological site degradation, but these hypotheses require further research, testing, and refinement. Understanding if and how cultural site condition is affected by dam-controlled flows is important to achieving the stated goals of the GCDAMP and Grand Canyon Protection Act. Because the condition of archaeological sites and other place-based cultural resources is inevitably a product of multiple interacting processes, determining the agents of degradation requires improving our understanding of the full suite of agents affecting cultural resource condition in the CRE (e.g., climate and weather events, human behavior, geomorphic and biotic processes), in addition to conducting additional focused research on direct, indirect, and interactive effects of flow regimes. To partially address this need, in FY06 the GCMRC initiated a multiyear, multifaceted archaeological site monitoring research and development project that will continue during the first years of this MRP. This work will be supported by compilation and analysis of existing archaeological site legacy data in FY06–FY07.

At a minimum, a better understanding of how dam-controlled flows affect erosion rates at cultural sites is needed. This need can be met by designing and implementing monitoring protocols that directly measure physical change at repetitive intervals and through integrating relevant data from other program areas, such as the physical sciences (e.g., flow-stage modeling, sandbar monitoring) and biological sciences (e.g., terrestrial vegetation monitoring) programs.

To date, very little research has been focused on evaluating how dam operations affect TCPs or other cultural resources besides archaeological sites. In addition to site-specific cultural resources, the Native American tribes who participate in the GCDAMP are concerned about how dam operations may affect traditionally valued terrestrial plants and animals in the CRE. Like the place-based cultural resources, culturally important biological resources are affected by dam-controlled flows both directly and indirectly. Direct effects include periodic inundation and flow-induced scouring and disturbance that prune older plants, induce new growth, open up areas for colonization, impact the characteristics of habitats used by various fauna, and redistribute seeds and nutrients. Direct effects also include the consequences related to timing and frequency of such inundation and flow-induced disturbance events. Indirect effects include changes to the sediment substrate from flows, changes to the water table and consequent effects to old high water-zone vegetation (e.g., mesquite), and long-term changes in species composition and abundance because of the timing, frequency and discharge level of dam-controlled flows. Presumably, monitoring and evaluating the effects of flows on culturally significant plants and animals can be most efficiently and effectively achieved by more closely integrating cultural resource monitoring objectives with physical and biological program elements of the science program. In FY06, the tribes are being funded to synthesize their existing monitoring data and define specific approaches to monitor culturally important resources in the CRE. In FY07 or FY08, the tribes will implement their proposed monitoring programs on a pilot basis (Project CUL 11.R2.07). The results of these and other pilot cultural resource monitoring projects will subsequently be evaluated by a cultural resource protocol evaluation panel (PEP) in FY10.

As noted above, core monitoring programs are currently under development (see discussion under research and development activities section below). The plan calls for implementation of revised core monitoring protocols for cultural resources for a 3-year pilot program in FY08–FY10, followed by a cultural protocol evaluation panel in FY10.

FY10 (New). Cultural Protocol Evaluation Panel Review

Following completion of research and development for core monitoring and effects monitoring and completion of a 3-year pilot monitoring program, a follow-up PEP review of the cultural program will be conducted to evaluate changes made to the program since the 2000 cultural PEP and evaluate the results of research and development work in FY06–FY10. Based on the findings of the second PEP, or Cultural PEP II, a refined core monitoring program will be implemented beginning in FY11.

Research and Development Activities

In FY07, the GCMRC will continue several research and development activities initiated in FY06 to evaluate the most appropriate core monitoring indicators and protocols for tracking archaeological site condition and the effectiveness of erosion-control treatments through time. Since erosion of archaeological sites is tied directly and indirectly to dam presence and dam operations, considerable effort will be devoted to refining methods for measuring and tracking erosion. However, erosion is only one of several factors affecting resource condition, so the evaluation of other indicators, such as human disturbance indicators and weather parameters, will also be pursued.

FY06–FY07. Research and Development Toward Core Monitoring (Project CUL.11.R1.07)

The project involves the following three tasks (for more detail, see project description in the FY07 Annual Work Plan):

1. **Task 1: Assessment of Archaeological Sites for Future Monitoring.** Continue geomorphic and archaeological integrity assessments initiated in FY06 at a subset of

archaeological sites in the CRE to define most appropriate protocols for future monitoring

2. **Task 2: Continue evaluations of existing legacy monitoring data.** The emphasis will be on evaluating the accuracy, consistency, redundancy, and statistical value of existing monitoring data. In FY07, we will also focus on defining appropriate applications for the existing data (e.g., attempt to utilize existing monitoring data to detect trends in site condition relative to dam operations) and evaluate utility and limitations of other legacy data, particularly the extensive photographic record that has been compiled by the NPS over the past 15+ years

3. **Task 3: Continue to evaluate monitoring protocols for quantifying geomorphic change.** This study component will compare and contrast alternative methods for measuring erosion/topographic change at a sample of sites. Specifically we will evaluate the trade-offs involved in using conventional survey methods versus ground-based and airborne LiDAR in terms of field and post-field processing time, efficiency, accuracy, precision, costs, equipment limitations, and short-term and long-term resource impacts. Additional sub-tasks that will be included under this protocol evaluation task are:

    - **FY07–FY08: Refine Protocols for Evaluating Erosion Control Effectiveness.** In addition to refining protocols for core monitoring, in FY07–FY08 the GCMRC proposes to continue evaluating and refining methods for measuring and tracking erosion-control effectiveness at a sample of treated sites. This evaluation process will build on a pilot study initiated by Utah State University under the treatment planning effort in FY06.

    - **FY07–FY08: Test and Refine Weather Monitoring Protocols.** This effort will explore options for monitoring weather parameters using various technologies at a sample of intensively monitored archaeological sites distributed throughout the CRE to meet multiple needs for weather monitoring data related specifically to the cultural resource monitoring program.

    - **FY07–FY08: Pilot Study to Evaluate Terrace Changes Using Remotely Sensed Imagery.** In order to explore the utility of existing remotely sensed imagery for tracking geomorphic change at archaeological sites, in FY07, the GCMRC will initiate a pilot study to evaluate rates of terrace retreat and arroyo erosion using digitized images of historical aerial imagery. This project hinges on completion of an ongoing FY06 internal GCMRC effort to digitize and evaluate the accuracy of historical aerial photographs that are currently stored in hard-copy format at the GCMRC library.

    - **FY07–FY08: Test and Refine Human Impact Monitoring Protocols.** This effort will explore options for tracking and quantifying impacts because of human visitation that result in measurable changes to archaeological site condition. These protocols will be developed in coordination with the NPS Colorado River Management Plan to meet multiple agency needs for human impact data in the CRE.

FY08–FY10. Pilot Integrated Archaeological Site Monitoring and Tribal Resources Monitoring Projects

As noted above, the results of this initial research and development phase will be incorporated into a pilot version of an integrated cultural resource monitoring project that will be implemented in FY08 on a trial basis for a 3-year period. The archaeological site monitoring program is being developed by the GCMRC in collaboration with Reclamation, NPS, Native American tribes, and other GCDAMP stakeholders to meet multiple needs for compliance with Sections 106 and 110 of the National Historic Preservation Act (for both Reclamation and NPS), as well as the mandates of the Grand Canyon Protection Act. In FY06, the tribes are being funded to develop or refine protocols for monitoring TCPs and other tribally valued resources. The tribal monitoring programs are being developed by the individual tribes who value these resources, but, 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. The GCMRC will confer with the Cultural Resources Ad Hoc Group (CRAHG, an ad hoc committee of the GCDAMP Technical Work Group) in developing specific criteria to help guide the site selection process for the long-term monitoring program and the specific protocols to be piloted in FY08–FY10. The specific details of the FY08–FY10 pilot monitoring programs will be determined upon completion of the initial research and development phase at the end of FY07 or early in FY08. This pilot monitoring effort comprises the second phase of research and development towards core monitoring and, as such, will conclude with a protocol evaluation panel review at the end of FY10.

In FY09 and beyond, additional research projects will be initiated to refine our understanding of how flows affect cultural resource sites in the CRE. Identified projects include the following:

FY09–FY10 (New). Expand Pilot Study to Evaluate Geomorphic Changes in the CRE Using Remotely Sensed Imagery

This project will build upon the results of the pilot study initiated in FY07. It will continue to explore the utility of using digitized historical aerial photographs to track and quantify geomorphic changes because of operations of the dam and interacting physical processes, using methods developed in the FY07 pilot effort and applying them to other reaches

of the CRE with high concentrations of culturally significant resources.

FY09–FY10 (New): Geomorphic Model of Archaeological Site Vulnerability

Another important element of the research and development program for cultural resources involves the development of a geomorphic model to help quantify future geomorphic change at archaeological sites under various flow and climatic regimes and evaluate future site vulnerability to erosion. This model will be integrated as a sub-model of the broader CRE conceptual model that is proposed for development in FY08–FY09. Development of the geomorphic model will build on some of the geomorphic and weather data that will be collected through the research and development program for core monitoring and experimental effects monitoring, as well as other data sources (e.g., improved STARS model for stage-discharge relations in the CRE).

Long-term Experimental Activities

Beginning in FY08, the following studies will be initiated in conjunction with experimental flows:

FY08–FY11. Evaluate Effects of BHBF Sediment Deposition at Archaeological Sites and TCPs

This focused study will assess the effects of BHBFs at historic properties in terms of sub-aerial sediment transport rates before and after BHBFs and the effects/rates of retention of flood deposits in arroyo mouths in relation to subsequent erosion at a sample of archaeological sites. This study will partially address SSQ 2-1, SSQ 2-3, and EIN 11.1.1.

FY08–FY11. Evaluate Effects of Steady Flows and Fluctuating Flows (ramping rates) on Archaeological Site Sediment Supply

This study will evaluate how critical sandbars that serve or have the potential to serve as key sediment source areas for archaeological sites change under experimental flows and how the sediment transport rates from these sandbars to the archaeological sites are affected by these changes. This study will partially address SSQ 2-1, SSQ 2-3, and EIN 11.1.1.

FY08–FY11. Test and Refine the Wiele Model

A model recently developed by Wiele and Torrizo (2005) predicts the response of sandbars at several critical archaeological site areas under varying flow and sediment-supply conditions. This study will evaluate the accuracy of the model predictions through comparing predicted deposition at these cultural sites against actual measurements of post-flood deposits. This study will partially address SSQ 2-1, SSQ 2-3, and EIN 11.1.1.

Integration

Archaeological site condition is the product of multiple interacting agents including dam presence, dam operations, human visitation, weather, and various other biological and physical processes. Thus, future monitoring of cultural resource conditions will necessarily rely on data from other GCMRC science programs. It may also require some focused interdisciplinary research for a limited period of time (2–5 years) in order to gather physical and biological data that are relevant to cultural concerns (e.g., tracking weather parameters in proximity to a sample of archaeological sites, measuring erosion rates at intervals that allow for analysis in relation to flow releases from Glen Canyon Dam, relating these data to impacts that are quantified at a sample of cultural sites). Some of these studies are already underway and others are proposed, but increased integration is needed across all program areas.

Physical Sciences

The Physical Science and Modeling Program will continue to track sediment supply and storage in the CRE using methods that will be formalized following the FY06 PEP review with respect to the physical sciences. The interests of the cultural program remain focused on the creation and retention of sandbar deposits above the 25,000 cfs stage, the potential for backfilling of erosional gullies by BHBFs, the quantification of sediment contributions from higher elevations in the CRE to the systemwide sediment budget, and the potential for redistribution of riverine sediments to higher elevation areas where archaeological sites, terrestrial resources, and TCPs are concentrated. The needs of the cultural program for data related to the sub-arial sedimentary deposits and processes in the CRE will be incorporated into the future sediment monitoring program.

Biological Sciences

Vegetation growth and vegetation cover is an important variable affecting erosion rates in the CRE. The development of repeat mapping capabilities using remotely sensed data to quantify vegetation change can also be applied to measuring vegetation change in and around archaeological sites. Once the techniques have been tested and refined, these methods will have utility as a monitoring tool for tracking vegetation changes at cultural sites.

In addition to the implications of vegetation cover for mediating erosion rates at archaeological sites, the Native American tribes who participate in the GCDAMP have interests in monitoring specific vegetation and faunal resources of the CRE because of their traditional cultural values. The tribes will be defining their needs for biological resources monitoring data in FY06–FY07, and a PEP of the terrestrial ecosystem monitoring program will be convened in FY07 to evaluate the

tribal monitoring protocols in conjunction with the terrestrial ecosystem (TEM) monitoring protocols that were piloted in FY02–FY05 by NAU and the University of New Mexico, with the intent of designing one or more monitoring approaches to serve the broad spectrum of interests for TEM data, including those of the Native American tribes.

NPS Colorado River Management Plan

In addition to increasing integration with other GCMRC science programs, there is need for close coordination with relevant monitoring and research programs being developed by Grand Canyon National Park (GRCA) under the auspices of the CRMP implementation effort. In FY06, GRCA is initiating a multiyear research and development effort to improve understanding of the interactive effects of recreational activities on the ecology and condition of natural and cultural resources in the CRE. While not directly focused on improving understanding of dam effects, these research and development efforts can help improve our understanding of dam effects by evaluating the role of visitation in affecting rates and types of deterioration at cultural resources. Previous research in GRCA and elsewhere shows that human visitation can adversely impact cryptobiotic crusts and vegetation cover and can lay the groundwork for future gully erosion through compacting soils and creating linear, compacted trails that channel run-off. Proximity to heavily used recreation sites (e.g., campsites) may be a significant variable in determining rates of archaeological site deterioration in the CRE—perhaps equal to or surpassing the effects of dam operations. However, unless and until recreation data can be compiled and analyzed in a systematic fashion, the relationship between recreation sites and archaeological site deterioration remains unknown. As noted previously under goal 9, the GCMRC proposes to closely coordinate future monitoring and research efforts with those of the NPS to reduce redundancy of effort while simultaneously enhancing our understanding of the interactive roles of recreation, dam operations, and weather in affecting cultural resource condition.

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

Goal 12 includes a variety of activities aimed at maintaining a high-quality science and adaptive management program. These activities transcend Glen Canyon Dam Adaptive Management Program (GCDAMP) goals 1–11 because they are fundamental to addressing priority Adaptive Management Work Group (AMWG) questions and related science questions and information needs. The activities fall into the following 7 categories:

1. Grand Canyon Monitoring and Research Center (GCMRC) staffing
2. Reporting
3. Independent science advice and review
4. Bridging science and management
5. Logistical support
6. Data acquisition, storage, and analysis
7. Administrative and information technology support

GCMRC Staffing

The objective of this activity is to maintain a staff of quality GCMRC managers and scientists to effectively plan, manage, coordinate, and execute an interdisciplinary science program to meet GCDAMP needs and provide high-quality and timely science support to the GCDAMP work groups.

The GCMRC will maintain a core staff of managers to effectively manage and administer GCMRC projects, supervise staff, oversee contracts and cooperative agreements, track budgets, and create a quality work environment. In addition, GCMRC staff will support the GCDAMP by providing timely scientific reports and information to the GCDAMP and assist the AMWG and Technical Work Group (TWG) to develop and implement efficient and effective collaborative management planning and management processes. The GCMRC staff was realigned to establish a Deputy Chief position in FY06 to provide more direct management and supervision of GCMRC activities and to coordinate implementation of the Monitoring and Research Plan, or MRP, within GCMRC.

The GCMRC will include permanent and temporary science and technical staff to implement or coordinate various monitoring and research projects. Contractors and cooperators will be used to conduct a large number of our field work activities and feed the data back to GCMRC scientists for analysis, synthesis, and publication. GCMRC scientists will be engaged in the implementation of field monitoring and research when in-house staff members with the appropriate expertise are available and their use is cost effective. The GCMRC will hold its own proposals to the same level of rigorous external peer review as all others.

Program Planning and Management (Project ADM 12.A2.07)

GCMRC's goal is to deliver a comprehensive ecosystem science program over the next 5 years that is effective in responding to management needs articulated through the GCDAMP and by the Department of the Interior (DOI). Productive, well-qualified personnel are critical to meeting and achieving this goal. In order to provide strong leadership that provides a quality science program that is responsive to the needs of the GCDAMP, the GCMRC will be administered by a core program management staff to direct GCMRC operations and oversee the five major program areas: Physical Sciences and Modeling; Biological Science; Cultural and Socioeconomic; Logistics; and Data Acquisition, Storage, and Analysis. In addition to their program management responsibilities, the Program Managers will also be experts in their respective fields. GCMRC Program Managers and scientific staff will maintain this expertise so they can provide high-quality technical assistance in the form of expert analysis, opinion, and advice to the Chief, TWG, and AMWG, as requested. The Cultural and Sociocultural Program Manager will also functions as the Native American Coordinator. The Program Managers will supervise additional technical and support staff, and act as project leads with their cooperators.

Reporting

The objective of this activity is to provide timely reporting of GCMRC science project accomplishments and findings. The GCMRC will work with contractors and cooperators to publish major results and finding in peer-reviewed journals and proceedings. Final reports and papers will be presented orally to the TWG and AMWG and posted on the GCMRC Web site for ready access by GCDAMP participants and interested parties. In addition, preliminary findings that have significant management implications will be presented to the TWG or appropriate ad hoc work groups before they are published to facilitate timely use of the new scientific findings in the GCDAMP process. Significant findings will also be published as U.S. Geological Survey (USGS) fact sheets or informational products in accordance with USGS policy. The GCMRC will also produce an annual accomplishment report in December of each year that will briefly summarize accomplishments or shortcoming for each project included in the biannual work plan (BWP). The annual accomplishment report will also include recommendations for modifications, as needed. In FY10 and FY11, the GCMRC will update the Knowledge Assessment Report and State of the Colorado River Ecosystem in Grand Canyon (SCORE) report to provide an updated synthesis of science information for use in planning the next phase of science and management activities.

Project Note: Reporting requirements will be subsumed within each project conducted or funded by the GCMRC.

Independent Science Advice and Reviews

The objective of this activity is to ensure that the GCMRC science program is efficient, unbiased, objective, and scientifically sound. To achieve this objective, the Science Advisors will be maintained and used to provide independent scientific oversight and technical advice to ensure that GCMRC science activities are efficient, unbiased, objective, and scientifically sound. The Science Advisors will be used in both a review and advisory capacity during the FY07–FY11 period to evaluate the efficacy and effectiveness of the science program. Using the Science Advisors in an advisory capacity will be closely monitored to ensure that it does not affect their objectivity as an external independent review panel.

The Science Advisors will be managed and operated in accordance with AMWG approved protocols adopted in October 2000. Eight scientists will serve as Science Advisors and an executive secretary will administer, coordinate, and report on their activities. In FY07, the Science Advisors will evaluate the most appropriate opportunities for implementing an integrated ecosystem science and modeling approach into the current science program and invoke greater interdisciplinary approaches in FY08–FY11 science activities. Specifically, by no later than September 2007, the Science Advisors will evaluate opportunities for increased use of integrated ecosystem science paradigms within GCMRC monitoring, research, and experimental activities, including the refinement and use of conceptual and predictive ecosystem models and decision-support tools. The assessment will evaluate improvements in information required by managers on Colorado River ecosystem (CRE) resources, GCMRC staffing, and costs of implementing new ecosystem strategies. The Science Advisors' recommendations will be reviewed by the GCDAMP and implemented as appropriate in FY08–FY11.

In addition to the Science Advisors' reviews, all GCMRC proposals, project-specific work plans, and final reports will be subjected to independent peer review in accordance with the established GCMRC peer-review process.

FY07–FY11. Independent Reviews (Project ADM 12.A4.07)

To increase the efficiency and quality of the science being developed by the GCMRC and used by the AMWG and the Secretary of the Interior, the GCMRC will maintain the established peer-review process. All unsolicited, solicited, or in-house proposals and all draft reports received by the GCMRC will undergo independent, external peer review. Additionally, the Science Advisors will be maintained to provide independent scientific oversight and technical advice to ensure that GCMRC science activities are efficient, unbiased, objective, and scientifically sound.

Bridging Science and Management

The success of the GCDAMP in general and the effective use of scientific information in the adaptive management process in particular are confounded by the following factors:

1. The ability of the GCMRC to design studies that will produce relevant scientific information depends on how well the GCDAMP managers clearly define and agree on resource goals and desired outcomes. This has been a challenge for the GCDAMP because of value-based conflicts and the varying levels of collaborative skills development possessed by GCDAMP stakeholders.

2. To be successful, GCMRC scientists and GCDAMP managers must work together as partners—partners that recognize that they each have distinct but complimentary roles. In some cases, the roles and responsibilities of the various groups and entities involved in the GCDAMP are not well defined, understood, or respected. In other cases, there is a perceived imbalance of power among stakeholders that limits their effectiveness influencing GCDAMP decisions and direction.

3. The success of the GCDAMP is dependent not only on the ability of the GCMRC to produce scientific information that is relevant to management needs, but also upon the effective use of that information by managers in the decision-making process. The challenge for the GCMRC

is to synthesize large amounts of diverse and often highly technical data into a form that is relevant to a decision with implications for multiple resources in different areas and time frames. The challenge for managers is to rely on synthesized information in the decision-making process.

The GCMRC proposes a collaborative strategy among scientists and GCDAMP participants over the next 5 years to improve the effectiveness of the GCDAMP and the use of scientific information. A major element of this strategy will include using the science advisors' review of the GCDAMP to develop an action plan for addressing priority issues, needs, or opportunities related to the effectiveness of the GCDAMP and the use of scientific information in the adaptive management process. Additionally, the feasibility of developing and using decision-support systems will be assessed following the science advisors' evaluation of opportunities for improving interdisciplinary, integrated science in the GCDAMP, which is planned for FY07. In FY08–FY09, the GCMRC will issue a contract to assess the feasibility of using decision-support systems and tools to facilitate the integration and use of scientific data and information in GCDAMP decision-making processes, including resource trade-off analyses, risk assessments, and innovative ways to organize and display data. The feasibility assessment will result in a prioritized implementation plan, schedule, and budget. Recommendations will be implemented in FY09–FY11 in accordance with established budget priorities.

FY07. GCDAMP Effectiveness Workshop (Project PLAN12.P2.07)

In FY06–FY07, the science advisors will conduct a limited review of the effectiveness of the GCDAMP. Results of the review and other information provided by the GCDAMP will be used by the GCMRC as a basis for organizing a 2–3 day workshop to develop an action plan for addressing priority issues, needs, or opportunities related to the effectiveness of the GCDAMP and the use of scientific information in the GCDAMP process. The workshop, which will include GCDAMP participants and national experts in collaboration, partnerships, Native American involvement, and conflict resolution, will occur in early 2007. The workshop will be designed and conducted in cooperation with GCDAMP participants. The GCMRC recommends the establishment of an ad hoc group made up of representatives of the TWG, AMWG, Science Advisors, and the Secretary's Designee to serve as a steering committee for the workshop. The action plan developed through the workshop will be implemented and tested over the 2008–11 program period.

FY07–FY08. Enhancing the Conceptual Ecosystem Model to Identify Critical Ecosystem Interactions and Data Gap (Project PLAN 12.P1.07)

In FY07–FY08, the GCMRC will work with the science advisors to identify and incorporate more robust, integrated ecosystem science approaches into GCMRC's overall program effort. The first step will be to evaluate redesign and expansion of the Colorado River ecosystem conceptual ecosystem model (CEM).

In FY08 and FY09, the GCMRC proposes to recruit a part-time/visiting ecosystem scientist/ecologist to work with GCMRC staff and cooperators to develop and implement an integrated, interdisciplinary ecosystem science program. The primary focus of the visiting scientist will be to integrate the science advisors' recommendations and the results of the CEM exercise into the GCMRC science program.

Logistical Support

Implementation of the GCMRC mission to provide scientific information to the GCDAMP begins with effective coordination of all technical and logistical support of research activities. The objective of this activity is to provide logistical support for field activities that emphasizes safety and cost effectiveness while complying with all permitting requirements with the National Park Service (NPS) and all other Federal, State, and Tribal agencies. The program encompasses the integration of both permitting and logistical operations.

Research projects supported by the GCMRC must acquire required permits in compliance with Federal, State, Tribal, and local agencies in which project activities are conducted. Research activities conducted within Grand Canyon National Park and Glen Canyon National Recreation Area require NPS Research and Collecting Permits and Access Permits for all river launches, backcountry use, overflights, and media (filming) production. All permits acquired for GCMRC-supported projects will be processed and submitted through the NPS Research Coordination and Support Program.

The GCMRC will provide complete logistical support for 30–50 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 will use a variety of motor- and oar-powered boats operated by contracted boat operators. Projects operating in the Glen Canyon reach of the Colorado River (Glen Canyon Dam to Lees Ferry) will be supported by a variety of motor-powered boats operated by GCMRC researchers and contracted boat operators. Additionally, research activities on the Little Colorado River and at other locations outside of Grand Canyon National Park boundaries are supported by helicopter services contracted with the Bureau of Reclamation. Ground-based support for research activities outside of the river corridor are also accomplished with the use of vehicles leased by the GCMRC.

FY07–Fy11. Logistics Base Costs (Project SUP 12.S1.07)

The GCMRC will use government-owned boats and river logistical equipment in conjunction with a contracted vendor who supplies technical and logistical boat operators.

Put-in and take-out transportation is provided through the use of Government Service Administration leased vehicles and contracted shuttle drivers.

Effective communication with principal investigators and sensitivity to and awareness of the challenges they face in implementing their studies enable the GCMRC to offer more customized (and therefore more cost effective and productive) logistical support than other support strategies used previously. Retaining control over the process of supporting trips also facilitates compliance with NPS and other regulations and allows greater control over issues sensitive to the general public and the "recreational river community."

The logistics budget will be distributed to GCMRC 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, including salaries, equipment replacement, and permitting costs.

Data Acquisition, Storage, and Analysis

The objective of the Data Acquisition, Storage, and Analysis (DASA) Program is to provide timely support for the acquisition, archiving, retrieval, analysis, and modeling of all scientific data sets and reports. These activities support most of the scientific projects undertaken by the GCMRC, making them a critical support function for advancing the 12 GCDAMP goals.

FY07–FY11. Preparation for Monitoring Data Acquisition (remote sensing) (Project DASA 12.D1.07)

This project provides multispectral digital images used for detecting macro-scale changes in habitat conditions throughout the Colorado River corridor below Glen Canyon Dam. These data are fundamental inputs to many of the GCMRC scientific studies and models used for spatial analysis and change detection. Quadrennial overflights are proposed as a broad strategy for the long-term monitoring program because gathering data through overflights at 4-year intervals balances budget constraints with the need to detect longer term (decade-scale) resource trends. The next planned over flight is scheduled to occur in FY09; the last overflight was conducted in May 2005.

FY07–11. Grand Canyon Integrated Oracle Database Management System (Project DASA 12.D2.07)

This project establishes an electronic repository for project data and the tools necessary to analyze and interpret this data, providing a fundamental support service to GCMRC scientific investigations and decision-support processes. Working with data stewards from each scientific program at GCMRC, the integrated database will be designed to accommodate both newly collected and existing data. Developing the integrated database design also involves extensive review of existing data sets and current data collection protocols. Tools, including Web-based interfaces, will be developed that enable users to extract related data sets and perform appropriate analyses.

FY07–FY11. Library Operations (Project DASA 12.D3.07)

The GCMRC library acts as the physical repository for reports and data generated by GCMRC scientists and cooperators. The library also acquires and makes available resources related to the Colorado River, Grand Canyon, and adaptive management. In order to facilitate the use of the materials maintained by the library, a searchable catalogue of library holdings is available through the GCMRC Web site. The Web-based catalogue also provides links to downloadable versions of project reports and other materials. Library staff are available to assist with research needs and the acquisition of materials needed to support monitoring and research activities. The library is available to the general public.

FY07–FY11. Legacy Analog Data Conversion (Analog to Digital – Reports and Imagery) (Project DASA 12.D4.07)

Through this project GCMRC staff will convert all materials in the library to digital format and make them available from the GCMRC Web site. A major emphasis of this effort is the conversion of analog overflight images to digital images to extend the historical information available for targeted resources, including sandbars, backwaters, and vegetation. The objective of the project is to make the specialized materials maintained by the GCMRC library easily available to users outside of Flagstaff, Ariz., and to protect unique items from damage or loss.

FY07–FY11. GIS General Support for Integrated Analyses and Projects, GIS Lead (Project DASA 12.D5.07)

The objective of the project is to support science program activities through spatial database development, programming, and analysis. As most GCMRC projects have a spatial component to them, GIS provides a means by which data collected in the CRE can be catalogued within a consistent spatial reference system. At the most basic level, this allows for the overlaying and querying of data sets collected from any and all projects within the GCMRC. The project will also provide a higher level of support for specific GIS application development and analysis. Services provided by the project include the creation of maps suitable for publications; design and printing of maps and graphics for posters; creation of improved base maps for Lake Powell and Grand Canyon; instructional sessions for staff, cooperators, and contractors on GIS layer development, integration and analysis; and advanced spatial analysis for monitoring projects.

FY07–FY11. Integrated Analysis and Modeling – Mapping Shoreline Habitat Changes (Project DASA 12.D6.07)

The main objective of the project is to study the shoreline environment along the Colorado River downstream of Glen Canyon Dam. As a result, the project will analyze multiyear multispectral digital imagery. A baseline data set of shoreline

habitat currently exists as a linear classification of six habitat types at 8,000 cfs for the year 2000. Three other remote sensing data sets exist for 2002–5 that will be used to extend the time series of the shoreline habitat for a 5-year period. Additionally, a need exists to expand this classification into higher stages (above 8,000 cfs up to at least 45,000 cfs) in an effort to better correlate shoreline habitat with fish data and recreation habitat data also collected by the GCMRC and its cooperators. The original classification scheme for the shoreline will be extended to include backwater habitats, providing an update to the existing backwater data set (developed by Utah State University) up to the year 2005 (Goeking and others, 2003). In addition to the classification effort, an automated suite of methods could be developed to facilitate shoreline change detection across a range of stages.

FY07–FY11. Survey Operations (Project SUP 12.S2.07)

All spatial data collected under the direction of the GCMRC requires referencing to the primary geodetic control network established by the National Geodetic Survey (NGS) and the GCMRC. The geodetic control network is the framework for the GIS. The primary network has been expanded to secondary and tertiary levels of control within the CRE in reaches of monitoring and research activities. Consistent methods and protocols have been developed and implemented for spatial data collection and its integration into the GIS. The trained GCMRC survey staff supports monitoring and research activities by collecting survey data with these protocols, and by delivering the data in the formats consistent with data standards.

FY07–FY11. Control Network (Project SUP 12.S3.07)

The objective of this project is to develop a high-precision control network throughout the CRE. Control monuments will be established at consistent intervals throughout the CRE and at locations required for accurate positions and elevations of past, current, and future data sets. The goal of the project is the expansion of the control network into the necessary areas before spatial data collection required by GCMRC research and core monitoring activities. Having stable control monuments and accurate coordinates completed before spatial data acquisition begins allows for reduction in the effort required in post-processing methods, and conservation of both human and funding resources. Historical data sets are accurately rectified for integration into the database.

Administrative and Information Technology Support

The objective of this activity is to provide a smooth running, transparent administrative operation that enables GCMRC scientists to focus on their research rather than on the administrative details. The Southwest Biological Science Center (SBSC) provides the oversight and management of facilities, burden and overhead; personnel issues; expenditure tracking; processing of and financial management of cooperative and interagency agreements; processing of contracts; timekeeping; bank card tracking and reconciliation; travel plans and voucher processing; and liaison activities among the USGS administrative groups (Western Region Budget and Fiscal Services and Contracting Offices, Headquarters in Reston, and the Biological Headquarters). In addition, this activity is innately involved with the USGS nationwide budget-tracking and reporting system known as BASIS+, which is used by the USGS Headquarters and Regional offices to make their annual reports to Congress and to respond to congressional inquiries with turnaround times as short as 12 hours. In addition, the SBSC Information Technology Department supports a variety of technology needs for various GCMRC program areas.

FY07–FY11. Administrative Operations (Project ADM 12.A1.07)

The goals of the project are to provide budgetary oversight and support to the Chief, Program Managers, and all employees of GCMRC so that they may conduct their responsibilities in the most ethical, professional, and efficient manner possible; to enable the employees to be unburdened, to the largest extent possible, by mundane administrative matters; and to support the USGS and the GCMRC missions of conducting unbiased scientific research.

GCMRC Component of SBSC Systems Administration Support (Project ADM 12.A5.07)

The Southwest Biological Science Center through its Information Technology (IT) Department supports a variety of technology needs for the GCMRC, including computer security, systems administration, procurement of new servers and computers, and Web site development and maintenance. The goal of the IT Department is to ensure that the GCMRC is able to conduct scientific and administrative functions smoothly and with the least amount of disruption in service as possible. These support, development, and maintenance services are cost shared between the GCMRC and the SBSC. The IT Department also maintains the security of GCMRC and SBSC networks up to current Federal standards and ensures all those who access the systems meet Federal security standards in order to protect personal information and scientific research that has not yet been released to the public. At the same time, the IT Department works in coordination with DASA to provide full and easy access to publicly released data via the GCMRC Web sites.

FY07–FY11. AMWG/TWG Participation (Project ADM 12.A3.07)

The goal of this project is to create an account to hold and track funds for the travel expenses of employees who participate in AMWG and TWG meetings.

CHAPTER 3. Funding for Proposed FY07–FY11 Monitoring and Research Plan

Table 3.1 identifies the total anticipated funding to support GCMRC monitoring and research activities related to the GCDAMP, including anticipated power revenues, continued Bureau of Reclamation (Reclamation) funding for Lake Powell monitoring, and anticipated U.S. Geological Survey (USGS) appropriations to support the GCDAMP activities. In general, funding priorities will be established in cooperation with the GCDAMP based on the guidance included in the final GCRMC Strategic Science Plan and Monitoring and Research Plan. Funding emphasis will be given to address the strategic science questions associated with priority AMWG questions and information needs (Appendix A). Specific funding priorities will be established through the Biannual Work Plan planning process.

To respond to expanding science needs, the GCMRC will work with the AMWG and the Secretary's Designee to (1) develop greater support from the Secretary of the Interior and Congress to maintain existing budgets and to expand budgets to meet critical needs that cannot be addressed within current budget constraints and (2) explore cooperative partnerships with GCDAMP agencies and others to address critical monitoring and research needs. For example, GCMRC will work with the Department of Interior (DOI) and Reclamation to secure the additional funds to assist with evaluating and testing of a temperature control device for Glen Canyon Dam. In addition, GCMRC will work with USGS and the DOI leadership to secure additional base funding to address high-priority monitoring and research needs related to the GCDAMP.

Table 3.1. Total anticipated funding to support the GCMRC Monitoring and Research Plan in fiscal years 2007 through 2011.

FUNDING SOURCES:	FY 2007	FY 2008	FY 2009	FY 2010	FY 2011	TOTALS:
Power Revenues Under Cap - Estimated USGS Portion[1]	8,094,034	8,336,855	8,586,961	8,844,569	9,109,907	42,972,326
USGS Appropriations - Assistance with Burden Costs (Cost Share)	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000	5,000,000
USGS Appropriations - Assistance for scientific research outside of but related to GCDAMP goals and activities[2]	0	1,000,000	1,000,000	1,000,000	1,000,000	4,000,000
BOR Operations & Maintenance (Water Quality Lake Powell & Tailwaters Agreement)[1]	226,659	233,459	240,463	247,676	255,107	1,203,364
TOTAL AVAILABLE FUNDS:	**9,320,693**	**10,570,314**	**10,827,424**	**11,092,245**	**11,365,014**	**53,175,690**

[1] Fiscal Year cost increases estimated at an average CPI increase of 3% per historical application used by the Bureau of Reclamation.

[2] This additional appropriated funding has been requested but has not yet been approved.

[3] Tribal Participation Funding is not included in this table.

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APPENDIX A. AMWG Priorities and Associated Strategic Science Questions from the GCMRC Strategic Science Plan

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)

Key Strategic Science Questions

1. To what extent are adult populations of native fish controlled by production of young fish from tributaries, spawning and incubation in the main stem, survival of young-of-year (YoY) and juvenile stages in the main stem, or by changes in growth and maturation in the adult population as influenced by main stem conditions? [FY06–FY11]

2. Does a decrease in the abundance of rainbow trout and other cold and warm water non-natives in Marble and eastern Grand Canyons result in an improvement in the recruitment rate of juvenile humpback chub to the adult population? [FY06–FY11]

3. Do rainbow trout immigrate from Glen to Marble and eastern Grand Canyons, and, if so, during what life stages? To what extent do Glen Canyon immigrants support the population in Marble and eastern Grand Canyons? [FY07–FY11]

4. Can long-term decreases in abundance rainbow trout in Marble and eastern Grand Canyons be sustained with a reduced level of effort of mechanical removal or will re-colonization from tributaries and from downstream and upstream of the removal reach require that mechanical removal be an ongoing management action? This question also applies to future removal programs targeting other nonnative species. [FY07–FY11]

5. What are the important pathways, and the rate of flux among them, that link lower trophic levels with fish and how will they link to dam operations? [FY06–FY09]

6. Are trends in the abundance of fish populations, or indicators from fish such as growth, condition, and body composition (e.g., lipids), correlated with patterns in invertebrate flux? [FY06–FY09].

7. Which tributary and mainstem habitats are most important to native fishes and how can these habitats best be made useable and maintained? [FY 08–FY09].

8. How can native and nonnative fishes best be monitored while minimizing impacts from capture and handling or sampling? [FY07–FY11].

AMWG Priority 2: Which cultural resources, including Traditional Cultural Properties (TCP), 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? (GCDAMP Goal 11).

Key Strategic Science Questions

1. Do dam controlled flows affect (increase or decrease) rates of erosion and vegetation growth at archaeological sites and TCP sites, and if so, how? [FY07–FY11]

2. How do flows impact Old High Water Zone terraces in the CRE (where the majority of archaeological sites occur), and what kinds of important information about the historical ecology and human history of the CRE are being lost due to ongoing erosion of the Holocene sedimentary deposits? [FY04–FY11]

3. If dam controlled flows are contributing to (influencing rates of) archaeological site/TCP erosion, what are the optimal flows for minimizing future impacts to historic properties? [FY09–FY11]

4. How effective are various treatments (e.g., check dams, vegetation management, etc.) in slowing rates of erosion at archaeological sites over the long term? [FY06–FY11]

5. What are the TCPs in the CRE, and where are they located? [FY06–FY11]

6. How can tribal values/data/analyses be appropriately incorporated into a science-driven adaptive management process in order to evaluate the effects of flow operations and management actions on TCPs? [FY06–FY08]

7. Are dam controlled flows affecting TCPs and other tribally-valued resources in the CRE, and, if so, in what respects are they being affected, and are those effects considered positive or negative by the tribes who value these resources? [FY06–FY11]

AMWG Priority 3: What is the best flow regime? (GCDAMP Goals 1-11)

Key Strategic Science Questions

1. Is there a "Flow-Only" operation (i.e. a strategy for dam releases, including managing tributary inputs with BHBFs, without sediment augmentation) that will restore and maintain sandbar habitats over decadal time scales? [FY08–FY11]

2. To what extent could predation impacts by nonnative fish be mitigated by higher turbidities or dam controlled high flow releases? [FY07–FY08]

3. What are the hydropower replacements costs of the Modified Low Fluctuating Flow (MLFF) (annually, since 1996)? [FY07–FY08]

4. What are the projected hydropower costs associated with the various alternative flow regimes being discussed for future experimental science (as defined in the next phase experimental design)? [FY06–FY07]

5. How is invertebrate flux affected by water quality (e.g., temperature, nutrient concentrations, turbidity) and dam operations? [FY06–FY09]

6. What GCD operations (ramping rates, daily flow range, etc.) maximize trout fishing opportunities and catchability? [FY07–FY08]

7. How do dam controlled flows affect visitors' recreational experiences, and what is/are the optimal flows for maintaining a high quality recreational experience in the CRE? [FY07–FY08]

8. What are the drivers for recreational experiences in the CRE, and how important are flows relative to other drivers in shaping recreational experience outcomes? [FY07–FY09]

9. How do varying flows positively or negatively affect campsite attributes that are important to visitor experience? [FY09–FY11]

10. How can safety and navigability be reliably measured relative to flows? [FY07–FY08]

11. How do varying flows positively or negatively affect visitor safety, health, and navigability of the rapids? [FY07–FY09]

12. How do varying flows regimes positively or negatively affect group encounter rates, campsite competition, and other social parameters that are known to be important variables of visitor experience? [FY07–FY09]

AMWG Priority 4: What is the impact of sediment loss and what should we do about it? (GCDAMP Goal 8)

Key Strategic Science Questions

1. Is there a "Flow-Only" operation (i.e. a strategy for dam releases, including managing tributary inputs with BHBFs, without sediment augmentation) that will restore and maintain sandbar habitats over decadal time scales? (FY 08–FY11)

2. How important are backwaters and vegetated shoreline habitats to the overall growth and survival of YoY and juvenile native fish? Does the long-term benefit of increasing these habitats outweigh short-term potential costs (displacement and possibly mortality of young humpback chub) associated with high flows? [FY07–FY11]

A**MWG 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? (GCDAMP Goals 1–4 and 7–10)

Strategic Science Questions

1. How do dam release temperatures, flows (average and fluctuating component), meteorology, canyon orientation and geometry, and reach morphology interact to determine mainstem and near shore water temperatures throughout the CRE? [FY06–FY08]

2. How is invertebrate flux affected by water quality (e.g., temperature, nutrient concentrations, turbidity) and dam operations? [FY06–FY08]

3. To what extent do temperature and fluctuations in flow limit spawning and incubation success for native fish? [FY03–FY08]

4. What is the relative importance of increased water temperature, shoreline stability, and food availability on the survival and growth of YoY and juvenile native fish? [FY03–FY08]

5. Will increased water temperatures increase the incidence of Asian Tapeworm in humpback chub or the magnitude of infestation, and if so, what is the impact on survival and growth rates? [FY03–FY08]

6. Do the potential benefits of improved rearing habitat (warmer, more stable, more backwater and vegetated shorelines, more food) outweigh negative impacts due to increases in nonnative fish abundance? [FY07–FY11]

7. How do warmer releases affect viability and productivity of native/nonnative vegetation? [FY07–FY11]