Developed in cooperation with the Glen Canyon Dam Adaptive Management Program

Monitoring and Research Plan to Support the Glen Canyon Dam Adaptive Management Program, Fiscal Years 2009–12

Prepared by the USGS Grand Canyon Monitoring and Research Center

TWG Review Draft—October 2008

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

U.S. Department of the Interior
DIRK KEMPTHORNE, Secretary

U.S. Geological Survey
Mark D. Myers, Director

U.S. Geological Survey, Reston, Virginia 2007

For product and ordering information:
World Wide Web: http://www.usgs.gov/pubprod
Telephone: 1-888-ASK-USGS

For more information on the USGS—the Federal source for science about the Earth,
its natural and living resources, natural hazards, and the environment:
World Wide Web: http://www.usgs.gov
Telephone: 1-888-ASK-USGS

Suggested citation:
U.S. Geological Survey, 2007, Monitoring and research plan in support of the Glen Canyon Dam Adaptive Management Program: Flagstaff, Ariz., U.S. Geological Survey, U.S. Geological Survey, Grand Canyon Monitoring and Research Center, 149 p.

CONTENTS

Figures

Tables

Monitoring and Research Plan to Support the Glen Canyon Dam Adaptive Management Program, Fiscal Years 2009–12

Prepared by the USGS Grand Canyon Monitoring and Research Center

Chapter 1. Introduction, Purpose, and Organization

Introduction

The Glen Canyon Dam Adaptive Management Program (GCDAMP) was established in early 1997 by the Secretary of the Interior to implement the Grand Canyon Protection Act of 1992 (GCPA), the 1995 Operation of Glen Canyon Dam Final Environmental Impact Statement (EIS), and the 1996 Record of Decision (ROD). Adaptive management in Grand Canyon was envisioned as a new paradigm to address environmental problems related to the operation of Glen Canyon Dam (GCD) through the dynamic interplay of ecosystem science, collaboration, and management. The GCDAMP consists of five components: 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 25 members, who include representatives from Federal and State resource management agencies, the seven Colorado River Basin States, Native American tribes, environmental groups, recreation interests, and contractors of Federal power from Glen Canyon Dam. The AMWG reviews and develops alternative dam operations and conservation measures and provides recommendations to the Secretary of the Interior in order to fulfill the Department of the Interior's (DOI) obligations under the GCPA.
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, conveys research results to AMWG members, and makes recommendations on budgets and work plans.

4. The **Grand Canyon Monitoring and Research Center** provides credible, objective scientific information on the effects of GCD operation and related natural, cultural, and recreational resources along the Colorado River from GCD to Lake Mead.
5. The **Independent Review Panels** assess program proposals and accomplishments to ensure scientific objectivity and credibility. A group of Science Advisors (SA), academic experts in fields germane to studies within the scope of the GCDAMP, serves as an IRP.

Science Planning Process

Beginning in 1997, a series of workshops to identify a hierarchy of goals, objectives, core-monitoring information needs (CMINs), and research information needs (RINs) were conducted by the AMP. Through this process, the AMWG also specified 12 GCDAMP goals to guide planning, monitoring, and research. However, the list of management objectives eventually grew to more than 40 and 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 and 12 GCDAMP goals to focus science activities. In 2005, to further focus science planning, the GCMRC initiated two knowledge assessment workshops that identified areas of scientific uncertainty and strategic science questions (SSQs) related to the five priority questions.

Science activities articulated in this document, the Monitoring and Research Plan to Support Glen Canyon Dam Adaptive Management Program, Fiscal Years 2009–12 (hereafter MRP) are organized according to the 12 GCDAMP goals. Within each goal, monitoring and research activities are focused on AMWG priority questions and SSQs that grew out of the knowledge assessment workshops (appendix A).

The MRP was developed by the GCMRC in cooperation with the GCDAMP Science Planning Group (SPG) to specify monitoring and research programs consistent with both the GCDAMP Strategic Plan (AMPSP) and the GCMRC Strategic Science Plan (SSP). The AMPSP was drafted by GCDAMP and the GCMRC in August 2001 and refined in 2002-2003. The plan identifies the AMWG's vision and mission, principles, goals, management objectives, information needs, and management actions. The SSP was developed by the GCMRC and GCDAMP and identifies strategies for providing science information that are consistent with the AMPSP and responsive to the goals, management objectives, and priority questions of GCDAMP participants. In addition, the MRP is responsive to the direction provided in the "Final Environmental Assessment: Experimental Releases from Glen Canyon Dam, Arizona, 2008 through 2012" dated February 29, 2008, and the "Final Biological Opinion for the Operation of Glen Canyon Dam" dated February 27, 2008. Major elements of these compliance documents include a March 2008 high flow experiment, a 5-year September-October steady flow experiment beginning in September 2008, a humpback chub nearshore ecology study, humpback chub translocations in the Little Colorado River, and nonnative fish control.

The MRP will be implemented through GCMRC's annual/biennial work plans which will identify the scope, objectives, and budget for the general activities described in the MRP. Projects identified in the FY2009 annual workplan are summarized in the MRP.

The MRP and the FY2009 annual work plan will be the foundation for the development of the FY2010–11 biennial work plan. In addition the following new information which is anticipated to become available in FY2009, will be used to inform the FY2010–11 biennial work plan, including (1) the general core-monitoring plan, (2) a science plan for evaluating the effects

of 2 months of late summer-early fall steady flows on fish recruitment and other high priority resources, and (3) recommendations from the Senior Ecologist and the Science Advisors to improve integrated, interdisciplinary ecosystem science in the GCDAMP Science Program.

The overall GCDAMP science planning and implementation process is depicted in Figure 1. As part of this process several reports will be developed, including:

- Annually, the GCMRC will report on accomplishments related to projects from the previous year's annual/biennial work plan. These annual reports will be used to track progress and inform discussion related to the next year's biennial work plan.
- At 5-year intervals, the GCMRC will synthesize new scientific information in 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. The next SCORE report and KAR will be completed in FY2012.
- The MRP and SSP will be updated within one year following completion of the SCORE report and KAR (FY 2013). As part of the revision, priority information needs and science questions will be evaluated by scientists and managers to determine what program revisions are needed.

As shown in Figure 1, the MRP incorporates information from other resource management agency plans and compliance documents such as the National Park Service (NPS) Colorado River Management Plan (CRMP), the 1993 Humpback Chub Comprehensive Plan, as amended and the February 2008 environmental assessment and biological opinion related to experimental releases from Glen Canyon Dam. The GCMRC will provide science information that is consistent with and supports these plans and compliance documents, as appropriate.

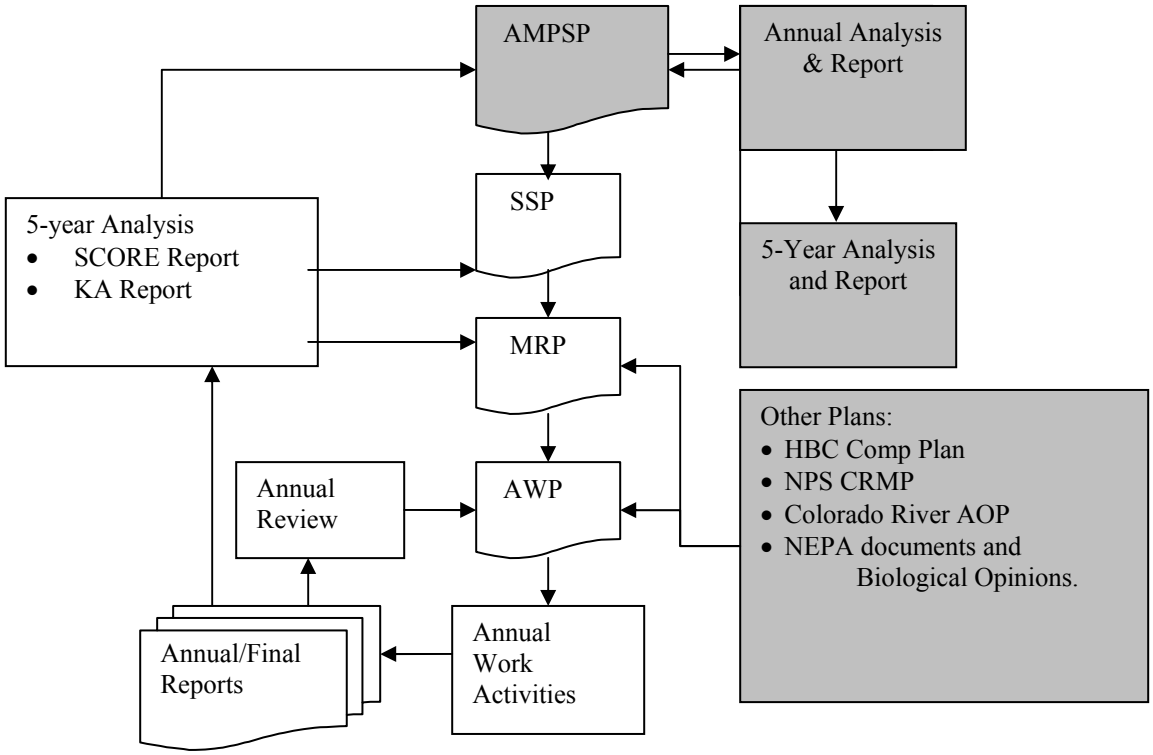

Figure 1. Collaborative science planning and implementation process. The Glen Canyon Dam Adaptive Management Program and the Department of the Interior have lead responsibility for the shaded boxes. The Grand Canyon Monitoring and Research Center has lead responsibility for the boxes that are not shaded. (Key to abbreviations in figure: AMPSP = Adaptive Management Program Strategic Plan; SSP = Strategic Science Plan; MRP = Monitoring and Research Plan; AWP = Annual Work Plan; SCORE = Status of the Colorado River Ecosystem; KA = Knowledge Assessment; HBC Comp Plan = Comprehensive Plan for Humpback Chub; NPS CRMP = Grand Canyon National Park's Colorado River Management Plan; Colorado River AOP = Annual Operating Plan for the Colorado River; NEPA = National Environmental Policy Act.) GCMRC science planning will be done in coordination with and to help inform the GCDAMP's strategic planning. Current science information will be made available to help inform management discussions resulted to priority goals/questions, desired future conditions, and management actions. Concurrent planning is essential to ensure that the science program is aligned with current management priorities.

Purpose

The purpose of the MRP is to describe the scope of a 5-year program of monitoring and research activities to address priority goals, questions, and information needs specified by the GCDAMP and DOI management agencies. The plan will identify specific science needs for FY2009; more general needs will be defined for FY2010–12.

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

- Improving interdisciplinary, integrated river science within the GCDAMP science program
- Building bridges between science and management
- Addressing priority AMWG goals/questions and associated SSQs as articulated in the KAR (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 FY2009–12 related to the 12 goals in the GCDAMP Strategic Plan. Monitoring and research activities are organized into one of three categories:

1. **Core-monitoring activities** are scientifically validated protocols to assess the condition and trend of priority GCDAMP resources (e.g., HBC, sediment, the food base, etc.).
2. **Research and development activities** are projects aimed at (1) addressing hypotheses or information needs related to a priority GCDAMP resource or (2) developing/testing new technologies or monitoring procedures.
3. **Long-term experimental activities** are a suite of flow and nonflow treatments and management actions designed to improve the condition of target resources (e.g., HBC, cultural sites, sediment, etc.) and, through monitoring and research, allow for an understanding of the relationship between treatment/management actions and target resources.

The five priority questions identified by the AMWG and the related SSQs (appendix A) were used to organize monitoring and research activities. The MRP is focused on these priority and science questions. Other GCDAMP goals and information needs will still be pursued, but with less intensity until priority issues of concern are resolved and funds can be reprogrammed or obtained through alternative sources.

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

Core-Monitoring Activities

The GCDAMP Strategic Plan defined core monitoring as follows:

> "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, nonnative control, etc.) affecting target resources" (Bureau of Reclamation, 2001).

The development of a long-term core-monitoring plan for the GCDAMP has been essential since the inception of the program in 1996. However, it has remained an elusive goal for a variety of reasons. First, the systematic development of monitoring programs generally involves a protocol evaluation panel (PEP) for each key resource area; several years of pilot testing of monitoring protocols; a period of analysis, synthesis, and reevaluation; and 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, the aquatic food base, recreation, and fisheries). Other factors have hindered rapid development of a core-monitoring plan, including:

- Lack of agreement among GCDAMP stakeholders about scope, purpose, 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 the effectiveness of experimental or 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 not adopted by the TWG or the AMWG and therefore not finalized. Nevertheless, the PCMP represents the best guidance currently available for the development of core-monitoring projects for FY2009–12.

Current monitoring projects associated with GCDAMP resources will be evaluated by the GCMRC and the TWG. Evaluation of the suitability of projects for core monitoring is critical because these activities have 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 projects will undergo the following technical evaluation process for determining core-monitoring status:

1. **General core-monitoring plan:** In FY2009, the GCMRC will draft a core-monitoring proposal that identifies by resource area the goals, objectives, scope, schedule, and funding for each proposed core-monitoring project. The proposal will be based on AMWG priorities, 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:** The GCMRC will conduct an annual TWG workshop to refine recommendations on 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 questions that managers would like to have addressed in the follow-up PEP 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 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. These reports will provide the TWG with sufficient information to evaluate individual projects. 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 by fiscal year

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, the projects will be reviewed during the development of the biennial work plan to incorporate new findings and monitoring techniques to improve their effectiveness. A more comprehensive review will be conducted at 5-year intervals.

The focus of the evaluation process described above will be to evaluate for core-monitoring status projects that have undergone a PEP evaluation, have been piloted and the

results peer reviewed, and have been implemented for one or more years using methods that are deemed to be adequate for long-term monitoring. Projects in this category and their anticipated review schedule include:

- Downstream surface-water parameters (discharge, stage measurements) and water-quality parameters related to sediment (e.g., suspended-sediment transport measurements and modeling) (FY2007)
- Status of Lees Ferry rainbow trout (RBT) (FY2009)
- Status of HBC in the Little Colorado River (LCR) (to be reviewed by a PEP using data on the Colorado River population) (FY2009)

Because of the commonalities involved in managing for the different fish populations, GCMRC will convene a single PEP for the Grand Canyon fish community in early 2009. Because GCMRC recognizes that there are important differences involved in managing for these two populations, separate recommendations for each species will be sought from the reviewers.

In addition, several monitoring projects that have undergone a 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 resource studies, , are in the initial phase of being developed and pilot tested through multiyear research and development projects. 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 FY2011. The proposed schedule of projects for review is as follows:

- Sand storage monitoring (FY2008)
- Terrestrial ecosystem monitoring (TEM) (FY2009)
- Status of HBC in the mainstem of the Colorado River (to be reviewed through PEP with LCR population) (FY2009)
- Integrated quality-of-water (IQW) monitoring (Lake Powell and downstream parameters, including specific conductivity, dissolved oxygen, and temperature) (FY2010)
- Kanab ambersnail (KAS) habitat and population monitoring (to be scheduled in coordination with USFWS)
- Camping beach monitoring (FY2011)
- Cultural site monitoring (archaeological, traditional cultural properties [TCPs]) (FY2011)
- Aquatic food base monitoring (FY2010–11)

The joint monitoring and management of a recreational fishery near the dam for a native fish community 45 miles (72 km) and more downstream is one of the challenges that GCMRC faces and GCDAMP. To help address this challenge GCMRC will conduct a protocol evaluation panel in FY 2009 directed at all of the fishes of the Colorado River in Grand Canyon. This will incorporate the various fish PEPs shown in the above list in a single PEP that solicits advice from a broad variety of fisheries scientists.

Monitoring of TCPs and tribal values in the Colorado River ecosystem (CRE) is a component of the GCDAMP; however, the GCMRC has faced numerous challenges in integrating tribal perspectives into the core monitoring program. Many of the issues that have hindered integration of tribal perspectives are similar to those of the larger adaptive management program, as previously described. Other confounding issues relate specifically to tribal perceptions about the fundamental nature of ecosystem processes, including the role of supernatural forces in affecting ecosystems processes and "health".

In 2006, the tribes were funded by the GCDAMP to define their monitoring projects, methods, and metrics for evaluating the resources and places of tribal interest in the CRE. These proposed tribal monitoring projects were presented to the TWG for review and discussion in FY2007, and the AMWG subsequently recommended the allocation of funding for future tribal monitoring efforts in FY08 and FY09. Many of the fundamental conflicts between western scientific approaches to monitoring and tribal perspectives about monitoring remain unresolved, however, and it will require continuing dialog between the tribes, GCMRC and non-tribal GCDAMP stakeholders to identify appropriate venues for reviewing, vetting and disseminating the outcomes of the tribal monitoring efforts in the future. In the meantime, the Bureau of Reclamation has established multiyear contracts with four of the tribal stakeholders in the AMP (Hopi, Hualapai, Southern Paiute Consortium, and Zuni) to implement monitoring programs for tribally valued resources in the CRE in accordance with tribe-specific interests and protocols.

Research and Development Activities

Research and development activities include projects aimed at (1) addressing hypotheses or information needs related to a priority GCDAMP resource(s) and (2) developing and testing new technologies or monitoring procedures. Examples of research and development goals 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. Develop integrated downstream flow, temperature, and suspended-sediment models
4. Evaluate quality of historical remote-sensing imagery for change detection
5. Conduct a near shore ecology study to relate river flow variables and ecological attributes of near shore habitats to better understand the relative importance of such habitats to juvenile native and nonnative fishes.

Long-Term Experimental Activities

Long-term experimental activities over the next 5 years will be based upon the direction provided in the "Final Environmental Assessment: Experimental Releases from Glen Canyon Dam, Arizona, 2008 through 2012" dated February 29, 2008, and the "Final Biological Opinion for the Operation of Glen Canyon Dam" dated February 27, 2008. The experimental activities, which will be coordinated with ongoing monitoring and research projects to maximize cost effectiveness include:

- *March 2008 High Flow* – GCMRC will report the results of the High Flow Experiment (HFE) conducted in March 2008. The HFE is aimed at addressing a variety of strategic science questions (Table 1) and restoring sand bars and related backwater habitats in the

Colorado River ecosystem; the experiment will all also address the affects of the high flow on other resources such as rainbow trout, camping beaches, aquatic food base, riparian vegetation, archaeological sites, and Lake Powell water quality. Table 2 summarizes the studies associated with the March 2008 HFE. More detailed descriptions are included in Chapter 2. Additional HFE may be conducted in the 2009-2012 period subject to review by the AMWG and approval by the Secretary of the Interior.

- *Modified Low Fluctuating Flow (MLFF) operations with Steady Flows in September and October (2008-2012)* -- In coordination with the Nearshore Ecology Study (see above), GCMRC will develop and implement a September/October Steady Flow Science Plan for 2008-2012. The science plan will primarily address whether MLFF in combination with the September-October steady flows are likely to improve the survival and recruitment of young humpback chub in the Colorado River ecosystem. The scope of the September/October Steady Flow Science Plan will be determined in coordination with BOR, FWS and the Technical Work Group

- *Nonnative Fish Control* – To address the threat of nonnative fishes on native fish in the Colorado River ecosystem, a nonnative fish control effort will be implemented in FY 2009-2012. GCMRC will prepare a nonnative fish control plan that addresses both cold and warm-water species to guide efforts in control of both cold- and warm-water nonnative fish species in both the mainstem of Marble and Grand canyons and in their tributaries. Assuming dam releases will be cool to cold during the period of the proposed action, control efforts will focus on nonnative trout in the vicinity of the Little Colorado River using mechanical removal and other methods.

Table 1. Strategic science questions from the GCMRC monitoring and research plan (MRP), related HFE science questions, and related HFE experimental studies

Question	Experimental Studies (Table 2)
Sediment and related resources	
MRP strategic science question: Is there a "flow-only" operation that will rebuild and maintain sandbar habitats over decadal timescales?	
High flow science question: How do conditions of suspended sediment concentration and grain size evolve and vary through time and by reach below Glen Canyon Dam during replication of the 2004 hydrograph under more highly enriched sand supply conditions; and how do these data compare with similar data collected at similar locations during the 1996 and 2004 high-flow experiments? Is the net mass balance of sand following the high flow net positive, negative, or neutral?	1.A
High flow science question: What is the minimum duration for high-flow experiments needed to build and maintain sandbars under sand-enriched conditions?	1B
High flow science question: Can the next high flow increase campable areas at sandbars on a sustainable basis?	1.C
High flow science question: Following a high flow, how Record of Decision (ROD) operations under 8.23 million acre-feet annual release volumes affect the persistence of sandbars and related backwaters compared to non-ROD operations that followed the 2004 high flow?	1.D
Humpback chub	
MRP strategic science question: How important are backwaters and vegetated shoreline habitats to the overall growth and survival of young-of-year and juvenile native fish? Does the long-term benefit outweigh short-term potential costs?	
High flow science question: Do high-flow experiments result in creation of backwater habitats that may benefit humpback chub and other native fishes? To what extent are backwater habitats created by a high flow used by humpback chub and other native fishes?	1.D
Cultural resources	
MRP strategic science question: How effective are various treatments in slowing rates of erosion at archaeological sites over the long term?	
High flow science question: Do sandbars deposited by high-flow experiments contribute to preservation of archaeological sites in the river corridor?	1.C
High flow science question: Do high-flow experiments contribute to added stability or erosion of archaeological sites located in close proximity to the river?	1.C

Strategic science questions: What Glen Canyon Dam operations maximize trout fishing opportunities and catchability? Do rainbow trout immigrate from Glen to Marble and eastern Grand Canyons, and if so, during what life stages?	
High flow science question: How will a high flow affect spawning, survival of early life history stages of rainbow trout (BBT) in the Lees Ferry reach? Will a high flow stimulate downstream migration of age-1 RBT?	4.A, 4.B
Strategic science questions: How is invertebrate flux affected by water quality and dam operations?	
High flow science question: How will a future high flow affect food production and availability for rainbow trout in the Lees Ferry reach? What are the effects of high-flow experiments on aquatic food production? How do these effects impact native fishes?	3
Strategic science questions: How is invertebrate flux affected by water quality and dam operations?	

Table 1. Strategic science questions from the GCMRC monitoring and research plan (MRP), related high flow science questions, and the experimental studies that would address in part or in whole individual questions.—Continued.

High flow science question: Will the next high flow result in higher nutrient releases and shrinking of the hypolimnion? Will the operation of the river outlet works and the penstocks at capacity measurably alter Lake Powell hydrodynamics or stratification, or alter release water quality?	5
Strategic science questions: Do dam controlled flows affect rates of erosion and vegetation growth at archaeological sites and TCP sites, and if so, how?	
High flow science question: Are open patches more susceptible to exotic species colonization and establishment than sites with existing vegetation following a disturbance?	2

Table 2. Description of experimental studies included in the HFE science plan

Experimental study	Description
	Sediment, archaeological sites, and backwaters
1.A. Sand budgeting	Data will be collected to determine the amount of sediment available in the system and its availability for restoring sandbars and camping beaches, patterns of erosion and deposition, and changes in sediment grain size
1B. Eddy-sandbar studies	Data will be collected on the evolution of specific eddy sandbars before, during, and after a high flow. These data may be used to improve the predictive capabilities of the existing sediment model and determine the optimal peak flows of future high-flow experiments.
1.C. Response of sandbars and select cultural site	Data will be gathered to determine (1) if sandbars throughout the Colorado River ecosystem gain or lose sand as the result of a sand-enriched high flow, (2) if new sand can offset gully erosion, and (3) if enlarged sandbars provide source material for the windborne

	transport of sand upslope into archaeological sites.
1.D. Backwater habitats	Measure backwater habitats and sample them for fish in spring and fall to evaluate how (a) backwaters formed by a high flow change over time and (b) how fish, particularly humpback chub, use backwaters.
	Riparian vegetation
2. Riparian vegetation studies	Study will document changes in riparian vegetation (native versus nonnative) following a high flow to determine if disturbances influence the success rate of nonnative species.
	Aquatic food base
3. Food availability	Data will be collected to determine how high-flow experiments affect the quantity and quality of food available to invertebrates and, ultimately, fish.
	Rainbow Trout
4.A. Redds study	Data will be collected to determine how high-flow experiments affect spawning and survival of early-life stages of rainbow trout in Lees Ferry
4.B. Movement study	Study will collect data to determine if high-flow experiments displace rainbow trout from Lees Ferry and if displacement varies by fish length
	Lake Powell
5. Lake Powell	Data to determine if a high flow results in higher nutrient releases and changes in the hypolimnion
	Conservation measures
6. Kanab ambersnail	To minimize impacts to an endangered species, Kanab ambersnail habitat at Vaseys Paradise will be moved
	Knowledge syntehsis
7. Synthesis of knowledge	Data and knowledge gained as the result of the high-flows test will be synthesized in an attempt to address strategic science questions

GCMRC will conduct an annual assessment of the population of adult humpback chub (≥200 mm [TL) using the age-structured mark recapture model (ASMR; Coggins 2007), This information will be provided to the Bureau of Reclamation and the Fish and Wildlife Service for use in evaluating the potential for reinitiation of Endangered Species Act consultation to determine if the September-October steady flows should be continued, discontinued, or expanded.

Another element of the experimental program for FY 2009- 2012 will involve annual monitoring of humpback chub in the reach of the Little Colorado River above Chute Falls, and undertaking periodic humpback chub translocations above Chute Falls as deemed necessary by the Fish and Wildlife Service. In addition, NPS and BOR are expected to translocate humpback chub from the Little Colorado River to several tributary streams in Grand Canyon including, Shinumo Creek, Havasu Creek, and Bright Angel Creek. Since theses efforts are not being funded through the GCDAMP they are not addressed in the MRP.

The final element of the experimental program for FY 2009- 2012 will involve annual monitoring of humpback chub in the reach of the Little Colorado River above Chute Falls, and undertaking periodic humpback chub translocations above Chute Falls as deemed necessary by the Fish and Wildlife Service. In addition, NPS and BOR are expected to translocate humpback chub from the Little Colorado River to several tributary streams in Grand Canyon including,

Shinumo Creek, Havasu Creek, and Bright Angel Creek. Since theses efforts are not being funded through the GCDAMP they are not addressed in the MRP.

In 2003, the GCDAMP began depositing $500,000 per year into a fund managed by Reclamation to pay for experimental research projects so that they can be conducted without financially impacting other aspects of the science program. The entire fund has been committed through FY 09 to data collection, data analysis and reporting associated with the March 2008 HFE. Each year, $500,000 will be set aside by the GCMRC into the Experimental Fund. Deposits to the Experimental Fund will cease when the balance reaches $2.5 million.

Integrated and Interdisciplinary Science

The GCMRC will emphasize an integrated, interdisciplinary science approach during the next 5 years. An interdisciplinary approach is the only practical way to link the physical, biological, and sociocultural components of the CRE. To provide a framework for integrating scientific activities, the MRP is structured around overarching SSQs (appendix A). The science approach will emphasize four areas, which are discussed in greater detail below. This approach will increase the likelihood of providing definitive answers to SSQs in the next 5 years.

Staffing and Organizational Capacity

In FY2008, the GCMRC recruited a part-time senior ecologist to work with GCMRC staff and cooperators to pursue integrated, interdisciplinary ecosystem-science strategies. Possible strategies include the application of the CRE conceptual model to science planning and project design, and the evaluation of decision-support tools to improve the application of science information in the GCDAMP process (see below).

Conceptual Ecosystem Model Enhancement

In 1998, Walters and others (2000) conducted a workshop to assist scientists and managers in developing a conceptual model of the CRE as affected by GCD operations. The model proved to be useful for understanding the relationship among ecosystem components, identifying knowledge gaps, and predicting the response of some ecosystem components to policy change. However, the model was unable 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 (CEM) will be pursued 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. A preliminary list of priority expansions of the CEM 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 nonflow management activities (e.g., operation of a TCD, mechanical removal of nonnative fish, translocation efforts for HBC, tributary triggers for HFEs)
- Linking Lake Powell and downstream temperature simulations to fine sediment, food web, and fisheries submodels

- 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
- Researching recreational use and campsite size, abundance, and distribution
- Developing cultural site change and protection strategies (archaeological sites, TCPs)
- Simulating financial impacts coupled to the flow/dam operations submodels

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 contribute 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 HBC and other native fishes. As part of the experimental program, the results of the HFE that was conducted in March 2008 will be analyzed and reported in FY 09 and FY 2010. Additional HFEs will be conducted subject to approval by the Secretary of the Interior.

Effects of Increased Water Temperatures on Priority AMP Resources

Since 2003, the Colorado River water temperatures below GCD have been increasing (figure 2) because of 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 warmer 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 (Andersen and others, submitted)
2. Increased numbers of juvenile HBC in comparison to recent years
3. A decline in the RBT 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

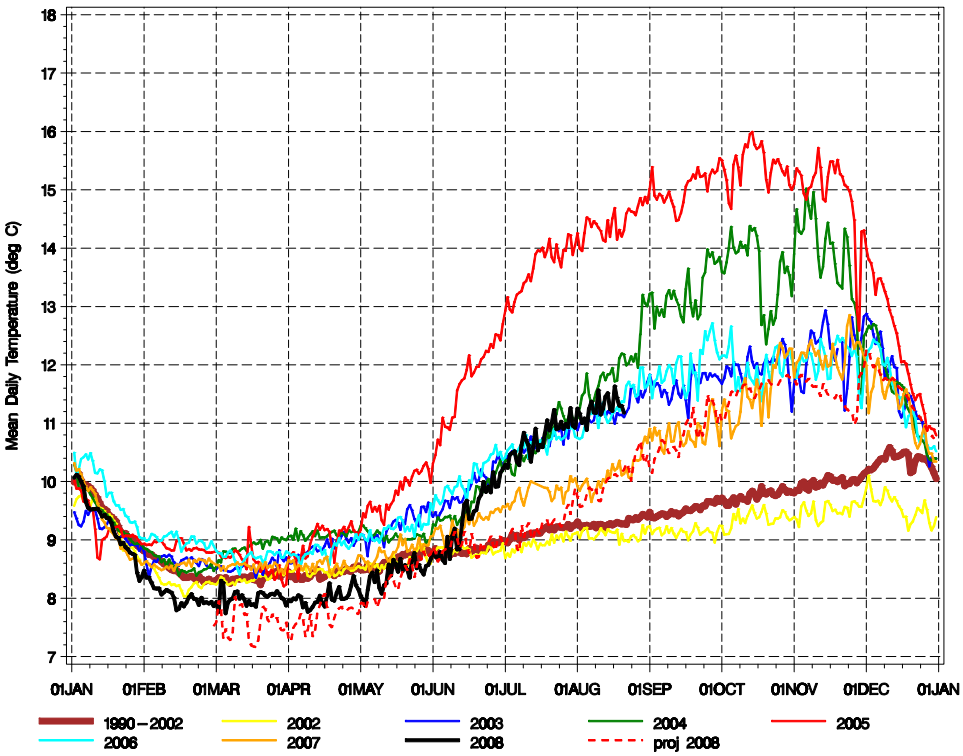

Figure 2. Glen Canyon Dam released water temperatures 2002 – 2008, compared with 1990-2002 average. The natural warming of the river occurred at least through water year 2008 and provides a unique opportunity to study the effects of warmer water on Colorado River ecosystem resources before the possible construction of a temperature control device. Water temperatures downstream of the dam gradually increase with distance from the dam. The GCMRC proposes the following studies and activities to evaluate the effects of natural river warming:

1. Develop and test a 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. Develop and test a nonnative fish management plan that will (1) assess the implications and expected response of both the native and nonnative fisheries communities to warmer water and (2) identify methods of control that will be tested/refined (FY2007–11)
4. 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 (FY2007–11)
5. Work with the U.S. Fish and Wildlife Service (USFWS) to finalize the HBC genetics management plan and a related plan for one or more refuges for HBC to avert the catastrophic decline of HBC populations associated with the proliferation of nonnative fishes

These studies and activities will also contribute to the evaluation of the efficacy of a Temperature Control Device (TCD) that would allow for regulation of the water temperatures and other water-quality parameters (e.g., dissolved oxygen). The primary goal of a TCD would be to create mainstem water-temperature conditions that promote natural reproduction and

recruitment of HBC in the mainstem of the Colorado River. The primary risk associated with warmer water temperatures involves the proliferation of warmwater nonnative fishes that may compete with or prey upon native fishes. A TCD can also provide the capability to release cold water from GCD to control the spread of warm water non native fishes that may result from warmer water releases from GCD.

Critical Monitoring and Research Needs Outside of the Colorado River Ecosystem

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 GCD 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) threats to the Little Colorado River (LCR), (2) Lake Powell water quality, and (3) effects of climate change and drought in the Colorado River Basin.

Threats to the Little Colorado River

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 water-quality contamination in upstream areas of the LCR watershed have been identified by the USFWS as a significant threat to the endangered HBC. The USFWS 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-quality sampling consistent with the 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 HBC in the lower reach of the LCR, and
- 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 GCD is the water released from Lake Powell. While extensive physical and biological data on Lake Powell water quality have been collected for more than two decades, the data have not been synthesized or subjected to analysis and modeling to simulate both temperature and dissolved oxygen characteristics for GCD releases. Under this activity, historical Lake Powell data will be synthesized to identify trends in water quality. 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 (i.e., 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. 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 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. Runoff in 2000–08 in the upper Colorado River Basin was the lowest in the period of record; Lake Powell is currently (2008) about 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., preservation of native fishes, sediment, cultural resources, and recreation).

Under this research initiative, basin-scale climate studies will be conducted on how new climate information could be used by water and other resource managers in the GCDAMP program. The 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 the dam) in ecosystem responses and their relationship to operation of GCD. This study will be carried out in cooperation with other USGS offices, the National Oceanic and Atmospheric Administration and Reclamation.

CHAPTER 2. Proposed FY2009–12 Monitoring and Research Plan Activities

Proposed science activities for FY2009–12 are summarized in table 3. These activities are categorized as core monitoring, research and development, and long-term experiments. All proposed science activities are related to both GCDAMP goals and AMWG priorities.

Chapter 2 summarizes the core-monitoring, long-term experimental, and research and development activities for GCDAMP goals 1–11 and describes general activities for goal 12. The chapter also discusses efforts to integrate monitoring and research activities across goals.

SSQs and information needs specified in the SSP will be used to drive monitoring and research activities for the next 5 years. In addition, GCMRC developed a crosswalk table (appendix A) showing how the Research Information Needs (RIN) in the GCDAMP Strategic Plan relate to the SSQs in the SSP. Through a review of this table, GCMRC identified four additional SSQs to be added to the MRP. These include:

- **SSQ RIN 1:** What habitats and habitat characteristics, if any, will enhance survival, growth, and reproduction of native Grand Canyon fishes, especially HBC, in the mainstem Colorado River?
- **SSQ RIN 2:** What are the most effective strategies and control methods to limit nonnative fish predation on, and competition with, native fishes?
- **SSQ RIN 4:** What are the effects of ramping rates on sediment transport and sandbar stability?
- **SSQ RIN 5:** What is the rate of change in eddy storage (erosion) during time intervals between HFEs?

In some cases, proposed research and monitoring activities concentrate on a single strategic science question. For example, most of the goal 8 research and monitoring activities are directed at answering this question: Is there a "flow-only" operation (i.e., a strategy for dam releases, including managing tributary inputs with HFEs, without sediment augmentation) that will restore and maintain sandbar habitats over decadal time scales?

For other goals, multiple SSQs and information needs have been identified because of the complexity of the issues and the current state of knowledge about how to best achieve a goal. For example, seven SSQs, two core-monitoring information needs, and two RINs are identified for goal 2 (native fish/HBC). It is impractical to "answer" all of the questions and information needs within the scope of this 5-year MRP. Answering the stated SSQs and information needs will require research and modeling on several fronts over an extended period of time. Proceeding on multiple fronts will provide for a balanced, robust, and integrated research program.

Table 3. 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 2009–12. 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 LTEP. 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 SSP (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.

Glen Canyon Dam Adaptive Management Program (GCDAMP) goal	Adaptive Management Work Group (AMWG) priority science questions and information needs(questions from the Strategic Science Plan (SSP) and MRP 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?*	Fiscal year (FY) 2010: Review and evaluate aquatic food base monitoring program for core-monitoring status. FY2010–ongoing: Implement aquatic food base core monitoring.	FY2009–12: Evaluate effects of fall steady flows on food web FY2009–10: Evaluate effects of the 2008 HFE on food web. FY2008-10:Evaluate the effects of various flow regimes on aquatic food base	FY09: Determine carbon budget to understand how energy is exchanged among organisms in the Colorado River; develop monitoring techniques and metrics for key organisms.
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 of rainbow trout (RBT) 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 Little Colorado River (LCR) and the mainstem.	FY2009: Review and evaluate HBC monitoring program for core-monitoring status in protocol evaluation panel (PEP). FY2009–ongoing: Implement HBC core monitoring.	FY2009–12: Evaluate effects of fall steady flows on humpback chub recruitment and FY2009–10: Evaluate effects of the 2008 HFE on backwater habitats.	FY2007–11: Perform a statistical review of existing HBC monitoring protocols and habitat data. FY2009–11: Evaluate protocols for warmwater and coldwater nonnative fish monitoring, removal, and control, and their effects on native fish.

Table 3. 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 2009–12. 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 LTEP. 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 SSP (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 SSP and MRP in italics)	Core-monitoring activities	Experimental activities	Research and development activities
2. HBC and other native fishes (B.)	AMWG Priority:1, 3, and 5 ***SSQ 1-2**: Does a decrease in the abundance of RBT and other coldwater and warmwater nonnatives in Marble and eastern Grand Canyons result in an improvement in the recruitment rate of juvenile HBC to the adult population?* ***SSQ 1-4:** Can long-term decreases in abundance of RBT 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 Colorado River ecosystem (CRE) and their impacts on native fish. ***SSQ RIN 2:** 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?	FY2009–12: Continue mainstem monitoring of fish community.		FY2009–10: Develop and test nonnative fish management plan. FY2009–11: Develop abundance estimation framework that allows better estimates of nonnative fish numbers in mechanical removal reaches. FY2009–10: Develop bioenergetic model to predict changes in fish communities in response to biotic and abiotic changes.
2. HBC 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			FY2009–10: Review data and literature on HBC in upper basin to see if HBC habitat can be identified, protected, and re-created below Glen Canyon Dam (GCD). FY 2009-12: Conduct near-shore ecology study.

Table 3. 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 2009–12. 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 LTEP. 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 SSP (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

	in the mainstem: spawning success, predation on YoY and juveniles, habitat (water, temperature), pathogens, adult maturation, food availability, competition?			
GCDAMP goal	**Priority science questions and information needs (questions from SSP and MRP in italics)**	**Core-monitoring activities**	**Experimental activities**	**Research and development activities**
2. HBC 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?* ***SSQ RIN 1:*** *What habitats and habitat characteristics, if any, will enhance survival, growth, and reproduction of native Grand Canyon fishes, especially HBC, in the mainstem Colorado River?*			FY2009 Develop and deploy alternative, noninvasive HBC monitoring gear to reduce stress on fish (e.g., remote passive integrated responder (PIT) tag reading, and sonic tags). FY2009: Evaluate the effects of trammel net sampling. FY2009–11: Following a PEP for HBC, develop one or more projects aimed at determining fate and habitat use of subadult HBC. FY 2009-12: Conduct mechanical removal in LCR reach.
3. Extirpated species		No projects	FY2009–11: Evaluate and plan temperature control device (TCD).	No projects.
4. RBT	AMWG Priority: 3 ***SSQ 3-6:*** *What GCD operations (ramping rates, daily flow range, etc.) maximize trout fishing opportunities and catchability?* **CMIN 4.1.2:** Determine annual proportional stock density of RBT in the Lees Ferry reach. **CMIN 4.1.4:** Determine annual standard condition (Kn) and relative weight of RBT in the Lees Ferry reach.	FY2009–11: Monitor status and trends of Lees Ferry population. FY20079 Review and evaluate RBT monitoring for core-monitoring status. FY2009–11: Implement RBT core monitoring.	FY2009: Evaluate effects of modified low fluctuating flow (MLFF) operations on RBT.	
5. Kanab ambersnail (KAS)	AMWG Priority: 3 **CMIN 5.1.1:** Determine and track the abundance and distribution of KAS at Vaseys Paradise.	FY2009: Monitor KAS habitat; evaluate for core-monitoring status in conjunction with U.S. Fish and Wildlife Service	FY2008–11: Evaluate effects of experimental flows, especially beach/habitat-building flows (BHBF), on KAS.	FY2009-11: Evaluate alternative survey methods of KAS habitat.

Table 3. 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 2009–12. 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 LTEP. 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 SSP (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

	CMIN 5.2.1: Determine and track the size and composition of the habitat used by KAS at Vaseys Paradise.	(USFWS) species status review.		
GCDAMP goal	**Priority science questions and information needs (questions from SSP and MRP in italics)**	**Core-monitoring activities**	**Experimental activities**	**Research and development activities**
6. Springs/riparian environments	AMWG Priority: 4 ***SSQ 2-1:*** *Do dam controlled flows affect (increase or decrease) rates of erosion and vegetation growth at archaeological sites and traditional cultural properties (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.	FY2009–11: Implement vegetation core monitoring.	FY2009–11: Evaluate allochthonous contribution during experimental flows.	FY2009 and ongoing: Conduct terrestrial mapping. FY2009–11: Conduct 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 nearshore 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?* *SSQ RIN 4: What are the effects of ramping rates on sediment transport and sandbar stability?* **CMIN 7.3.1:** What are the status and trends of water quality releases from GCD?	FY2009: Monitor Lake Powell using existing protocols. FY2009: Convene PEP for Lake Powell monitoring. FY2009–11: Monitor downstream integrated quality of water (including suspended-sediment flux). FY2010–11: Implement Lake Powell core monitoring.	FY2009–11: Collect water-quality and suspended-sediment data in support of experimental flow research.	FY2009–10: Perform Lake Powell synthesis and modeling. FY2009–11: Develop advanced downstream flow, temperature, and suspended-sediment models.

Table 3. 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 2009–12. 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 LTEP. 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 SSP (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 SSP and MRP 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?* *SSQ 4-3: What are the effects of ramping rates on sediment transport and sandbar stability?* *SSQ 4-4: What is the rate of change in eddy storage (erosion) during time intervals between BHBFs?*	FY2007–11: Implement recommendations from the final sediment transport modeling review PEP, or SEDS-PEP (summer 2006). FY2007: Detect trends in sandbars through biennial measurements of sand-storage changes as reflected in campsite area monitoring (see goal 9, below).	FY2008–11: Evaluate the effects of BHBFs and alternative ramping rates on sandbars and sediment.	FY2007–11: Map change in nearshore habitat resulting from 2004 BHBF; convert exiting overflight analog images to digital to facilitate research.

Table 3. 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 2009–12. 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 LTEP. 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 SSP (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

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.	FY2007–11: Monitor change in sandbar campable area, topography, and volume (see above, project linked to sandbar monitoring).	FY2008–11: Evaluate effects of experimental flows and ramping rates on campsites.	FY2007–08: Complete campsite inventory and Geographic Information Systems (GIS) atlas. FY2007–08: Evaluate use of field data vs. remotely sensed data for campable area monitoring. FY2009: Evaluate vegetation encroachment on campsites; revisit Weeden survey data.

GCDAMP goal	Priority science questions and information needs (questions from SSP and MRP 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,*		FY2008–11: Evaluate effects of experimental flows and ramping rates on visitor safety and health.	FY2007 or 08: Compile and analyze existing safety data. FY2008–09: Evaluate relative importance and potential effects of different flows on recreation experience qualities. FY2010–11: Update regional recreation economic surveys.

Table 3. 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 2009–12. 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 LTEP. 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 SSP (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

	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?*			
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).	FY2007–11: Monitor power generation and market values under current and future dam operations.	FY2008–11: Evaluate economic implications of experimental flows (with focus on hydropower and the Basin Fund).	

GCDAMP goal	Priority science questions and information needs (questions from SSP and MRP 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?*	FY2011: Convene cultural PEP II.	FY2008–11: Evaluate effects of experimental flows on sediment supply and deposition at archaeological sites and TCPs.	FY2007: Research and develop core monitoring (develop protocols for archaeological sites and TCPs). FY2007: Implement Technical Work Group (TWG) approved tribal monitoring projects. FY2008–10: Perform integrated archaeological site monitoring (pilot project).

Table 3. 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 2009–12. 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 LTEP. 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 SSP (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

	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. (Science Planning Group [SPG] revised CMIN) **CMIN 11:2.1:** Determine the condition of traditionally important resources and locations using tribal perspectives and values. (SPG revised CMIN)			FY2009–10: Expand pilot study to evaluate geomorphic changes in the CRE using remotely sensed imagery. FY2008–10: Develop geomorphic model of archaeological site vulnerability.
12. High-quality monitoring, research, and adaptive management program (A.) Data acquisition, storage, and analysis (DASA)	AMWG Priority:1,2, 3, 4, and 5	FY2007–11: Perform remote sensing activities related to the preparation, acquisition, and storage of 2009 terrestrial resource monitoring data.	No projects	FY2007–11: Convert existing analog images (especially overflight imagery) and reports to digital formats (see also goal 8). FY2007–11: Perform 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 MRP seeks to advance goal 1 by addressing discrete scientific questions, information needs, and objectives related to these conditions. Specifically, AMWG priority questions from the KAR were used to frame key SSQs for GCDAMP goal 1. The SSQs 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 FY2009–12 carry forward two elements of the overall MRP: core monitoring, and research and development. Food base monitoring and research are discussed in terms of the objectives they are designed to achieve and the individual element of the plan they support.

Core-Monitoring Activities

Monitoring the Aquatic Food Base

The aquatic PEP (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 FY2010, 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.

FY2009–11. 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 FY2010–12.

Research and Development Activities

Trophic Linkages

Resource managers for native and nonnative fishes need to understand the amounts and quality of aquatic food resources that are available to fishes to 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 RBT and HBC, but there is very little data on the food base for other fish that are common in the CRE. Further, the relative contribution of allochthonous and autochthonous carbon to invertebrate and, ultimately, fish production remains unclear. This is problematic—an understanding of the carbon sources that contribute to invertebrate and fish production is critical to making informed management decisions, because these different types of carbon may be differentially affected by dam operations. Activities in this category address SSQ 1-5, SSQ 1-6, and SSQ 5-2.

FY2009–10. Aquatic Food Base (Project BIO 1.R1.07)

This project was initiated in 2005 to identify energy pathways and quantify basal resources through multiple approaches. Field work on the project began in spring 2006. 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 FY2010, will contribute to the development of a core-monitoring program for the Grand Canyon food base in the future.

Long-Term Experimental Activities

Current studies of the aquatic ecosystem food web are focused on understanding how energy is transferred among organisms, and which energy sources have limited availability. Some GCDAMP stakeholders are also interested in understanding how dam operations affect the amount of primary and secondary production (especially algae, diatoms, and invertebrates) that may be available to native and nonnative fishes as it drifts down the Colorado River in Grand Canyon. In FY2008 and continuing until FY2010 a study will be implemented to evaluate the impacts of various flow regimes on the aquatic foodbase.

Integration

Physical Sciences

Five of the seven study reaches in the whole-system carbon-cycling project are fine-grained integrated sediment transport (FIST) 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. 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 the total transported material, with the remainder being sand, silt, and clay. If this relationship holds up, the food base project will be able to estimate organic inputs from tributary flood events based on estimates of sediment 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 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 mechanical removal 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 RBT in the removal reach have been eating and how this may or may not impact HBC entering and exiting the LCR.

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 MRP for FY2009–12 seeks to address discrete scientific questions, information needs, and objectives that support maintenance of viable populations of native fish. AMWG priority questions from the KAR were used to frame key SSQs for GCDAMP goal 2. The SSQs that emerged as the focus of monitoring and research activities for goal 2 are listed below. Relevant SPG-prioritized CMINs, RINs, and a summary question posed by the SA (SA 1) are also listed below.

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 RBT and other cold and warm water nonnatives in Marble and eastern Grand Canyons result in an improvement in the recruitment rate of juvenile HBC to the adult population?
3. **SSQ 1-4.** Can long-term decreases in abundance of RBT 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 2.4.3. 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?

11. **SSQ RIN 1.** What habitats and habitat characteristics, if any, will enhance survival, growth, and reproduction of native Grand Canyon fishes, especially HBC, in the mainstem Colorado River?
12. SSQ RIN 2. What are the most effective strategies and control methods to limit nonnative fish predation and competition on native fish?

Note: Razorback sucker (RBS) 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

Activities to support goal 2 range from monitoring to provide decision makers with status and trends information on native and nonnative fishes, to research on the habitat preferences of HBC and the effects of modified low fluctuating flows (MLFF) on RBT. Individually, activities can generally be characterized as core monitoring, research and development, or experimental, in keeping with the structure of the MRP; 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 USFWS and the Arizona Game and Fish Department (AZGFD).

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 and assessing progress towards meeting recovery goals. Monitoring of fishes is led by the GCMRC with GCDAMP partners, especially the USFWS and the AZGFD, to provide managers with information to support management decisions. Varying flow regimens and nonflow actions (especially the mechanical removal of nonnative fishes near the LCR inflow) have been implemented in recent years. Continued monitoring is needed to evaluate whether these actions have been beneficial or detrimental to native and nonnative fishes. Because of its Federal endangered status, the HBC is often the focus of Grand Canyon fish monitoring. HBC monitoring will be conducted in accordance with the standards specified in the HBC recovery plan ((USFWS, 2002). Current monitoring will be maintained in FY2007 and FY2008, building on the current long-term dataset for HBC and other fish species. Monitoring results will also be used to develop core monitoring for HBC, the subject of a PEP scheduled for FY2008. The recommendations from this PEP will be implemented in FY2009 and beyond. The primary questions and information needs addressed by these activities are SSQ 1-1, SSQ 1-2, and CMIN 2.1.2.

FY2009–12. Little Colorado River Humpback Chub Monitoring Lower 15 km (Project BIO 2.R1.07)

This monitoring of the known spawning tributary of HBC in Grand Canyon will be led by the USFWS. Sampling is conducted with hoop nets during four annual trips, two in the spring and two in the fall, as a continuation of the LCR HBC stock assessment program initiated in fall

2000. These trips will occur in March, April, September, and October, and provide spring and fall abundance estimates of HBC in the LCR. Tags deployed in fish during fall and spring LCR trips may be available for later recapture during mainstem activities. In addition to the short-term estimates that these sampling trips will support, the monitoring provides continued data collection to advance the age-structured mark recapture (ASMR) open population model for HBC.

FY2009–12. Little Colorado River Humpback Chub Monitoring Lower 1,200 m (Project BIO 2.R2.07)

This monitoring maintains a dataset that has been conducted annually, with few exceptions, since the 1980s. HBC are monitored with hoop nets near the mouth of the LCR. The monitoring is led by the AZGFD.

FY2009–12. Humpback Chub Monitoring Above Chute Falls (Project BIO 2.R3.07)

This project, led by the USFWS, monitors the population of HBC found above Chute Falls (river mile 9.1), a frequent if inconsistent barrier to upstream fish movement in the LCR. HBC were 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.

FY2009–12. 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 coincides with three of the four lower 15 km LCR sampling events to achieve concurrent sampling, consistent with reviewer recommendations. While HBC 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 spring and once in 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.

FY2009–12. Nonnative Control Planning and Nonnative Control Pilot Testing (Project BIO 2.R5.07 and Project BIO 2.R6.07)

One of the biotic factors thought to be limiting to native fishes is nonnative fish, which may compete with native fish for food and prey on young native fish. This threat was addressed during FY2003–06 with the mechanical removal of RBT and other nonnative fish using boat electrofishing. With warming of the Colorado River in Grand Canyon, the nonnative fish species posing the greatest threat to natives may change to species more adapted to warmer water. The threats from nonnative species will be addressed in a comprehensive nonnative control plan to be developed in FY2007–10. Pilot projects will be implemented, assessed, and refined. The DIDSON camera may be deployed with some gear types to evaluate its efficacy. Questions and information needs addressed by these projects are SSQ 1-4, SSQ 5-6, CMIN 2.4.1, SSQ RIN 2, and RIN 2.4.3.

FY 2009-12. Mechanical control of nonnative fishes.

Participants in the April 2007 workshop convened by GCMRC to support the LTEP process (GCMRC 2008) concluded that control of nonnative fishes was an important action to take to help support the native fishes of Grand Canyon. The workshop participants further concluded that, although not as much learning would be accomplished, it was important to initiate nonnative control efforts as soon as possible, keeping nonnative species at low levels whenever possible. They also cited the economic efficiency of keeping nonnative species low as opposed to allowing them to rise to high levels before instituting control methods. Consistent with these recommendations, GCMRC proposes to remove nonnative fishes with electroshocking in the Little Colorado River reach of the mainstem Colorado River. This approach will also allow for a population estimation of rainbow trout in this reach to help supply hard data in support of management decision making. This project fulfills one of the requirements of the 2008 Biological Opinion.

Modeling Populations

As managers and scientists strive to conserve the natural resources of Grand Canyon, it is important to characterize the size and trend of the resident HBC population over time. The GCMRC has taken the lead in estimating population size and trend and will continue to lead this effort in the future. Population characterization and modeling 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 predict changes in response to the changing environment, and development of abundance estimation procedures for nonnative fishes. Analysis of data collected in the field informs decisions on 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.

FY2009–11. Stock Assessment of Native Fish in Grand Canyon (model development) (Project BIO 2.R7.07)

To provide the most current information on HBC status and trend information, the GCMRC ASMR database will be updated annually with the most recent data from routine monitoring. Following this update, the database will be reanalyzed using (where appropriate) both open and closed ASMR-based abundance estimators. We will rely on ASMR models and other appropriate models to determine trends in HBC abundance and recruitment. Finally, we will evaluate the applicability of similar techniques as described above to assessing stocks of flannelmouth sucker (FMS) and bluehead sucker (BS). This project fulfills one of the requirements of the 2008 Biological Opinion.

FY2009–11. Abundance Estimation Procedures (Project BIO 2.R8.07)

Currently, the traditional Zippin abundance estimator is used to estimate the abundance of nonnative fish (primarily RBT) 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. The Bayesian Inference using the Gibbs sampler program (BUGS) will be used to fit models to our removal data.

FY2009–10. 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 during the mechanical removal project.

Monitoring Technology Research

The native fish population of Grand Canyon, especially HBC, 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 to evaluate populations can cause stress and reduce the growth of these animals, especially when they are handled repeatedly (e.g., Paukert and others, 2005). Negative effects of capture, especially of endangered fishes, have led researchers to seek less invasive methods such as alternative gears and remote monitoring technologies. 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 FY2007. The question addressed by these projects is SSQ 1-8.

FY2007–09. 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 (NAU) 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.

FY2007–12. 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 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.

FY2007–12. 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,

implanting them with tags, and releasing them to see if the equipment is effective in the Colorado River.

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 serve to direct long-term monitoring, population modeling, and the selection of flow regimens. To the extent possible, the characteristics of habitats that are most important to native fishes (physical, water quality), particularly in the mainstem Colorado River, need to be identified. Habitat characteristics needed by YoY and juvenile HBC are most important to identify and protect because of the endangered status of this species. GCMRC will develop a project to use existing and new data to investigate habitat use by young HBC and other native fishes, especially in the mainstem Colorado River. GCMRC intends that SSQ RIN 1 will be addressed through modeling habitat usage, mining the available data for information on HBC captures, and developing one or more new collection efforts to help understand the habitat use by and fate of subadult HBC and other native fishes.

The questions addressed by the project below are SSQ 1-1, SSQ 1-7, and SA 1. A PEP for RBT will be conducted in FY2008. The issues of RBT predation on HBC and other native fishes (SSQ RIN 3) will be discussed with the panelists with the specific aim of developing one or more projects that investigate the threat to native fishes from RBT piscivory and where Grand Canyon RBT are produced.

FY2009–10. 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 on 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 its value in defining important habitat characteristics, including river flows, water-quality characteristics, and physical habitat.

FY 2009-12. Near shore ecology

One of the fundamental questions for managers in Grand Canyon is determining what habitats in the mainstem are most important for HBC, especially sub-adult HBC. Sand-mediated backwater habitats have been extensively studied on the theory that they are very important for young HBC, but much more limited attention has been paid to other mainstem habitats. For this reason, GCMRC has been developing a project to investigate the relative importance of mainstem habitats, particularly for juvenile HBC. This project was supported by USFWS by being included in the 2008 Biological Opinion.

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.

To address this information need, GCMRC staff and cooperators will try to detect changes in the abundance and distribution of different shoreline habitat types, especially sandbars and backwaters, in the Colorado River (Data Acquisition, Storage, and Analysis Program [DASA] 12.D7.09). In terms of fish, knowledge of the distribution, abundance, and change potential of these habitats in the mainstem will help scientists evaluate the mainstem's potential to support young HBC under various flow regimes. This project will build on the baseline dataset of shoreline habitat for six habitat types at the 8,000-cfs elevation developed from 2000 data. Three other remote-sensing datasets from 2002–05 data will be used to extend the time series for a 5-year period. Using data taken in different years will extend the dataset 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

Food base research is closely associated with the fish community in Glen and Grand Canyons because most 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, flux in fish populations can be correlated with the flux of the food base to 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 GCD release regimens. Additional details of integration strategies and products are provided above and in the FY2009 annual work plan.

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

Goal 3 is not currently a GCDAMP priority goal; however, the goal is part of the NPS and USFWS long-term resource management objectives. If goal 3 becomes a higher priority for GCDAMP in the future, the feasibility of reintroducing the target extirpated species will be investigated first.

The knowledge gained from GCMRC monitoring and research on key ecosystem drivers—the operation of the GCD, 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 CRE improves and changes, the NPS, USFWS, and the AZGFD 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 RBT population above the Paria River is an important activity for evaluating population status and trends to determine whether they are meeting goal 4. Therefore, monitoring of this population is to continue during FY2009–12. Monitoring data will be used to support a PEP scheduled for FY2009. The fate of trout eggs and very young fish in response to dam operations will be the subject of continuing research in FY2009. The primary SSQ, CMINs, and RIN 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 RBT in the Lees Ferry reach.
3. **CMIN 4.1.4.** Determine annual standard condition (Kn) and relative weight of RBT in the Lees Ferry reach.
4. **RIN 4.1.1.** What is the target proportional stock density (i.e., tradeoff between numbers and size) for RBT in the Lees Ferry reach?

Monitoring and Research

Core-Monitoring Activities

Monitoring of the RBT 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 FY2009 PEP, which, in turn, will be used as guidance for core monitoring of RBT population above the Paria River.

FY2009. Status and Trends of Lees Ferry trout (Project BIO 4.M1.07)

Electrofishing as a sampling technique to estimate the biological parameters used to assess fishery status and trends . 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.

FY2009. RBT Redds and Larvae (Project BIO 4.E1.07)

Analysis of redd (nest) production, egg production, and larval survival will be continued in FY2009 to determine population responses to flows and to inform the PEP process. Information from this project and monitoring helps managers and peer reviewers to address RIN 4.1.1, as well as 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 aquatic food base project will monitor fish population and habitat responses to various experimental flow regimens. The results of monitoring will contribute to understanding what flow regimens best support and maintain the RBT present below GCD.

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 KAS population 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. What amount of variability is natural (the natural condition that managers are trying to achieve) will be one of the prime questions addressed by the USFWS as part of their status review of this species . The USFWS has not definitively scheduled the status review at the time of the writing of this document. Another important issue for USFWS to consider will be the taxonomic status of the Vaseys Paradise population. This population was included in other populations in a 2007 genetics study under contract with the GCMRC at the University of Arizona. The GCMRC will be closely involved in providing science support to the USFWS during their review.

GCMRC in cooperation with partner agencies will continue to address the following CMINs for the KAS:

1. **CMIN 5.1.1.** Determine and track the abundance and distribution of KAS at Vaseys 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 KAS at Vaseys Paradise.

Monitoring and Research Activities

Core-Monitoring Activities

Population and habitat monitoring methods for KAS continue to be refined. Working closely with AZGFD and NPS, GCMRC is providing logistics support and data analysis for ongoing monitoring. The species status review conducted by the USFWS 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 NPS when determining their core-monitoring needs. Monitoring activities address CMIN 5.1.1 and CMIN 5.2.1.

FY2009–12. Monitoring Kanab Ambersnail (Project: BIO 5.R1.07)

Habitat surveys at Vaseys Paradise include surveying the total area of the habitat and 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 Vaseys Paradise to determine the extent of the habitat can be invasive. Remote technologies like oblique orthorectified imagery and land-based LiDAR might be used to determine area cover and plant height without the need to step into the habitat. Alternative methods will be tested in FY2009 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. Initial results, presented to cooperating agencies in 2007, suggested that the Kanab ambersnail may be more genetically similar than originally thought to other oxyloma species. Additional genetic research, using more diverse species for comparison, was conducted with financial support from GCMRC, among others. Results from the updated analysis are expected to be presented to USFWS and other cooperating agencies, including GCMRC, during FY 2009 and then considered by USFWS during their species status review.

Long-Term Experimental Activities

Experimental Flows Population Monitoring and Habitat Salvage

In November 2004, before the 2004 experimental HFE, the GCMRC and the AZGFD temporarily removed habitat patches that were determined to be subject to scouring. These patches were moved above the inundation level and then returned to their original locations. The habitat survived the temporary removal and habitat loss was successful averted during the high-elevation flow. 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 ensure confidence in this result, monitoring of this technique, and especially its safety for the KAS population, should accompany future HFEs.

Integration

The KAS 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 components 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 understanding 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 goal of developing remote monitoring and modeling capabilities to inform management needs.

Monitoring and research activities related to goal 6 address the following SSQs and 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 HBC) 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 exists in the river corridor 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 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. This work is being developed as core monitoring. As part of this development, the project was subjected to a PEP in 2007. The PEP results have been used to direct the project in future years. These monitoring activities address SSQ 2-1, CMIN 6.1.1, CMIN 6.2.1, CMIN 6.5.1, and CMIN 6.6.1.

FY2009–12. Vegetation Mapping (Project BIO 6.R1.07)

FY2009–12. Vegetation Transects (Project BIO 6.R2.07)

These two field-based projects are designed to complement 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 overflight digital imagery (a product of the DASA 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 occurring over a 5-year time frame. The two projects complement 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 during the two knowledge assessment workshops, which are 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 how short-duration high flows (discharges greater than 31,000 cfs), may change riparian vegetation. This topic will be considered within the scope of the vegetation synthesis.

FY2009–12. Vegetation Synthesis (Project BIO 6.R3.07)

The vegetation synthesis project will use 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 KAR. For example, the KAR revealed that there was some certainty about the relationship of marsh community development and flows for the CRE, but that this certainty decreased as one progressed upslope. Additionally, the KAR found a 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 meeting these needs and will be implemented in two parts. Part I (FY2007–09) will address local processes and systemwide change, and Part II (FY2009–11) 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 FY2009. An 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 correlated with stage variation will provide a general picture of vegetation response to the changes in operations associated with long-term experimental planning from FY2009–12.

Integration

Riparian vegetation is a critical interface between aquatic and terrestrial environments around the world. In the CRE, the vegetation serves as a host for invertebrates, provides breeding and foraging habitat for birds and 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 addressed in part 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, a better understanding of the influence of vegetation on cultural resources is needed (which was noted in the KAR). 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 GCDAMP ecosystem goals

Strategic Science Questions and Information Needs

Measures of water quality, including temperature, sediment concentration, and dissolved constituents, are closely related to many GCDAMP ecosystem goals. Water quality in the CRE downstream from GCD is affected by Lake Powell water quality, tributary inputs, and instream processes. It is, therefore, essential that the GCMRC water quality research and monitoring include efforts in Lake Powell and throughout the downstream river corridor.

In 2004, the AMWG identified several priority questions, one of which relates directly to downstream quality of water, particularly water temperature below GCD: AMWG Priority 3: What is the best flow regime?

During the 2005 knowledge assessment workshops, biological scientists also identified uncertainty about achieving fishery and food web objectives related to downstream water quality and temperature. As a result, the scientists formulated several key SSQs for GCDAMP goal 7 around those uncertainties. The most critical SSQs 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 nearshore 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?
4. **SSQ 4-1.** Is there a "Flow-Only" operation (i.e., a strategy for dam releases, including managing tributary inputs with HFEs, without sediment augmentation) that will restore and maintain sandbar habitats over decadal time scales?
5. **SSQ 4-3.** What are the effects of ramping rates on sediment transport and sandbar stability?

As part of the GCDAMP strategic plan, several 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 CRE.
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 CRE.
3. **CMIN 7.3.1.** What are the status and trends of water quality releases from GCD?

Monitoring of stage and discharge below GCD provides a means for determining when dam operations are in compliance with the 1996 ROD, 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 (1) the Lake Powell and Glen Canyon Dam tailwater water quality project and (2) the downstream integrated quality of water project. All of the activities related to goal 7 carry forward one or more of the three elements of the MRP: core monitoring, research and development, and long-term experimentation. Individual monitoring and research activities are discussed in terms of the element of the plan they 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 GCD, and dam operations affect the quality of water released from GCD to the 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 SSQ 3-5, SSQ 5-1, and SSQ 5-3.

FY2009–12. Quality-of-Water Monitoring of Lake Powell and the Glen Canyon Dam Tailwater (Project BIO 7.R1.09)

Water quality in Lake Powell, including temperature, makes a fundamental contribution to the aquatic environment downstream of GCD. This monitoring project maintains a 40-year database of water-quality information that managers can use to understand the aquatic environment available to organisms downstream. These data are 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 is currently in internal review. This report will inform further analysis in future years concerning 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 PEP anticipated in FY2010 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). Measurements and modeling estimates for tributary sand influx and main channel efflux are used to support experimental flow triggers related to HFEs and to evaluate other research flows, such as alternative fluctuating operations and stable flows. Temperature, flow, and stage data are also available for use by scientists in assessing habitat characteristics for aquatic organisms. This effort addresses SSQ 5-1.

FY2009–12. Downstream Integrated Quality-of-Water Monitoring (below Glen Canyon Dam) (Project PHY 7.M1.09)

The downstream IQW monitoring project focuses primarily on monitoring but also supports research on experimental flows, including HFEs. There are several general components to the monitoring strategy for goal 7 relating to the downstream IQW project:

- Monitor and report real-time data of release pattern of GCD (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 CRE that focus on manager needs and supports modeling below GCD (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 GCD (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 GCD (ecosystem's efflux of fine sediments)
- Monitor to support experimental flows; as need arises, collect additional similar data in support of experimental flows released from GCD

Research and Development Activities

Advanced Development of Downstream Flow, Temperature, and Sediment Modeling

FY2009–12. Integrated Flow, Temperature, and Sediment Modeling (Project PHY 7.R2.09)

Modeling capability is needed to provide predictive capacity in linking dam operations with changes in the physical environment, including water flow, sediment conditions, and temperature. Better models for water flow are needed to predict the depth and velocity of flow for specified locations for specified dam operations. Models for sediment transport are needed to help determine the optimal magnitude and duration for HFEs and estimate the potential long-term impact of changes in dam operations or sediment supply conditions. Temperature models are needed to link dam operations with temperature dynamics in the downstream channel and, in particular, near-shore habitats. Thus, the goal of the modeling activities is to provide increased predictive capabilities in the form of simulations that can be used as planning tools for linking dam operations to changes in the physical environment. Models of the physical system are also needed to develop and expand interdisciplinary relationships with biological, cultural, economic, and recreational elements of GCDAMP.

During the 2009 to 2012 period, GCMRC will continue and finalize existing modeling efforts including:

- 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
- Development of multi-dimensional modeling tools to improve understanding and prediction capability concerning the interaction between main-channel and sediment flux and eddy sediment storage as well as relations between main-channel and nearshore water temperature
- Investigation of sandbar stability under differing dam operation scenarios using numerical models and laboratory experimentation
- 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 these efforts are being finalized, GCMRC scientists and cooperators will work to identify future modeling needs. This process was initiated in September 2008 with a joint workshop that included sediment scientists and TWG representatives. The modeling program will continue with this dialog to ensure that modeling activities are aligned with stakeholder needs and interests.

Long-Term Experimental Activities

Experimental Flow Support

As need arises, the IQW project will collect additional quality-of-water and suspended-sediment data in support of experimental flows released from GCD, including future HFE tests. Depending upon the suite of flow tests in the long-term experimental design, additional experimental studies, such as alternative fluctuating flows, might also be the focus of field measurements, flume experiments, and modeling simulations to address the above science questions related to fine sediment dynamics, conservation of sandbars, etc.

An experimental plan was developed for the 2008 HFE, which consisted of 41,000 to 45,000 cfs for approximately 2 ½ days under sand-enriched conditions from the Paria and Little Colorado Rivers (see tables 1 and 2). Depending on specific circumstances and GCDAMP goals, a similar experimental plan would be used for possible future HFEs.

Because the IQW project consists of continuous monitoring of flow and sediment at the specified measurement locations, additional work is not required or proposed in association with the fall steady flow experiment. The effects of the planned steady flows on flow, suspended sediment concentrations, and mainstem water temperatures will be integrated within the IQW project. Water temperature in nearshore environments will be investigated in cooperation with the nearshore ecology study.

Integration

Interdisciplinary studies between the IQW project and other resource areas have great potential and have been highly productive, resulting in high-resolution data streams for temperature, conductivity, and suspended-sediment data throughout the CRE. Integration will be necessary to answer most of the SSQs 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 biologists 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 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 HFE implementation) to contribute to wind-transported sand into arroyos and other geomorphic settings where archaeological sites have eroded.

During the monitoring and research period of FY2007–11, continued efforts will be made to link core monitoring within the downstream IQW project to food web, fishery, recreation, and archaeological science projects. Special emphasis will be placed on the collection of temperature data that supports improved modeling capabilities for predicting downstream water temperature in the main channel and nearshore habitats. These nearshore data will be collected within the context of seasonal field activities conducted within the fishery, food web research trips, and at sites where those science efforts are already being focused.

The primary objective for promoting use of the IQW core-monitoring data to achieve greater integrated science will be not only to collect these data, but to make them readily accessible to other cooperating scientists and managers so that they can be integrated into focused research and development, as well as experimental research efforts. Historical temperature, flow, and sediment data will be used also in updating and advancing the Grand Canyon conceptual model developed in the late 1990s. Conceptual modeling workshops held during 2009–12 will have access to quality-of-water data from both Lake Powell and downstream IQW efforts.

Sand bar mapping and change detection studies, scheduled for 2009 and beyond, will also have the advantage of using the continuous fine-sediment mass balance core-monitoring data to evaluate sandbar area, volume, and grain-size changes. These changes are being identified over the period 1999–2009, as airborne, remote-sensing missions capture imagery of ecosystem shorelines. With these core-monitoring data for fine-sediment flux, scientists and managers may better evaluate the relationship between dam operations (including HFE 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 the GCDAMP ecosystem goals

Strategic Science Questions and Information Needs

The research and monitoring plan for sediment storage is designed to address scientific questions and information needs relating to the identified long-term goal of achieving and maintaining sufficient sandbars and related habitats. In 2004, the AMWG identified several priority questions, including priority question 4, which relate directly to sediment: What is the impact of sediment loss, and what should we do about it?

In addition, during the 2005 knowledge assessment workshops, sediment scientists also identified uncertainty about achieving sandbar conservation objectives and posed key SSQs for GCDAMP goal 8 around those uncertainties. The most critical strategic science questions that emerged as the focus of monitoring and research activities for goal 8 are

- **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?
- **SSQ 4-3.** What are the effects of ramping rates on sediment transport and sandbar stability?
- **SSQ 4-4.** What is the rate of change in eddy storage (erosion) during time intervals between BHBFs?

Also identified as part of the GCDAMP Strategic Plan are several Core Monitoring Information Needs which are addressed in the goal 8 sediment monitoring program (CMINs), including:

CMIN 8.1.1. Determine and track the biennial sandbar area and fine-sediment volume and grain-size changes within eddies below 5,000 cfs stage, by reach. (fourth-ranked goal 8 CMIN).

CMIN 8.2.1. Track, as appropriate, the biennial or annual sandbar area, volume and grain-size changes within and outside of eddies between 5,000 and 25,000 cfs stage, by reach. (second-ranked goal 8 CMIN).

CMIN 8.5.1. Track, as appropriate, the biennial sandbar area, volume, and grain-size changes above 25,000 cfs stage, by reach (fifth-ranked goal 8 CMIN).

CMIN 8.6.1. Track, as appropriate, changes in coarse sediment (> 2 mm) abundance and distribution.

CMIN 9.3.1. Determine and track the size frequency, and distribution of camping beaches by reach and stage level in Glen and Grand Canyons (top-ranked goal 9 CMIN).

Monitoring and Research Activities

Three monitoring and research activities are categorized below: 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 SEDS-PEP review process during 1998–2006 (final report available at www.gcmrc.gov). This resulted in the preparation by GCMRC of a sediment core monitoring plan (*Draft Report to the Technical Work Group of the Glen Canyon Dam Adaptive Management Program: Recommended Protocols for Core Monitoring of Sediment within the Colorado River Ecosystem Below Glen Canyon Dam, Part IV – Developing a Scientifically Based Long-Term Monitoring Plan for the GCDAMP*). The plan has been reviewed by the science advisors and is currently being reviewed by the TWG. The portion of that plan pertaining to goal 8 is the basis for the monitoring plan described herein.

Core-Monitoring Activities

Research and monitoring efforts have guided the development of the current fine sediment core monitoring plan. Results from reach-based fine sediment monitoring that occurred between 2002 and 2005 demonstrated that 90% or more of the fine sediment is stored in the eddies and channel at elevations lower than the 8,000 ft^3/s stage (Hazel and others, 2006). Additionally, this study demonstrated that change in that low-elevation sediment storage computed from repeat measurements over short reaches (~ 10 km) is not consistent with the change in storage over longer reaches (~50 km) computed based on the measurements of sediment transport (Topping and others, 2006). While the measurements of sediment transport that are made as part of the goal 7 IQW monitoring program will be used to detect changes in sediment storage in long reaches over short timescales (up to ~ 2 yr), accumulated uncertainty in these measurements will prevent the determination of longer-term (5 – 10 yr and longer) trends in sediment storage with adequate certainty. The transport monitoring is necessary to track the accumulation and fate of tributary inputs and provide information needed to plan high flow events. However, in order to determine whether sediment storage in the system as a whole is increasing, decreasing, or stable requires repeat measurements of sand storage throughout the entire system. For these reasons, goal 8 fine sediment monitoring includes system-wide measurements of channel and eddy sand storage in addition to monitoring related to high-elevation sandbars, campsites, and backwaters.

Low-elevation sand storage will be monitored by annual (excluding years with HFEs), measurements of the area and volume of fine sediment over long reaches (> 50 km) using multibeam bathymetric surveys, ground-based topographic surveys, underwater video transects, and limited underwater microscope data collection for bed grain size. This task is planned to be performed on a systemwide basis every 5–10 years in order to estimate fine sediment budgets over timescales for which the goal 7 mass balance sediment budgets likely become inconclusive. In addition to providing this key sediment budget information (i.e., the status of the fine sediment "bank account"), these data will provide information on the location and geometries of backwaters thought to be important habitat for native fish. Currently, it is logistically impossible to survey the bathymetry of the entire river in any given year. Therefore, a different reach of the river will be surveyed each year on a rotating basis. The reaches will correspond to the segments outlined in the goal 7 mass balance core-monitoring project, such that upon completion of a repeat survey for a given reach all components of the sediment budget (the sediment influx at the upstream gage, the sediment efflux at the downstream gage, and the change in storage between

the gages) for that reach will have been measured directly. The reaches are as follows: Reach 1: RM 0 to RM 30 (upper Marble Canyon); Reach 2: RM 30 to RM 61 (lower Marble Canyon); Reach 3: RM 61 to RM 87 (eastern Grand Canyon); Reach 4: RM 87 to RM 166 (central Grand Canyon); Reach 5: RM 166 to RM 226 (western Grand Canyon).

These surveys will occur in the late spring and will only be completed in years without HFEs; thus, in the absence of HFEs, each reach would be surveyed every 5 years, or, if HFEs occurred on average every other year, then each reach would be surveyed on average every 10 years. The 5–10 year interval is considered by sediment scientists to be sufficient to detect long-term trends in the fine sediment budget based on changes in topography and bathymetry. Because reaches 4 and 5 are much longer than reaches 1-3, it is possible that portions of these reaches will not be surveyed. Existing side-scan sonar data may be used to identify the portions of these reaches that are most likely to store fine sediment. It is also possible that continued technological advancements and improvements in methods will allow for complete surveys of these reaches in the future.

Monitoring High Elevation Sandbar Deposits and Campsites

Sandbars and campsites will be monitored by infrequent remotely-sensed inventory and annual ground-based measurements. Approximately every 4 years (excluding years with HFEs), the system-wide area of fine sediment above the stage associated with a discharge of 8,000 cfs (i.e., approximately 10 percent of the fine sediment in the CRE) will be monitored using orthrectified hyperspectral aerial photography images collected during overflights (the volume of fine sediment may also be monitored if light detection and ranging (LIDAR) sensors are also deployed). These remote-sensing data are also used to help monitor the magnitude and trends in campsite area, backwater area and distribution, the availability of open dry sand on sandbars, as well as for other resource areas such as riparian vegetation monitoring. An overflight is scheduled to occur next in spring 2009.

A subset of sandbars and campsites located throughout the CRE will be monitored annually using conventional ground-based surveying methods. This dataset is commonly referred to as the "NAU sandbar time series" and is the longest running dataset on the state of sandbars currently available (initiated in 1990). Previous studies have shown that this monitoring effort tracks significant trends in the area of sand above the 8,000 cfs stage (Schmidt and others, 2004). This task is conducted in coordination with goal 9 core monitoring and will take place in the fall of each year and will include measurements of the area and volume of fine sediment above the stage associated with 8,000 cfs.

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

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 main channel rapids, upper pools, and runs above rapids and through deposition of new gravel on existing debris fans and eddies. These geomorphic changes influence the ecosystem's flow dynamics in and between rapids and effectively increase the abundance of gravel substrates spatially. Monitoring of changes resulting from continuing tributary inputs of gravel will be conducted as part of the repeat channel mapping, thus enabling detection of long-term trends in coarse sediment storage. Although debris fans will not be mapped during the

channel mapping, changes in water surface elevation that result from debris flows will be detected. In the event of large tributary debris flows that significantly alter the navigational characteristics of the main channel, additional field activities may be needed on a contingency basis.

Research and Development Activities

Research and Development in Support of Goal 8 Monitoring

Research and development activities occur in goal 8 in association with the core monitoring activities, described above. These activities will include analysis of the channel mapping data to detect topographic and bathymetric change between surveys, and analysis of overflight imagery for changes in sand area.

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 HFEs. For this reason, in support of the evaluation of experimental flows from GCD, GCMRC program staff will collect, as need arises, additional sand storage data throughout the main channel of the CRE. No additional sediment monitoring is planned to occur related to the fall steady flows.

Two specific types of experimental sediment activities that are anticipated during the FY2009–12 period of monitoring and research are described below.

High Flow Experiments Tests

Sediment research results from the 2004 HFE test suggested that short-duration, 41,000–45,000-cfs dam releases 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 recommended that the sediment-enriched test be repeated during the winter or spring months to determine whether repeated 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 figure 3.

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 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 HFE test is intended to answer the primary strategic science question for sediment (SSQ 4.1) listed above. If a future HFE 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 determine the optimal recurrence interval for HFEs that is required to achieve the desired sandbar resources throughout the ecosystem. The 2008 HFE was implemented as part of this approach and results will address these questions.

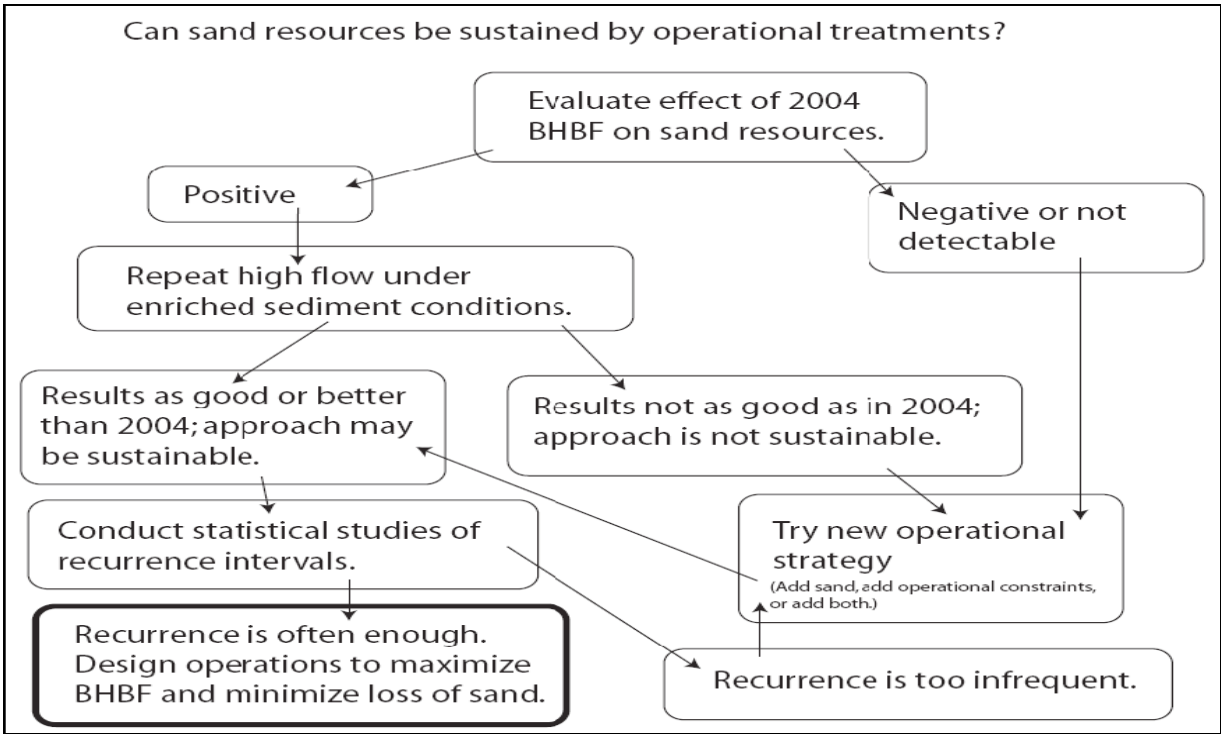

Figure 3. Flow chart showing the proposed experimental strategy for evaluating a flow-only operational strategy. The experiment will evaluate if restoration and maintenance of sandbars below Glen Canyon Dam can be successful using repeated beach/habitat-building flows during years when tributaries produce average to above-average sand inputs to the Colorado River ecosystem.

Experimentally Evaluate Alternative Ramping Rates

The stability of sandbars and their fate following HFEs 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 downramp 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 downramp rates, are therefore identified as a priority for further experimental flow research to determine if downramping at more than the currently allowed rate of 1,500 cfs/h significantly increases sandbar erosion rates between episodes of beach building and sandbar restoration.

Data relating to alternative ramping rates (SSQ RIN 4) could be collected through experimental field measurements, modeling, and laboratory studies of alternative fluctuating flows during 2009–12. Data would also be collected before and after HFEs, using methods developed for sandbar monitoring during 2000–05. Sandbar measurements will focus on areas identified in recent synthesis research reports as representative for eddy and sandbar responses within Glen, Marble, and Grand Canyons. New methods will also be used to refine information

on how alternative ramping rates and daily stage ranges (relative to the ROD) influence sandbar stability and related habitats below the dam. Ongoing monitoring data on suspended-sediment transport will also be evaluated to determine how alternative fluctuating flow operations influence downstream sand transport (export).

Integration

Sand storage studies will continue to be integrated into monitoring and research on recreation camping sites, terrestrial vegetation, 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 will be used to verify results of the fine-sediment mass flux element of the downstream IQW project, as well as to verify sand-transport- and sandbar-modeling results.

An example of an integrated project related to sediment resources is the analysis of mapping shoreline habitat changes project that is currently nearing completion. This effort was undertaken as an experimental support activity associated with the collection of digital remotely sensed imagery from May 2005 (systemwide data were also collected in 2002 and 2004) and was directly related to conservation measures identified with the November 2004 HFE test.

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 MRP seeks to address discrete scientific questions, information needs, and objectives required to achieve goal 9.

In 2004, the AMWG identified several priority questions. Priority 3 relates directly to goal 9: What is the best flow regime?

In addition, a number of SSQs related to the effects of flows on recreation emerged from the knowledge assessment workshop conducted in July 2005. These SSQs 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 CRE. The most critical SSQs 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 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 SPG subsequently refined and prioritized the CMINs to define 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 CRE.
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 CRE.

Note: In June 2005, a 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 NPS CRMP. In addition to the SSQs, the recommendations provided in the PEP report form the foundation for the FY2009–12 recreation program described below.

Monitoring and Research Activities

Monitoring and research activities related to recreation for FY2009–12 encompass all three elements of the MRP: 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 FY2009–12, the GCMRC will continue to monitor changes in campable area at the NAU sandbar study sites, while concurrently exploring alternative methods to evaluate changes throughout the CRE.

FY2009–12. Sandbar and Campable Area Monitoring (Project REC.9.R1.07)

In FY2009–12, the GCMRC will monitor campable area at the NAU sandbar study sites using conventional survey methods as in the past (Kaplinski 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 FY2009–12 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 on the effects of changing sandbar area and morphology on campable area.

Concurrently, in FY2009–10, the GCMRC will explore options for using remote-sensing data to evaluate changes in campable area through focused research and development. Previous research (see Project REC 9.R2.07 and Project REC 9.2.R3.07 below) have explored specific alternative means of measuring open sand area using remotely sense data and GIS analysis techniques. In 2009, GCMRC will conduct an overflight and gather 4-band digital imagery. This data will be used to assess changes in campable area due to vegetation encroachment throughout the river corridor. These results will be evaluated through comparing remotely

sensed measurements with surveyed measurements obtained from a subset of campsites being monitored with repeat total station surveys.

Status and Trends in Recreational Angling

A key interest of recreational anglers in lower Glen Canyon is the quality of the RBT fishery (specifically size, number, and health of fish), which is directly related to the available food supply. In FY2009–12, the condition of the Lees Ferry trout fishery will be monitored through routine stock assessment procedures conducted by 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 and steady flow experiments), while a focused research effort will be conducted in FY2010–11 to improve our understanding of how flows affect other recreational attributes (see Project 9.R5.10 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 future experiments and management actions can be evaluated. Furthermore, they recommended that the GCMRC invest in studies to 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 FY2009–12 in response to the 2005 PEP recommendations.

FY2007–09. Compile Campsite Inventory and Geographic Information Systems Atlas (Project REC 9.R3.07)

The last comprehensive campsite inventory was completed more than 20 years ago after the 1983 uncontrolled release from GCD. 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. Beginning in FY2007, and continuing through FY08-09, GCMRC has been working collaboratively with Grand Canyon National Park staff to compile an up-to-date inventory and Geographic Information Systems (GIS) atlas of all previously and currently available campsites in the CRE. When completed, the campsite atlas will include information on campsite 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 the basis for evaluating recreation impacts on other CRE resources of concern such as archaeological sites.

FY2009. Evaluate Campable Area Monitoring Results Using Measured Field Data vs. Remotely Sensed Data (Project REC 9.R2.07)

An initial comparison of campable area monitoring results derived through field measurements and GIS-based analysis of remotely sensed imagery and topography was initiated in FY2007. A pilot effort conducted in FY2005 demonstrated that estimates derived from remotely sensed data consistently overestimated campable area, compared with measurements derived from field surveys; therefore, one desired outcome of the proposed study was the development of an algorithm to allow comparisons of previously collected campable area data (derived from field surveys) with future data derived from remotely sensed imagery. Due to other priorities, including the initiation of the High Flow Experiment in spring 2008, a final report on this work was not completed. A written report will be prepared summarizing the results of this study in FY09, Depending on final results, it may be possible to transition the campable area monitoring program to one based largely, or exclusively, on remotely sensed imagery.

FY2009. Compile and Analyze Existing Safety Data (Project REC 9.R4.09)

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 being funded for implementation in FY2009.

FY2010–11. Evaluate the Relative Importance of and Tradeoffs to Recreation-Related Attributes Affected by Flows on Recreation Experience (Project: REC 9.R5.10)

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 downriver with consequent implications for social encounters and crowding; and the size, abundance, and condition of RBT). Flows affect these recreational attributes in varying and sometimes conflicting ways. The purpose of this study is to determine the relative importance of the recreation-related physical, biological, and social attributes and conditions that are affected by flows, and to analyze the tradeoffs to recreational experience quality that are created by implementing various flow regimes.

FY2011. 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 image maps of CRE campsites. The NPS is currently working on relocating the photo points used to obtain the images. In FY2007–08, using volunteer photographers, the NPS located and duplicated (with snap shot photographs) many of the 1973 Weeden survey photographs. This work will continue in FY2009, and these data will be integrated into the campsite atlas. In FY10-11, GCMRC proposes to duplicate the images using volunteer and professional

photographers, and undertake a formal analysis of differences between the photographic images from the Weeden survey and identical images collected in 2010–11. This analysis will provide a diachronic perspective on campsites change in the CRE during the past 35+ years.

FY2010. Quantify Vegetation Encroachment at Campsites

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

FY2010–11. Update Regional Recreation Economic Studies

By FY2010, existing economic baseline studies will be 20 to 25 years old, so in FY2010–11, economic valuation studies for CRE-based recreation will be repeated.

Long-Term Experimental Activities

Several studies will be initiated in conjunction with the experimental flows of FY2009–12 to evaluate the effects of various experimental flows on recreation. These studies will evaluate the effects of high flow, ramping rates, and steady flow experiments on beach morphology, size, and distribution (e.g., campable area), as well as post-HFE effects on 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 HFEs on Campsites

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

Evaluate Effects of HFEs, 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 GCD EIS 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 could 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 might be more conducive to spreading human pathogens than others. This project will evaluate human health

risks associated with different 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 NPS.

Integration

Physical Science Program

Changes in campable area are largely, but not exclusively, caused by 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). Evaluating the effect of sandbar morphology on campable area requires comparisons of topographic data derived from the sand storage monitoring program against prior campable area survey results. This program underwent a PEP review in FY2006 in part to define core-monitoring protocols for tracking sediment storage in the CRE. Although the protocols for sand storage monitoring have not yet been defined, campable area monitoring will continue to a large degree to rely on and be integrated with data derived from the Physical Science and Modeling Program.

In addition, flow-stage modeling based on the improved sediment transport and river simulation (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 GCMRC's DASA 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, 2005, and 2009 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 the 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 GCDAMP reviews have identified the need for more emphasis to be placed on the 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 CRE.

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 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

In August 2004, the AMWG identified the third priority question: "What are the best flows?" This question has obvious implications for hydropower, because "the best flows" are evaluated both from the perspective of optimizing hydropower generation and also in terms of optimizing 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 MRP focuses on discrete scientific questions, information needs, and objectives.

The 2005 knowledge assessment workshops identified two key SSQs 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 SPG reviewed, revised, and prioritized the 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 GCD hydropower generation and opportunity costs under MLFF operations have been identified as information needs by the GCDAMP. These parameters are routinely monitored by Reclamation and the 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. The data will then be made available through the GCMRC Web site.

FY2009–12 (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 FY2008, GCMRC DASA staff developed and tested computer programs for organizing and serving tabular data sets through a web-based application. In FY2009, the GCMRC will work with Reclamation and WAPA to serve and archive 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

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., the LSSF 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 recommendations to the DOI.

In preparation for conducting future experimental flows, an economic analysis of predicted hydropower opportunity costs under various alternative experimental scenarios was undertaken in FY2006. This study evaluated 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) provided input on the models and assumptions used to generate the results and will provide hydropower production cost and power sales data to be factored into the analyses. In the future, independent studies are needed to evaluate the accuracy of these predicted costs and in necessary, refine the models for predicting costs of future experiments.

FY2010–11. Evaluate Economic Implications of Experimental Flows

Once the experiment is initiated, the GCMRC will track costs associated with the 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 FY2011–12, 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 projected 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 AMWG identified the following questions as the second highest priority of the GCDAMP: "Which cultural resources, including TCPs, are within the Area of Potential Effect 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, Reclamation and the NPS have agreed to develop a treatment plan for 161 archaeological sites of the 323 sites potentially affected by dam operations in the CRE. The sites subject to treatment have been determined by NPS to be actively deteriorating through a variety of agents. With immediate treatment needs now being addressed by Reclamation and NPS, 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 agents of deterioration in affecting cultural resources, and the long-term effectiveness of the treatment measures.

To focus monitoring and research activities for cultural resources even more, the MRP is placing its attention on five key SSQs, which are as follows:

1. **SSQ 2-1.** Do dam controlled flows increase or decrease rates of erosion at archaeological sites and traditional cultural property (TCP) sites, and if so, how?
2. **SSQ 2-2.** How do flows impact old high-water zone (OHWZ) terraces in the CRE, 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?
3. **SSQ 2-3.** If flows contribute to archaeological 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 CMINs under goal 11. The GCDAMP SPG subsequently refined and prioritized the CMINs for cultural resources to define the most important monitoring needs under each GCDAMP goal for the allocation of 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 CRE through tracking rates of erosion, visitor impacts, and other relevant variables. Determine the condition and integrity of TCPs in the CRE.
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 research on direct, indirect, and interactive effects of flow regimes. To partially address this need, in FY2006 the GCMRC initiated a multiyear, multifaceted archaeological site-monitoring research and development project to continue during the first years of this MRP. This work included the compilation and analysis of existing archaeological site legacy data in September, 2007 (Kintigh and others, 2007

At a minimum, a better understanding of how dam-controlled flows affect erosion rates at cultural sites is needed. This need can be met through implementing monitoring protocols that 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 consequences related to the timing and frequency of 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 OHWZ 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 effectively achieved by integrating cultural resource monitoring with physical and biological elements of the science program. In FY2006, the tribes were funded to synthesize their existing monitoring data and define approaches to monitor culturally important resources in the CRE. In FY2008, the tribes received funding to begin (or continue) implementing 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 PEP in FY2010.

As noted above, core-monitoring programs are currently under development (see discussion under research and development activities section below). The current plan calls for

implementation of revised core-monitoring protocols for cultural resources as part of a 3-year pilot program in FY2009–11, followed by a cultural PEP later in FY2011.

FY2011 (New). Cultural Protocol Evaluation Panel Review

Following completion of research and development for core monitoring and effects of 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 since the 2000 cultural PEP and evaluate the results of research and development in FY2006–11. Based on the findings of the second PEP, or Cultural PEP II, a refined core-monitoring program will be implemented beginning in FY2012.

Research and Development Activities

In FY2009–11, the GCMRC will continue several research and development activities initiated in FY2006 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 conditions, so the evaluation of other indicators, such as human disturbance indicators and weather parameters, will also be pursued.

FY2006–07. Research and Development toward Core Monitoring (Project CUL.11.R1.07)

The project involved the following three tasks (for more detail, see project description in the FY2007 and FY08 annual work plan):

1. **Task 1: Assessment of archaeological sites for future monitoring.** Continue geomorphic and archaeological integrity assessments initiated in FY2006 at a subset of archaeological sites in the CRE to define the 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 FY2007, 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 the 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 tradeoffs 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- and long-term resource impacts. Additional subtasks that will be included under this protocol evaluation task are

    - FY2007–08: Refine protocols for evaluating erosion control effectiveness. In addition to refining protocols for core monitoring, in FY2007–08 the GCMRC continued 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 USU under the treatment planning effort in FY2006.

- FY2007–08: Test and refine weather-monitoring protocols. This effort explored 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.
- FY2007–08: Test and refine human impact-monitoring protocols. The original plan (in 2007) was to explore options for tracking and quantifying impacts of human visitation that result in measurable changes to archaeological site condition, and develop protocols for monitoring impacts in coordination with the NPS Colorado River Management Plan in order to meet multiple agency needs for human impact data in the CRE; however, the NPS subsequently elected to develop monitoring protocols for the CRMP independently of the GCMRC. In FY2009, CRMP monitoring protocols will be evaluated by GCMRC and incorporated, as appropriate, with protocols being developed to track physical changes at archaeological sites, and particularly for human impacts such a biological crust damage, soil compaction, and trailing that directly influence rates of erosion, vegetation parameters, and other site attributes potentially affected by dam operations and directly influencing site stability.

FY2009–11. 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 FY2009 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 comply with Sections 106 and 110 of the National Historic Preservation Act (for both Reclamation and NPS) and the mandates of the Grand Canyon Protection Act. In FY2006, the tribes were funded to 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 TWG) to develop criteria to guide the site selection process for the long-term monitoring program and the specific protocols to be piloted in FY2008–10. The details of the FY2009–11 pilot monitoring programs will be determined upon completion of the initial research and development phase, which is currently targeted for December 2008. This pilot monitoring effort constitutes the second phase of research and development towards core monitoring and will conclude with a PEP review at the end of FY2011.

In FY2009 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:

FY20010–11 (New). Expand Pilot Study to Evaluate Geomorphic Changes in the CRE using Remotely Sensed Imagery

This project was originally planned to be implemented in FY2007, but due to multiple technical hard and soft ware issues related to scanning and orthorectifying existing legacy imagery, it was not possible to implement the pilot study in FY2007 or FY2008 as originally planned. In FY2010, we will evaluate terrace changes using remotely sensed imagery in a pilot study, and if the pilot study proves successful, we will expand the effort in FY11. The GCMRC will initiate a pilot study in FY2010 to explore the utility of existing remotely sensed imagery for tracking geomorphic change at archaeological sites, and specifically, for evaluating rates of terrace retreat and arroyo erosion using digitized images of historical aerial imagery. In 2011, we will continue to explore the utility of using digitized historical aerial photographs to track and quantify geomorphic changes due to dam operations and interacting physical processes, using methods developed in the FY2010 pilot effort and applying them to other reaches of the CRE with high concentrations of culturally significant resources. As in the past, this project hinges on the completion of an ongoing internal GCMRC efforts to digitize and evaluate the accuracy of historical aerial photographs that are currently stored in hard-copy format at the GCMRC library

FY2010–11 (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 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 submodel of the broader CRE conceptual model that is proposed for development in FY2009–10. 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., the improved HEC-RAS model for depicting stage discharge relations in the CRE).

Long-Term Experimental Activities

Beginning in FY2008, the following studies have been or will be initiated in conjunction with experimental flows:

FY2008–12. Evaluate Effects of HFE Sediment Deposition at Archaeological Sites and TCPs.

This focused study will assess the effects of HFEs at a sample of historic properties in terms of subaerial sediment transport rates before and after the high flow event 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.

FY2008–12. 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.

FY2008–12. 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 by 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 GCD, and 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 with respect to the physical sciences following the FY2006 PEP review. 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 HFEs, 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 subaerial sedimentary deposits and processes in the CRE will be incorporated into the future sediment monitoring program.

Biological Sciences

Vegetation growth and cover are important variables affecting erosion rates in the CRE. Repeat mapping capabilities using remotely sensed data that are being developed to quantify vegetation change could 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 monitoring tools for tracking vegetation changes at cultural sites.

The Native American tribes who participate in the GCDAMP are interested both in the implications of vegetation cover for mediating erosion rates at archaeological sites and in monitoring of vegetation and faunal resources of the CRE because of their traditional cultural values. The tribes was to define their needs for biological resources monitoring data in FY2006–07; a PEP of the TEM program was convened in FY2007 to evaluate the tribal monitoring

protocols in conjunction with the TEM protocols that were piloted in FY2002–05 by NAU and the University of New Mexico. The PEP was intended to design 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, close coordination is needed with relevant monitoring and research programs being developed by Grand Canyon National Park (GRCA) under the auspices of CRMP implementation. In FY2006, GRCA is initiating a multiyear research and development effort to improve understanding of the 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 programs can improve our understanding by evaluating how visitation could affect 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 runoff. 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 GCDAMP goals 1–11 because they are fundamental to addressing priority AMWG questions and related science questions and information needs. The activities fall into the following seven categories:

1. GCMRC staffing
2. Reporting
3. Independent science advice and review
4. Bridging science and management
5. Logistical support
6. DASA
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 TWG to develop and implement effective collaborative management planning and processes..

The GCMRC will include permanent and temporary science and technical staff to implement or coordinate monitoring and research projects. Contractors and cooperators will conduct a large amount of our field work activities and feed the data back to GCMRC scientists for analysis, synthesis, and publication. GCMRC scientists will be engaged in 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 DOI. Productive, well-qualified personnel are critical to meeting and achieving this goal. To provide strong leadership and a quality science program responsive to the needs of the GCDAMP, a core program management staff will direct GCMRC operations and oversee the five major program areas: Physical Sciences and Modeling; Biological Science; Cultural and Socioeconomic; Logistics; and DASA. 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 function 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 findings in peer-reviewed publications. 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 other 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 USGS fact sheets or informational products in accordance with USGS policy. The GCMRC will produce an annual accomplishment report in December of each year that will briefly summarize accomplishments or shortcomings for each project included in the biannual work plan. The annual accomplishment report will also include recommendations for project modifications, as needed. In FY2011 and FY2012, the GCMRC will update the KAR and SCORE reports 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 provide independent scientific oversight and technical advice. The SA will be used in both a review and advisory capacity to evaluate the efficacy of the science program. Using the SA in an advisory capacity will be closely monitored to ensure that it does not affect SA objectivity as an external independent review panel.

The SA will be managed and operated in accordance with AMWG approved protocols adopted in October 2000. In FY2009 GCMRC will review and revise these protocols in coordination with the TWG and AMWG. Up to eight scientists will serve as SA and an executive secretary will administer, coordinate, and report on their activities. In cooperation with the Senior Ecologist, the SA will evaluate the best opportunities for implementing an integrated ecosystem science and modeling approach into the current science program and invoking greater interdisciplinary approaches in FY2009–12 science activities. Specifically, the SA will assist in evaluating 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 CRE resources, GCMRC staffing, and costs of implementing new ecosystem strategies. SA recommendations will be reviewed by the GCDAMP and implemented as appropriate in FY2009–12.

FY2009–12. 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 in accordance with the established GCMRC peer-review process and USGS Fundamental Science Practices.

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 of GCDAMP stakeholders.
2. To be successful, GCMRC scientists and GCDAMP managers must work together as partners—partners who recognize that they both have distinct but complementary 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 SA 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 SA evaluation to discover opportunities for improving interdisciplinary, integrated science in the GCDAMP. In FY2010–11, the GCMRC will enter into a contract/cooperative agreement to assess the feasibility of using decision-support systems and tools to facilitate the integration of scientific data and information in GCDAMP decision-making processes, including resource tradeoff analyses, risk assessments, and innovative organization and display of data. The feasibility assessment will result in a prioritized implementation plan, schedule, and budget. Recommendations will be implemented in FY2011–12 in accordance with established budget priorities.

FY2010. GCDAMP Effectiveness Workshop (Project PLAN 12.P2.07)

In FY2010, GCMRC will facilitate a 2- to 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 will include GCDAMP participants and national experts in collaboration, partnerships, Native American involvement, and conflict resolution. The workshop will be designed and conducted in cooperation with Secretary's Designee and GCDAMP participants. The GCMRC recommends the establishment of an ad hoc group made up of representatives of the TWG, AMWG, SA, 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 2011–12 program period.

FY2009–10. Enhancing the CEM to Identify Critical Ecosystem Interactions and Data Gaps (Project PLAN 12.P1.07).

In FY2009-2010, the GCMRC will work with the senior ecologist (Dr. Carl Walters) and the SA to identify and incorporate more robust integrated ecosystem science approaches into the GCMRC program. The first step will be to evaluate redesign and expansion of the CRE CEM.

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 NPS and all other Federal, State, and Tribal agencies. Research projects supported by the GCMRC must acquire required permits for project activities in compliance with Federal, State, Tribal, and local agencies. The program integrates both permitting and logistical operations.

Research activities conducted within GRCA 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 (GCD 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 LCR and at other locations outside of GRCA boundaries are supported by helicopter services provided by the Department of the Interior's Office of Aircraft Services (OAS). Ground-based support for research activities outside of the river corridor are also accomplished with the use of vehicles leased by the GCMRC.

FY2009–12. 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 in the past. Retaining control over support of trips also facilitates compliance with NPS and other regulations and allows greater control over issues that are sensitive for 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 DASA Program is to provide timely support for the acquisition, archiving, retrieval, analysis, and modeling of all scientific datasets 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.

FY2009–12. Preparation for Monitoring Data Acquisition (remote sensing) (Project DASA 12.D1.09)

This project provides multispectral digital images used for detecting macro-scale changes in habitat conditions throughout the Colorado River corridor below GCD. 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 overflight is scheduled to occur in FY2009; the last overflight was conducted in May 2005.

FY2009–12. Grand Canyon Integrated Oracle Database Management System (Project DASA 12.D2.09)

This project establishes an electronic repository for project data and the tools necessary to analyze and interpret these 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 accommodate both newly collected and existing data. Developing an integrated database design also involves extensive review of existing datasets and current data-collection protocols. Tools, including Web-based interfaces, will be developed that enable users to extract related datasets and perform appropriate analyses.

FY2009–12. Library Operations (Project DASA 12.D3.09)

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. To facilitate the use of library materials, 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.

FY2009–12. Legacy Analog Data Conversion (analog-to-digital reports and imagery) (Project DASA 12.D4.09)

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.

FY2009–12. GIS General Support for Integrated Analyses and Projects, GIS Lead (Project DASA 12.D5.09)

The objective of this project is to support science program activities through spatial database development, programming, and analysis. Most GCMRC projects have a spatial component, and 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 datasets 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.

FY2009–12. Integrated Analysis and Modeling (Project DASA 12.D7.09)

The main objective of the project is to study the shoreline environment along the Colorado River downstream of GCD. The project will analyze multiyear multispectral digital imagery. Baseline data sets of shoreline habitat currently exist for the years 2002 and 2005 as area classifications across computer-modeled flow lines. These classes include cliff, debris fan, cobble bar, talus, vegetation, and exposed sand. Additional remote-sensing data sets (2000 and 2009) will be incorporated into the time series of the shoreline habitat project. Future work will be needed to better correlate shoreline habitat with fish data and recreation habitat data collected by GCMRC and its cooperators. Processes exist to automate shoreline irregularities that may provide slack water environments and thermal sink habitats which are indicative of backwaters. In addition to the classification effort, an automated suite of methods could be extended to facilitate shoreline change detection across a range of stages.

FY2009–12. 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 CRE river reaches. Consistent methods and protocols have been developed for spatial data collection and its integration into the

GIS. Trained GCMRC survey staff support monitoring and research by collecting survey data with these protocols and delivering the data in formats consistent with data standards.

FY2009–12. Control Network (Project SUP 12.S3.07)

The objective of this project is to develop a high-precision control network throughout the CRE and at locations required for accurate positions and elevations of past, current, and future datasets. The goal of the project is the expansion of the control network into the necessary areas before collecting the spatial data required by GCMRC research and core-monitoring activities. Having stable control monuments and accurate coordinates completed before spatial data acquisition begins reduces the effort required in post processing and promotes conservation of both human and funding resources. Historical datasets 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 and financial management of cooperative and interagency agreements; processing of contracts; timekeeping; bank card tracking and reconciliation; travel planning 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). This activity is closely 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 h. In addition, the SBSC Information Technology Department supports technology needs for various GCMRC program areas.

FY2009–12. Administrative Operations (Project ADM 12.A1.07)

The goals of this 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 SBSC through its Information Technology 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 possible disruption in service. 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 that all those who access the systems meet Federal security

standards to protect personal information and scientific research that has not yet been released to the public. The IT Department also works in coordination with DASA to provide full and easy access to publicly released data via the GCMRC Web sites.

FY2009–12. 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 FY2009–12 Monitoring and Research Plan

Table 4 identifies the total anticipated funding to support GCMRC monitoring and research activities related to the GCDAMP, including anticipated power revenues, continued Reclamation funding for Lake Powell monitoring, and anticipated 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 GCMRC SSP and MRP. Funding emphasis will be given to address the SSQs 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. 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 4. Total anticipated funding to support the GCMRC Monitoring and Research Plan in fiscal years 2009 through 2012 (tribal participation is not included in this table).

FUNDING SOURCES	Fiscal year (FY) 2009	FY2010	FY2011	FY2012	TOTALS
Power revenues under cap—estimated USGS portion[(1)]	$7,876,244	$8,112,531	$8,355,907	$8,606,584	$32,951,266
Power Revenues under cap held in Experimental Fund by Reclamation	$500,000	$500,000	$500,000	$500,000	$2,000,000
Reclamation Appropriated Funding for Near Shore Ecology	$500,000	$500,000	$500,000	$500,000	$2,000,000
USGS appropriations—assistance with burden costs (cost share)	$1,000,000	$1,000,000	$1,000,000	$1,000,000	$4,000,000
USGS appropriations—Administrative, Budget and IT support	$380,000	$410,000	$435,000	$460,000	$1,685,000
Reclamation operations and maintenance (Water Quality Lake Powell and Tailwaters Agreement)[(1)]	$227,251	$234,068	$241,091	$248,324	$950,734
TOTAL AVAILABLE FUNDS	**$10,483,495**	**$10,756,599**	**$11,031,998**	**$11,314,908**	**$43,587,000**

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

References Cited

Anders, P., Bradford, M., Higgins, P., Nislow, K.H., Rabeni, C., and Tate, C., 2001, Grand Canyon Monitoring and Research Center protocols evaluation program: Final report of the aquatic protocol evaluation panel, unpublished, 43 p.

Bureau of Reclamation, 2001, Strategic Plan Glen Canyon Dam Adaptive Management Program (Final Draft. August 17, 2001): Salt Lake City, Utah, Upper Colorado River Region, 52 p.

Fairley, H., Coggins, L., Fritzinger, C., Gonzales, M., Gushue, T., Hueftle, S., Kennedy, T., Liszewski, M., Melis, T., Ralston, B., Topping, D., Vernieu, W., and Wright, S., 2005. Provisional Core Monitoring Plan Final Draft.

Gloss, S.P., Lovich, J.E., and Melis, T.S., eds., 2005, The state of the Colorado River ecosystem in Grand Canyon: U.S. Geological Survey Circular 1282, 220 p.

Goeking, S.A., Schmidt, J.C., and Webb, M.K., 2003, Spatial and temporal trends in the size and number of backwaters between 1935 and 2000, Marble and Grand Canyons, Arizona: Cooperative Agreement 0WRAG0059.

Kaplinski, M., Behan, J., Hazel, J.E., Jr., Parnell, R.A., and Fairley, H.C., 2005, Recreational values and campsites in the Colorado River ecosystem, *in* Gloss, S.P., Lovich, J.E., and Melis, T.S., eds., The state of the Colorado River ecosystem in Grand Canyon: U.S. Geological Survey Circular 1282, p. 193–205.

Kearsley, M.J.C., Cobb, N., Yard, H., Lightfoot, D., Brantley, S., Carpenter, G., and Frey, J., 2006, Inventory and monitoring of terrestrial riparian resources in the Colorado River corridor of Grand Canyon: an integrative approach: 2004 draft report to the U.S. Geological Survey Grand Canyon Monitoring and Research Center, cooperative agreement no. 01-WRAG-0044 and 01-WRAG-0034, 126 p.

Kintigh, K., Altschul, J., Lipe, w. and Urquhart, N. S., 2007, Legacy Monitoring Data Review Panel Report to the Grand Canyon Monitoring and Research Center, November 29, 2007. Report on file, US Geological Survey, Grand Canyon Monitoring and Research Center, Sociocultural Program files, Flagstaff, Arizona.

Loomis, J., Cole, D., Foti, P., Manning, R., Moisey, R.N., Ratcliffe, R., 2005. Final Report of the protocol evaluation panel (PEP) for the recreation monitoring program of the Grand Canyon Monitoring and Research Center (GCMRC). dated September 28, 2005. On file, Grand Canyon Monitoring and Research Center, Flagstaff, Ariz.

Melis, T.S., Wright, S.A., Ralston, B.E., Fairley, H.C., Kennedy, T.A., Andersen, M.E., Coggins, L.G. Jr., and Korman, J., 2006, 2005 Knowledge assessment of the effects of Glen Canyon Dam on the Colorado River ecosystem: an experimental planning support document, U.S. Geological Survey, Flagstaff, Ariz., 82 p.

Paukert, C.P., Ward, D.L., Sponholtz, P., and Hilwig, K.D., 2005, Effects of repeated hoopnetting and handling on bonytail chub: Journal of Freshwater Ecology, v. 20, p. 649–653.

Porter, M.E., 2002, Riparian vegetation responses to contrasting managed flows of the Colorado River in Grand Canyon, Arizona: Flagstaff, Northern Arizona University, M.S. thesis, 33 p.

Stevens, L.E., Schmidt, J.C., Ayers, T.J., and Brown, B.T., 1995, Flow regulation, geomorphology, and Colorado River marsh development in the Grand Canyon, Arizona: Ecological Applications, v. 5, p. 1025–1039.

U.S. Fish and Wildlife Service, 2002, Humpback chub (*Gila cypha)* recovery goals: amendment and supplement to the Humpback Chub Recovery Plan: Denver, Colo., U.S. Fish and Wildlife Service, Region 6.

Walters, C., Korman, J., Stevens, L.E., and Gold, B., 2000, Ecosystem modeling for evaluation of adaptive management policies in the Grand Canyon: Journal of Conservation Ecology, v. 4, no. 2, http://www.consecol.org/vol4/iss2/art1/.

Wiele, S.M., and Torizzo, M., 2005, Modeling of sand deposition in archaeologically significant reaches of the Colorado River in Grand Canyon, USA, *in* Bates, P.D., Lane, S.N., and Ferguson, R.I., eds., Computational fluid dynamics: application in environmental hydraulics: Hobeken, N.J., Wiley, p. 357–394.

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 nonnatives 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 HFEs, 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 Glen Canyon Dam 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 HFEs, 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]

APPENDIX B. Crosswalk between Research Information Needs identified in the GCDAMP Strategic Plan and Strategic Science Questions in the Fiscal year (FY) 2007–11 Monitoring and Research Plan.

No.	Adaptive Management Work Group (AMWG) Sequence Number and Category	AMWG Priority	Research information needs (RIN) no.	RIN text	Strategic science questions (SSQs), relevant core-monitoring information needs (CMINs), and Science Advisor (SA) questions. Questions listed below are from the Monitoring and Research Plan (MRP).	Comments
1	1, A	1	2.1.2	Quantify sources of mortality for humpback chub (HBC) <51 mm in rearing habitats in the Little Colorado River (LCR) and mainstem, and determine how these sources of mortality are related to dam operations.	**New SSQ. What habitats and habitat characteristics, if any, will enhance survival, growth, and reproduction of native Grand Canyon fishes, especially HBC, in the mainstem Colorado River?**	The current draft of the HBC management plan calls for a contract to investigate fate of young of year (YoY) HBC. GCMRC is initiating work to address this RIN in FY2007. A new research and development activity will be added to the MRP to further address this RIN.
2	1.5, A	1	2.1.3	What is the relationship between size of HBC and mortality in the LCR and the mainstem? What are the sources of mortality (i.e., predation, cannibalism, other) in the LCR and the mainstem?	**New SSQ. What habitats and habitat characteristics, if any, will enhance survival, growth, and reproduction of native Grand Canyon fishes, especially HBC, in the mainstem Colorado River?**	The current draft of the HBC management plan calls for a contract to investigate the fate of YoY HBC. The Grand Canyon Monitoring and Research Center (GCMRC) is initiating work to address this RIN in FY2007. A new research and development activity will be added to the MRP to further address this RIN.

No.	Adaptive Management Work Group (AMWG) Sequence Number and Category	AMWG Priority	Research information needs (RIN) no.	RIN text	Strategic science questions (SSQs), relevant core-monitoring information needs (CMINs), and Science Advisor (SA) questions. Questions listed below are from the Monitoring and Research Plan (MRP).	Comments
3	2, A	1	2.1.4	What habitats enhance recruitment of native fish in the LCR and mainstem? What are the physical and biological characteristics of those habitats?	**New SSQ. What habitats and habitat characteristics, if any, will enhance survival, growth, and reproduction of native Grand Canyon fishes, especially HBC, in the mainstem Colorado River?** **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?	GCMRC is initiating work to address this RIN in FY2007.
4	2, A	1	2.1.5	Determine the timing and quantity of YoY HBC dispersal (passive and active) from the LCR.	**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	This is informally documented by the consistent observation that catch of young HBC in the mainstem follows spates of monsoonal flows from the LCR. Timing and relative abundance can be addressed quantitatively by

No.	Adaptive Management Work Group (AMWG) Sequence Number and Category	AMWG Priority	Research information needs (RIN) no.	RIN text	Strategic science questions (SSQs), relevant core-monitoring information needs (CMINs), and Science Advisor (SA) questions. Questions listed below are from the Monitoring and Research Plan (MRP).	Comments
					population as influenced by mainstem conditions?	relating the catches in the current GCMRC database to LCR flow data; GCMRC has been pursuing this question in FY2007 and will continue in later years. Determining absolute abundances would require good survivorship of captured and tagged young fish and high likelihood of capturing tagged young fish, both of which are tenuous assumptions.
5	2, C	1	2.2.3	What are the measurable criteria that need to be met in order to remove jeopardy for HBC in the Colorado River ecosystem (CRE)?	None proposed.	Policy question. To support the existing (currently set aside) recovery goals, the U.S. Fish and Wildlife Service (USFWS, 2002) set measurable criteria that we assume would be more stringent than necessary to remove jeopardy. The Grand Canyon population may already meet the 2002 recovery goal targets, being revised in 2007.
6	2, A	1	2.2.5	What are the appropriate habitat conditions for HBC spawning? Where are these found? Can they be created in the mainstem?	**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	Existing data show that HBC are reproducing in the physical conditions of the LCR. Recommendations of the April 2007 science workshop were forwarded to the Bureau of Reclamation for their consideration in the upcoming Environmental Impact Statement (EIS). These recommendations attempted, among other things, to

No.	Adaptive Management Work Group (AMWG) Sequence Number and Category	AMWG Priority	Research information needs (RIN) no.	RIN text	Strategic science questions (SSQs), relevant core-monitoring information needs (CMINs), and Science Advisor (SA) questions. Questions listed below are from the Monitoring and Research Plan (MRP).	Comments
					and how can these habitats best be made useable and maintained? **New SSQ.** What habitats and habitat characteristics, if any, will enhance survival, growth, and reproduction of native Grand Canyon fishes, especially HBC, in the mainstem Colorado River?	describe optimization of mainstem conditions for HBC, and may be tested beginning in water year 2009.
7	2, A	1	2.2.8	What combination of dam release patterns and nonnative fish control facilitates successful spawning and recruitment of HBC in the CRE?	**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 1-4.** Can long-term decreases in abundance of rainbow trout (RBT) in Marble and eastern Grand Canyons be sustained with 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? **New SSQ.** What habitats and habitat characteristics, if any, will enhance survival,	Limiting variables will be important to a timely answer to this question. It is reasonable to think that warmer temperatures (for example, using a temperature control device [TCD]) may be more important that either of the two parameters suggested in this question. Recommendations of the April 2007 science workshop were forwarded to Reclamation for their consideration in the upcoming EIS. These recommendations attempted, among other things, to describe optimization of mainstem conditions for HBC, and may be tested beginning in water year 2009.

No.	Adaptive Management Work Group (AMWG) Sequence Number and Category	AMWG Priority	Research information needs (RIN) no.	RIN text	Strategic science questions (SSQs), relevant core-monitoring information needs (CMINs), and Science Advisor (SA) questions. Questions listed below are from the Monitoring and Research Plan (MRP).	Comments
					growth, and reproduction of native Grand Canyon fishes, especially HBC, in the mainstem Colorado River?	
8	2, A	1	2.2.9	What is the appropriate role of HBC augmentation as a management strategy to establish mainstem spawning aggregations?	None proposed.	Policy and management question. The HBC genetics management plan will address the technical/management aspects of this question. Policy aspects will have to be taken up by the Secretary, GCDAMP committees, and managers, especially USFWS and Arizona Game and Fish Department (AZGFD).
9	2, A	5	2.3.2	How will warming mainstem temperatures affect the abundance and distribution of parasites/disease?	**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? **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?	A report on investigations of the effects of parasites on HBC is expected by the end of FY2007. This report should shed additional light on this RIN.
10	2, A	1	2.4.1	What are the most effective strategies and control methods	**New SSQ.** What are the most effective strategies and control methods to limit	This RIN is being specifically addressed in the MRP through the

No.	Adaptive Management Work Group (AMWG) Sequence Number and Category	AMWG Priority	Research information needs (RIN) no.	RIN text	Strategic science questions (SSQs), relevant core-monitoring information needs (CMINs), and Science Advisor (SA) questions. Questions listed below are from the Monitoring and Research Plan (MRP).	Comments
				to limit nonnative fish predation and competition on native fish?	nonnative fish predation on, and competition with, native fishes?	nonnative control project. A project manager was hired for this purpose in FY2006.
11	2, A	1	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?	**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? **New SSQ.** What life stage(s) of RBT pose the greatest threat to HBC and other native fishes? Are the RBT that threaten HBC resident fish, produced in the LCR reach of the Colorado River, or are these RBT immigrants that were spawned in the Lees Ferry reach?	This RIN is being specifically addressed in the MRP through the nonnative control project. A project manager was hired for this purpose in FY2006.
12	2, A	1	2.6.1	What is a viable population?	**SSQ 1-5.** What are the important pathways that link lower trophic levels with fish and how will they link to dam operations?	M.O. 2.6 refers to flannelmouth sucker (FMS), bluehead sucker (BHS), and speckled dace (SD). Policy and management question. There is a textbook answer to this question associated with system carrying capacity, demographics, and genetics, but to develop a Grand Canyon-specific answer requires an understanding of the productivity of the system and how fish utilize that productivity. System productivity is being investigated by the current aquatic food base program.
13	2, A	1	2.6.2	What are the significant threats to these species?	**SSQ 1-1.** To what extent are adult populations of native fish controlled by production of	This RIN is also addressed by the HBC Comprehensive Plan.

No.	Adaptive Management Work Group (AMWG) Sequence Number and Category	AMWG Priority	Research information needs (RIN) no.	RIN text	Strategic science questions (SSQs), relevant core-monitoring information needs (CMINs), and Science Advisor (SA) questions. Questions listed below are from the Monitoring and Research Plan (MRP).	Comments
					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?	
14	2, A	1	4.2.6	To what extent are RBT below the Paria River predators of native fish, primarily HBC? At what size do they become predators of native fish, especially HBC, i.e., how do the trophic interactions between RBT and native fish change with size of fish?	**SSQ 1-4.** Can long-term decreases in abundance of RBT 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?	The listed SSQ most directly addresses the first part of this RIN. The second part of the RIN largely has to do with ontogenetic feeding shift and gape size available from the extensive RBT literature. A project will be added to the MRP to address this RIN.
15	2, A	6+	5.2.2	How does the size and quality of the habitat used by Kanab ambersnail (KAS) change in response to an experiment performed under the Record of Decision (ROD), unanticipated event, or other management action?	None proposed.	Annual monitoring is tracking changes in KAS habitat consistent with CMINs for this resource.
16	2, A	3	12.9.2	What is the best combination of dam operations and other management actions to achieve the vision, mission, goals, and objectives of the GCDAMP?	None proposed.	Policy question. Conservation of natural resources is a general goal for many of the GCDAMP/GCMRC projects, but determining whether objectives have been met will require that objectives be established.
17	2, A	3	12.9.3	What are the relationships	None proposed.	Ongoing monitoring of natural and

No.	Adaptive Management Work Group (AMWG) Sequence Number and Category	AMWG Priority	Research information needs (RIN) no.	RIN text	Strategic science questions (SSQs), relevant core-monitoring information needs (CMINs), and Science Advisor (SA) questions. Questions listed below are from the Monitoring and Research Plan (MRP).	Comments
				between dam operations and other management actions in their effects on resources addressed by GCDAMP management objectives?		cultural resources provides some of the data needed to answer this RIN. Recommendations of the April 2007 science workshop were forwarded to Reclamation for their consideration in the upcoming EIS. These recommendations, among other things, proposed dam operation to benefit HBC, and may be tested beginning in water year 2009.
18	2.5, Done	1	2.1.1	What is the minimum population size of HBC that should be sustained in the LCR, to ensure a viable spawning population of HBC in the LCR?	**SSQ 1-5.** What are the important pathways that link lower trophic levels with fish and how will they link to dam operations?	This RIN has policy and science elements. There is a textbook answer to this question associated with system carrying capacity, demographics, and genetics, but to develop a Grand Canyon-specific answer requires an understanding of the productivity of the system and how fish utilize that productivity. The GCDAMP, through GCMRC, is currently investigating the transfer of biologic energy among organisms in Grand Canyon. The ultimate legal answer to this RIN is expected to be contained in the revision of the Recovery Goals re-initiated in 2007.
19	2.5, A	1	2.2.4	What is the relationship between the "aggregations" in the mainstem and LCR? Are mainstem aggregations "sinks"	None proposed.	The referenced 2006 paper by Paukert and others answers much of this RIN. Aggregations don't appear to be sinks, although additional data

No.	Adaptive Management Work Group (AMWG) Sequence Number and Category	AMWG Priority	Research information needs (RIN) no.	RIN text	Strategic science questions (SSQs), relevant core-monitoring information needs (CMINs), and Science Advisor (SA) questions. Questions listed below are from the Monitoring and Research Plan (MRP).	Comments
				of the LCR? Are aggregations real or due to sampling bias?		are needed. There is a relatively high level of site fidelity exhibited by HBC, and recent sampling of both aggregations and random sites (addresses bias) suggests that aggregations are maintained over time.
20	2.5, A	1	2.4.2	Determine if suppression of nonnative predators and competitors increases native fish populations?	**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? **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?	This RIN is being specifically addressed in the MRP through the nonnative control project. A project manager was hired for this purpose in FY2006. This RIN is also addressed by continuing the long-term monitoring of HBC.
21	2.5, A	1	2.4.6	What are the population dynamics of those nonnative fish that are the major predators and competitors of native fish?	**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?	This RIN is being specifically addressed in the MRP through the nonnative control project. A project manager was hired for this purpose in FY2006. Monitoring of these species is carried out as described in a CMIN.
22	2.5, A	6+	4.2.1	What is the rate of emigration	**New SSQ.** What life stage(s) of RBT pose the	An additional research project to

No.	Adaptive Management Work Group (AMWG) Sequence Number and Category	AMWG Priority	Research information needs (RIN) no.	RIN text	Strategic science questions (SSQs), relevant core-monitoring information needs (CMINs), and Science Advisor (SA) questions. Questions listed below are from the Monitoring and Research Plan (MRP).	Comments
				of RBT from the Lees Ferry reach?	greatest threat to HBC and other native fishes? Are the RBT that threaten HBC resident fish, produced in the LCR reach of the Colorado River, or are these RBT immigrants that were spawned in the Lees Ferry reach?	address RBT threats to native fishes will be added to the MRP. Current monitoring, along with ongoing investigations (described in a CMIN) of alternative monitoring methods using tags (FY2007 and beyond), will provide much needed information.
23	2.5, A	6+	4.2.2	What is the most effective method to detect emigration of RBT from the Lees Ferry reach?	**New SSQ.** What life stage(s) of RBT pose the greatest threat to HBC and other native fishes? Are the RBT that threaten HBC resident fish produced in the LCR reach of the Colorado River, or are these RBT immigrants that were spawned in the Lees Ferry reach?	This issue is being explored in FY2007 and beyond through exploration of sonic tags and other possible monitoring methods. The monitoring is being carried out consistent with this CMIN.
24	2.5, C	6+	5.1.5	What is the taxonomic identity of the Oxyloma snails at Vaseys Paradise? Is a change to the existing taxonomic status warranted?	(No additional SSQ because of relatively low AMWG priority.)	GCDAMP-funded research has recently been compiled by the University of Arizona and should be available in 2007. Taxonomic change appears warranted but any regulatory change is a USFWS policy decision.
25	2.5, C	6+	5.1.6	What is the range of occurrence of the ambersnail taxon found at Vaseys Paradise? (NOTE: Intended to address the issue of whether this is an endemic population or a relict population or part of a metapopulation.)	(No additional SSQ because of relatively low AMWG priority.)	Taxonomic review by the University of Arizona will also report on geographic ranges of taxa.

No.	Adaptive Management Work Group (AMWG) Sequence Number and Category	AMWG Priority	Research information needs (RIN) no.	RIN text	Strategic science questions (SSQs), relevant core-monitoring information needs (CMINs), and Science Advisor (SA) questions. Questions listed below are from the Monitoring and Research Plan (MRP).	Comments
26	3, A	1	1.5.3	How has the value and availability of drift as a food source for HBC changed with the implementation of ROD operations?	**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?	Current food base research is using available historical data, but some aspects of this question can never be addressed because certain data were not collected historically.
27	3, A	5	2.2.7	Determine if implementation and operation of the TCD and/or steady flows represent a technically feasible, ecologically sustainable, and practical option for establishing mainstem spawning.	None proposed.	Testing of a TCD will require construction and operation. A recent GCMRC flows analysis with temperature modeling suggests a two-unit TCD could elevate mainstem flow temperatures to levels that would encourage spawning but would not alone produce steady flows; however, HBC may always depend primarily on tributary spawning. The recommendations of the April 2007 science workshop were forwarded to Reclamation for their consideration in the upcoming EIS. These recommendations attempted, among other things, to describe dam operation to improve mainstem conditions for HBC. They may be tested beginning in water year 2009.
28	3, A	1?	2.2.10	What techniques are available to determine natal stream of fishes in the CRE?	None proposed.	Isotopes of carbon, nitrogen, and hydrogen appear to have excellent promise for addressing this question.

No.	Adaptive Management Work Group (AMWG) Sequence Number and Category	AMWG Priority	Research information needs (RIN) no.	RIN text	Strategic science questions (SSQs), relevant core-monitoring information needs (CMINs), and Science Advisor (SA) questions. Questions listed below are from the Monitoring and Research Plan (MRP).	Comments
						Carbon and nitrogen isotopes are part of the existing food base program; GCMRC is seeking additional funding to include hydrogen isotopes.
29	3, A	1	2.2.12	What are the impacts of research activities on mortality, recruitment, and the population size of HBC?	**SSQ 1-8:** How can native and nonnative fishes best be monitored while minimizing impacts from capture and handling or sampling?	GCMRC initiated a study in FY2007 to evaluate the impacts of trammel nets on native fishes. In addition, GCMRC will ask HBC PEP to address this question, as well as effective testing methods that may be pursued.
30	3, A	1	2.3.1	How do parasite/disease loads affect population viability?	**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? **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?	
31	3, A	1	2.4.4	What are the target population levels, body size, and age structure for nonnative fish in the CRE that limit their levels to those commensurate with the	None proposed.	This RIN is being specifically addressed in the MRP through the nonnative control project. A project manager was hired for this purpose in FY2006. The biological energy

No.	Adaptive Management Work Group (AMWG) Sequence Number and Category	AMWG Priority	Research information needs (RIN) no.	RIN text	Strategic science questions (SSQs), relevant core-monitoring information needs (CMINs), and Science Advisor (SA) questions. Questions listed below are from the Monitoring and Research Plan (MRP).	Comments
				viability of native fish populations?		modeling is expected to provide insights to help answer this RIN.
32	3, A	1	2.4.5	What are the sources (natal stream) of nonnative predators and competitors?	None proposed.	Nonnative control planning (FY2007) seeks to determine the relative biological importance of this question. The answer to this question may go outside the current scope of the GCDAMP.
33	3, A	6+	5.1.9	How can incidental take for KAS at Vaseys Paradise be minimized?	None proposed.	The National Park Service (NPS) addresses this concern on a regular basis; limiting recreation access and moving vegetation mats in burlap appear to be effective mitigation measures during experimental high-flow events.
34	3, A	5	7.1.3	What are the potential ecological effects of increasing mainstem water temperatures?	**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 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?	This question is likely to be addressed through the Long-Term Experimental Plan (LTEP).
35	3, A	3	7.4.4	How does flow rate and fluctuation affect habitat availability and utilization by	**SSQ 1-1.** To what extent are adult populations of native fish controlled by production of young fish from tributaries, spawning and	This question is likely to be addressed through the LTEP.

No.	Adaptive Management Work Group (AMWG) Sequence Number and Category	AMWG Priority	Research information needs (RIN) no.	RIN text	Strategic science questions (SSQs), relevant core-monitoring information needs (CMINs), and Science Advisor (SA) questions. Questions listed below are from the Monitoring and Research Plan (MRP).	Comments
				fish and other organisms?	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?	
36	3, A	2	11.1.3	What are the thresholds triggering management actions?	**SSQ 2-1.** Do dam controlled flows increase or decrease rates of erosion and vegetation growth at arch sites and traditional cultural properties (TCPs), and if so, how? **SSQ 2-2.** How do flows impact old high-water zone (OHWZ) terraces in the CRE, 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 terraces? **SSQ 2-3.** If flows contribute to arch site/TCP erosion, what are the optimal flows for minimizing impacts to these cultural resources? **SSQ 2-4.** How effective are various treatments (e.g., check dams, vegetation	This RIN is ultimately a management/policy decision related to desired future conditions, but ongoing research on the relationships between flows, climate, subaerial sediment transport, and data collected through monitoring efforts can help determine the best answer. Recommendations of the April 2007 science workshop were forwarded to Reclamation for their consideration in the upcoming EIS. These recommendations attempted, among other things, to describe optimization of mainstem conditions for HBC, including action triggers, and may be

No.	Adaptive Management Work Group (AMWG) Sequence Number and Category	AMWG Priority	Research information needs (RIN) no.	RIN text	Strategic science questions (SSQs), relevant core-monitoring information needs (CMINs), and Science Advisor (SA) questions. Questions listed below are from the Monitoring and Research Plan (MRP).	Comments
					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 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? **CMIN 11.1.1** (Science Planning Group [SPG] revised) Determine the condition and integrity of prehistoric and historic sites in the CRE through tracking rates of erosion, visitor impacts, and other relevant variables. Determine the condition and integrity of TCPs in the CRE.	tested beginning in water year 2009.
37	3, A		* IN 12.1	Develop information that can be used by the Technical Work Group (TWG), in collaboration with GCMRC, to establish current and target levels for all resources within the GCDAMP as called for in the GCDAMP strategic plan.	None proposed.	Policy and management question. GCMRC can assist, but ultimately managers need to decide what target conditions the GCDAMP is trying to attain.
38	3, A	3	12.9.1	What is the impact on downstream resources of short-term increases to maximum flow, daily fluctuations, and downramp limits?	**New SSQ.** What are the effects of ramping rates on sediment transport and sandbar stability? **New SSQ**. What is the rate of change in eddy storage (erosion) during time intervals between beach habitat-building flows (BHBFs)?	To be determined through the LTEP. Several reports have been published since 1998 by sediment scientists that provide information addressing this question. However, ramping rate studies were still identified as being needed during the 2005 knowledge assessment workshop. Ramping rates

No.	Adaptive Management Work Group (AMWG) Sequence Number and Category	AMWG Priority	Research information needs (RIN) no.	RIN text	Strategic science questions (SSQs), relevant core-monitoring information needs (CMINs), and Science Advisor (SA) questions. Questions listed below are from the Monitoring and Research Plan (MRP).	Comments
						research is best undertaken initially through flume experiments and modeling and then through field verification below Glen Canyon Dam (GCD). The new SSQs included here were derived from the 2006 Knowledge Assessment Report (KAR) and admittedly pertain to only one of several downstream resources of interest.
39	3.5, Done	1	2.2.1	What is a viable population and what is the appropriate method to assess population viability of native fish in the CRE? What is an acceptable probability of extinction over what management time period for HBC throughout the CRE?	None proposed.	Policy and management questions. Determination of viable population and acceptable extinction probability is up to management agencies. Recent publications on the age-structured mark recapture (ASMR) model provide strong support for this method to assess population size/trend.
40	3.5, A	1	2.3.3	How does nonnative fish control/affect disease/parasite loads? (Note: The concept is if there are fewer hosts, there will be a lower incidence of parasites.)	**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?	
41	3.5, A	6+	4.2.7	What dam release patterns most effectively maintain the Lees Ferry RBT trophy fishery while limiting RBT survival below the Paria River?	**SSQ 3-6.** What GCD operations (ramping rates, daily flow range, etc.) maximize trout fishing opportunities and catchability?	This question would be most appropriately addressed as an LTEP study.

No.	Adaptive Management Work Group (AMWG) Sequence Number and Category	AMWG Priority	Research information needs (RIN) no.	RIN text	Strategic science questions (SSQs), relevant core-monitoring information needs (CMINs), and Science Advisor (SA) questions. Questions listed below are from the Monitoring and Research Plan (MRP).	Comments
42	3.5, A	2	11.1.2	What are the historic properties within the area of potential effects?	**SSQ 2-1.** Do dam controlled flows increase or decrease rates of erosion and vegetation growth at arch sites and TCPs, and if so, how? **SSQ 2-2.** How do flows impact OHWZ terraces in the CRE, 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 terraces? **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 those resources? **CMIN 11.1.1** (SPG revised) Determine the condition and integrity of prehistoric and historic sites in the CRE through tracking rates of erosion, visitor impacts, and other relevant variables. Determine the condition and integrity of TCPs in the CRE.	The RIN question was answered in the 1995 EIS: 336 archaeological sites. There are still uncertainties regarding which sites are affected by which specific aspects of dam operations, and how dam processes interact with other elements of the environment to effect those changes; these uncertainties are being addressed through R&D studies in FY2007–09. There are also continuing uncertainties about the numbers and locations of TCPs (see comment below). Reclamation, as lead agency for Section 106 compliance, has the responsibility for completing TCP identification.
43	3.5, A	2	11.1.2.a	For each tribe and living community, what are the register eligible TCPs?	**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 those resources?	This information need remains unresolved. Reclamation is supposed to address this RIN in the context of National Historic Preservation Act (NHPA) compliance, although it is unclear how much progress has been made in recent years towards answering this question.
44	4, A	6+	1.1	What are the fundamental trophic interactions in the	**SSQ 1-5.** What are the important pathways that link lower trophic levels with fish and	

No.	Adaptive Management Work Group (AMWG) Sequence Number and Category	AMWG Priority	Research information needs (RIN) no.	RIN text	Strategic science questions (SSQs), relevant core-monitoring information needs (CMINs), and Science Advisor (SA) questions. Questions listed below are from the Monitoring and Research Plan (MRP).	Comments
				aquatic ecosystem?	how will they link to dam operations?	
45	4, A	6+	1.4	What is the current carbon budget for the CRE?	**SSQ 1-5.** What are the important pathways that link lower trophic levels with fish and how will they link to dam operations?	
46	4, A	1	2.2.2	Determine if a population dynamics model can effectively predict response of native fish under different flow regimes and environmental conditions.	None proposed.	No models with appropriate data are available to address this RIN; however, such a model is a long-term goal. Coggins continues to refine a Grand Canyon model for both natives and nonnatives.
47	4, A[1]	1	2.2.6	What are the criteria for establishment of spawning aggregations (i.e., how does one determine if it is "established")? [1] Normally, this RIN would be placed in Category C. However, pursuant to the 2001 Department of the Interior Appropriations Bill that established the power revenue cap, this RIN is placed in Category A.	**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?	This is primarily a policy determination. However, a population viability analysis could be conducted to shed light on this question.
48	4, A	6+	2.6.5	How are movement patterns for FMS, BS, and SD in the CRE	**SSQ 1-1.** To what extent are adult populations of native fish controlled by production of	Studies focused specifically on FMS, BHS, or SD are not high priority for

No.	Adaptive Management Work Group (AMWG) Sequence Number and Category	AMWG Priority	Research information needs (RIN) no.	RIN text	Strategic science questions (SSQs), relevant core-monitoring information needs (CMINs), and Science Advisor (SA) questions. Questions listed below are from the Monitoring and Research Plan (MRP).	Comments
				affected by age, natal stream, and dam operations?	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?	next 5 years.
49	4, A	6+	2.6.6	How is the rate of mortality for FMS, BS, and SD in the CRE related to individual body size? What are the sources of mortality for FMS, BS, and SD in the CRE?	**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?	Studies focused specifically on FMS, BHS, or SD are not high priority for next 5 years.
50	4, A	6+	5.1.4	Identify and evaluate alternative Management Actions to ensure viability of KAS at Vaseys Paradise where (1) the population dynamic model predicts loss of population viability, or (2) monitoring discovers substantial habitat or KAS population declines.	(No additional SSQ because of relatively low AMWG priority.)	The USFWS is conducting a species status review in 2006–07 that will help prioritize this information need.
51	4, A	6+	5.1.8	What are the measurable criteria that need to be met to remove jeopardy for KAS at	(No additional SSQ because of relatively low AMWG priority.)	The USFWS is conducting a species status review in 2006–07 that will help prioritize this information need.

No.	Adaptive Management Work Group (AMWG) Sequence Number and Category	AMWG Priority	Research information needs (RIN) no.	RIN text	Strategic science questions (SSQs), relevant core-monitoring information needs (CMINs), and Science Advisor (SA) questions. Questions listed below are from the Monitoring and Research Plan (MRP).	Comments
				Vaseys Paradise?		
52	4, A	6+	6.4.1	How have the abundance, composition, and distribution of the sand beach community changed since dam closure (1963), high flows (1984), interim flows (1991), and the implementation of ROD operations (1996)?	(No additional SSQ because of relatively low AMWG priority.)	This will be a focus of the vegetation synthesis project initiated in FY2007. Current work being conducted is consistent with CMINs.
53	4, A	6+	6.5.3	How has the abundance and distribution of nonnative species changed since dam closure (1963), high flows (1984), interim flows (1991) and the implementation of ROD operations (1996)?	(No additional SSQ because of relatively low AMWG priority.)	This will be a focus of the vegetation synthesis project initiated in FY2007. Current work being conducted consistent with CMINs.
54	4, A	5	7.1.2	What are the most likely downstream temperature responses to a variety of scenarios involving a TCD on GCD?	**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 nearshore water temperatures throughout the CRE?	This information need for the mainstem has been largely addressed through the temperature modeling conducted for the experimental flow analysis. Additional modeling is being initiated in 2007 to increase accuracy and to include nearshore habitats.
55	4, A	6+	7.2.3	Which metals should be measured? Where and how often?	(No additional SSQ because of relatively low AMWG priority.)	Please refer to the PEP review report on quality of water from 1999.
56	4, A	3	7.4.3	How do changes in flow	**SSQ 3-5.** How is invertebrate flux affected by	

No.	Adaptive Management Work Group (AMWG) Sequence Number and Category	AMWG Priority	Research information needs (RIN) no.	RIN text	Strategic science questions (SSQs), relevant core-monitoring information needs (CMINs), and Science Advisor (SA) questions. Questions listed below are from the Monitoring and Research Plan (MRP).	Comments
				volume and rate of change affect food base and energy productivity in the CRE?	water quality (e.g., temperature, nutrient concentrations, turbidity) and dam operations?	
57	4, A	4	8.5.1	What elements of ROD operations (upramp, downramp, maximum and minimum flow, modified low fluctuating flow (MLFF), habitat maintenance flow (HMF), and BHBF) are most/least critical to conserving new fine-sediment inputs, and stabilizing sediment deposits above the 25,000 cfs stage?	**New SSQ**. What are the effects of ramping rates on sediment transport and sandbar stability? **New SSQ.** What is the rate of change in eddy storage (erosion) during time intervals between BHBFs?	Several reports have been published since 1998 by sediment scientists that provide information addressing this question. However, ramping rate studies were still identified as being needed during the 2005 knowledge assessment workshop. These new SSQs were derived from those discussions among sediment scientists and are taken from the 2006 KAR. Ramping rates research is best undertaken initially through flume experiments and modeling and then through field verification below GCD. The second question is best addressed through future BHBF testing and long-term monitoring of sand storage between such tests.
58	4, A	4	** Supporting Information Need (SIN): 8.5.3	What is the relationship between turbidity and biological processes?	**SSQ 3-5.** How is invertebrate flux affected by water quality (e.g., temperature, nutrient concentrations, turbidity) and dam operations?	
59	4, A	4	** SIN 8.5.6	What are the grain-size characteristics of sandbars associated with designated riparian vegetation zones?	(No additional SSQ because of relatively low AMWG priority.)	This SIN is a legitimate science question and should be pursued as support becomes available. Grain-size data from terrestrial beach

No.	Adaptive Management Work Group (AMWG) Sequence Number and Category	AMWG Priority	Research information needs (RIN) no.	RIN text	Strategic science questions (SSQs), relevant core-monitoring information needs (CMINs), and Science Advisor (SA) questions. Questions listed below are from the Monitoring and Research Plan (MRP).	Comments
						environments were collected within the fine-grained integrated sediment transport (FIST) study reaches using innovative "beach ball" digital cameras (Rubin and others, written commun.) and verified with standard sieving methods. These methods can be further developed and used in conjunction with terrestrial vegetation monitoring to resolve this question further, if the existing data are not adequate.
60	4, A	2	11.1.1	What are the sources of impacts to historic properties?	**SSQ 2-1.** Do dam controlled flows increase or decrease rates of erosion and vegetation growth at arch sites and TCPs, and if so, how? **SSQ 2-2.** How do flows impact OHWZ terraces in the CRE, 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 terraces? **CMIN 11.1.1** (SPG revised). Determine the condition and integrity of prehistoric and historic sites in the CRE through tracking rates of erosion, visitor impacts, and other relevant variables. Determine the condition and integrity of TCPs in the CRE.	
61	4, A	2	11.1.3.b	How should adverse effects to historic properties be mitigated?	**SSQ 2-3.** If flows contribute to arch site/TCP erosion, what are the optimal flows for minimizing impacts to these cultural resources?	The RIN is primarily a management decision, not a science question, although ongoing research for core monitoring (e.g., study of check dam

No.	Adaptive Management Work Group (AMWG) Sequence Number and Category	AMWG Priority	Research information needs (RIN) no.	RIN text	Strategic science questions (SSQs), relevant core-monitoring information needs (CMINs), and Science Advisor (SA) questions. Questions listed below are from the Monitoring and Research Plan (MRP).	Comments
					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? **CMIN 11.1.1** (SPG revised). Determine the condition and integrity of prehistoric and historic sites in the CRE through tracking rates of erosion, visitor impacts, and other relevant variables. Determine the condition and integrity of TCPs in the CRE. **CMIN 11.2.1** (SPG revised). Determine the condition of traditionally important resources and locations using tribal perspectives and values.	effectiveness and erosion rates) can provide data helpful to making a scientifically sound management decision.
62	4, A	2	11.2.3	Determine acceptable methods to preserve or treat traditionally important resources within the CRE.	**SSQ 2-3.** If flows contribute to arch site/TCP erosion, what are the optimal flows for minimizing impacts to these cultural resources? **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? **CMIN 11.1.1** (SPG revised). Determine the condition and integrity of prehistoric and historic sites in the CRE through tracking rates of erosion, visitor impacts, and other relevant variables. Determine the condition and integrity of TCPs in the CRE. **CMIN 11.2.1** (SPG revised). Determine the condition of traditionally important resources and locations using tribal perspectives and	The issue of acceptability is largely a management decision for Reclamation, NPS, tribes, and other GCDAMP stakeholders to discuss and resolve. Ongoing research and development for core monitoring (e.g., the study of check dam effectiveness) will provide data helpful to informing this management decision.

No.	Adaptive Management Work Group (AMWG) Sequence Number and Category	AMWG Priority	Research information needs (RIN) no.	RIN text	Strategic science questions (SSQs), relevant core-monitoring information needs (CMINs), and Science Advisor (SA) questions. Questions listed below are from the Monitoring and Research Plan (MRP).	Comments
					values.	
63	4.5, A	6+	2.5.3	What characteristics define suitable habitat for razorback sucker (RBS)? Does suitable habitat for RBS occur in the CRE?	(No additional SSQ because of relatively low AMWG priority.)	Not a current GCDAMP high priority.
64	4.5, A	6+	2.6.4	What is the age structure, including relationship between age and size of FMS, BS, and SD in the CRE?	(No additional SSQ because of relatively low AMWG priority.)	Not a current GCDAMP high priority.
65	4.5, A	1	4.1.3	To what extent is there overlap in the Lees Ferry reach of RBT habitat and native fish habitat?	**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?	
66	4.5, A	6+	4.2.3	How is the rate of emigration	**SSQ 1-1.** To what extent are adult populations	Habitat work by Korman and

No.	Adaptive Management Work Group (AMWG) Sequence Number and Category	AMWG Priority	Research information needs (RIN) no.	RIN text	Strategic science questions (SSQs), relevant core-monitoring information needs (CMINs), and Science Advisor (SA) questions. Questions listed below are from the Monitoring and Research Plan (MRP).	Comments
				of RBT from the Lees Ferry reach to below the Paria River affected by abundance, hydrology, temperature, and other ecosystem processes?	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?	evaluation of tagging methods by GCMRC and AZGFD are addressing this need in FY2007 and beyond.
67	4.5, A		4.2.5	To what extent is there overlap in the CRE below the Paria River of RBT habitat and native fish habitat?	**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	

No.	Adaptive Management Work Group (AMWG) Sequence Number and Category	AMWG Priority	Research information needs (RIN) no.	RIN text	Strategic science questions (SSQs), relevant core-monitoring information needs (CMINs), and Science Advisor (SA) questions. Questions listed below are from the Monitoring and Research Plan (MRP).	Comments
					availability, competition?	
68	4.5, A	6+	6.2.1	How has the patch number, patch distribution, composition, and area of the NHWZ community changed since dam closure (1963), high flows (1984), interim flows (1991) and the implementation of ROD operations (1996)?	**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? **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.	Vegetation monitoring and synthesis projects in FY2007 and beyond are addressing this information need. Monitoring is being conducted consistent with CMINs for this resource.
69	4.5, A	6+	6.5.1	Determine if nonnative species are expanding or contracting at a local scale (patch or reach).	**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?	Vegetation monitoring and synthesis projects in FY2007 and beyond are addressing this information need. Monitoring is being conducted consistent with CMINs for this resource.
70	4.5, A		** SIN 7.2.2	Which water quality variables influence food base and fisheries in the CRE?	**SSQ 5-2.** Is invertebrate flux affected by water quality (e.g., temperature, nutrient concentrations, turbidity) and dam operations? **SSQ 1-5.** What are the important pathways that link lower trophic levels with fish and how will they link to dam operations?	
71	4.5, A	4	* IN 8.1	If sediment cannot be preserved in the system using available management actions, what is the feasibility (including technical, legal, economic, and policy issues) of sediment augmentation as a means of achieving this goal?	None proposed.	Partly addressed through the FY2005–06 sediment augmentation engineering feasibility study (see Randle and others, 2007). No additional SSQ can be justified until such time that the SSQ relating to the flows-only sediment question is resolved through further tests of the

No.	Adaptive Management Work Group (AMWG) Sequence Number and Category	AMWG Priority	Research information needs (RIN) no.	RIN text	Strategic science questions (SSQs), relevant core-monitoring information needs (CMINs), and Science Advisor (SA) questions. Questions listed below are from the Monitoring and Research Plan (MRP).	Comments
						BHBF concept.
72	4.5, A	4	** SIN 8.5.4	What is the role of turbidity and how can it be managed to achieve biological objectives?	**SSQ 3-5.** How is invertebrate flux affected by water quality (e.g., temperature, nutrient concentrations, turbidity) and dam operations?	Aside form food base project, this is a relatively low priority at this time.
73	4.5, A		8.6.2	How do ongoing inputs of coarse-sediment from tributaries alter the distribution of main channel habitats needed by benthic organisms within pools, runs, and eddies throughout the CRE?	**SSQ 3-5.** How is invertebrate flux affected by water quality (e.g., temperature, nutrient concentrations, turbidity) and dam operations?	No additional SSQs are offered at this time owing to the relatively low AMWG priority assigned to this topic.
74	4.5, A	2	11.2.1	What are traditionally important resources and locations for each tribe and other groups?	**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 those resources? **CMIN 11.1.1** (SPG revised). Determine the condition and integrity of prehistoric and historic sites in the CRE through tracking rates of erosion, visitor impacts, and other relevant variables. Determine the condition and integrity of TCPs in the CRE. **CMIN 11.2.1** (SPG revised). Determine the condition of traditionally important resources and locations using tribal perspectives and values.	As previously noted for RIN 11.1.2a, this information need remains unresolved. Reclamation is supposed to answer this RIN in the context of NHPA compliance. Some of this information may be provided indirectly by tribes through completing their FY2006 monitoring protocol development project.
75	4.5, A	2	11.2.2	What is the baseline measure	None proposed.	The RIN specifically references

No.	Adaptive Management Work Group (AMWG) Sequence Number and Category	AMWG Priority	Research information needs (RIN) no.	RIN text	Strategic science questions (SSQs), relevant core-monitoring information needs (CMINs), and Science Advisor (SA) questions. Questions listed below are from the Monitoring and Research Plan (MRP).	Comments
				for resource integrity?		tribally valued resources (MO 11.2) but this question really applies to all GCDAMP monitored resources. Baseline conditions have been established at the start of the GCDAMP (1996). This IN should be determined as part of the target setting process for all GCDAMP resources.
76	4.5, A		12.3.1	As necessary, investigate the most effective methods to integrate and synthesize resource data.	None proposed.	This is a major focus of the FY2007–11 GCMRC strategic plan and MRP.
77	4.5, A		12.5.5	Identify the desired level of information, education, and outreach provided for Glen and Grand Canyon river users and the general public.	None proposed.	A possible task for the Public Outreach ad hoc Group (POAGH).
78	4.5, A		12.11.1	What are the most effective methods to maintain or attain the participation of externally-funded investigators?	None proposed.	A possible AMWG task.
79/80	5, A	3	1.1.1/1.1.2	How are the composition and biomass of primary producers between GCD and the Paria River affected by flow and water quality (including nutrients, temperature, light regime, toxins, dissolved oxygen), waterborne diseases,	**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 inverte**b**rate flux affected by	

No.	Adaptive Management Work Group (AMWG) Sequence Number and Category	AMWG Priority	Research information needs (RIN) no.	RIN text	Strategic science questions (SSQs), relevant core-monitoring information needs (CMINs), and Science Advisor (SA) questions. Questions listed below are from the Monitoring and Research Plan (MRP).	Comments
				or other factors?	water quality (e.g., temperature, nutrient concentrations, turbidity) and dam operations?	
81	5, A	3	1.1.4	What are the habitat characteristics between GCD and the Paria River that most affect primary productivity? How are these characteristics affected by GCD operations?	**SSQ 5-2.** Is invertebrate flux affected by water quality (e.g., temperature, nutrient concentrations, turbidity) and dam operations?	
82	5, A		1.2	How are the production, composition, density, and biomass of the benthic invertebrate community affected by primary productivity vs. allochthonous inputs?	**SSQ 1-5.** What are the important pathways that link lower trophic levels with fish and how will they link to dam operations?	
83	5, A		1.2.2	What is the estimated productivity of benthic invertebrates for the reach between GCD and the Paria River? (Note: If the cost of obtaining these data, relative to the benefit suggests the information is not worth the expense, this RIN will not be pursued.)	**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?	
84	5, A		1.3	What food base criteria do other agencies use to assess aquatic ecosystem health?		GCMRC will research this RIN as part of the food base project final report.

No.	Adaptive Management Work Group (AMWG) Sequence Number and Category	AMWG Priority	Research information needs (RIN) no.	RIN text	Strategic science questions (SSQs), relevant core-monitoring information needs (CMINs), and Science Advisor (SA) questions. Questions listed below are from the Monitoring and Research Plan (MRP).	Comments
85	5, A		1.4.1	How are the composition and biomass of benthic invertebrates in the CRE below the Paria River affected by flow, water quality (including nutrients, temperature, light regime, toxins, dissolved oxygen), new invasive species, waterborne diseases, or other factors? (Note: If the cost of obtaining these data, relative to the benefit suggests the information is not worth the expense, this RIN will not be pursued.)	**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?	
86	5, A		1.5.2	How do top-down effects (grazing and predation) affect the abundance and composition of drift?	**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?	
87	5, A	5	2.6.7	How does temperature modification in the mainstem affect recruitment and mortality for FMS, BS, and SD originating from tributary spawning?	**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?	May be tested as part of the LTEP if a TCD is constructed.

No.	Adaptive Management Work Group (AMWG) Sequence Number and Category	AMWG Priority	Research information needs (RIN) no.	RIN text	Strategic science questions (SSQs), relevant core-monitoring information needs (CMINs), and Science Advisor (SA) questions. Questions listed below are from the Monitoring and Research Plan (MRP).	Comments
88	5, A	6+	5.1.2	What parameters have the greatest influence on population viability of KAS at Vaseys Paradise (e.g., parasites, predation, discharges, habitat size, quality, and human use/visitation)?	(No additional SSQ because of relatively low AMWG priority.)	This is being addressed by the USFWS species status review in 2006–07.
89	5, A	6+	5.1.3	Develop a population dynamic model to predict KAS viability under different flows and environmental conditions.	None proposed.	No additional SSQ because of relatively low AMWG priority.
90	5, A	6+	5.2.1	How does the size, quality, and recovery time of KAS habitat change following natural scours or other events?	(No additional SSQ because of relatively low AMWG priority.)	Variable flows/events will be needed to address this RIN. It may be more appropriate to consider it as an EIN to be addressed as part of the LTEP.
91	5, A	6+	6.1.1	How has the abundance, composition, distribution, and area of the marsh community changed since dam closure (1963), high flows (1984), interim flows (1991) and the implementation of ROD operations (1996)?	**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?	Monitoring conducted consistent with CMINs.
92	5, A or B	6+	6.3.2	What dam operations (Category A), or other	**SSQ 2-1.** Do dam controlled flows affect (increase or decrease) rates of erosion and	Monitoring conducted consistent with CMINs.

No.	Adaptive Management Work Group (AMWG) Sequence Number and Category	AMWG Priority	Research information needs (RIN) no.	RIN text	Strategic science questions (SSQs), relevant core-monitoring information needs (CMINs), and Science Advisor (SA) questions. Questions listed below are from the Monitoring and Research Plan (MRP).	Comments
				management actions (Category B), have the potential to maintain the OHWZ community at the current stage elevation, or establish the community at a lower stage elevation?	vegetation growth at archaeological sites and TCP sites, and if so, how?	
93	5, A		* IN 6.4	How much allochthonous material (e.g., leaf litter) is exchanged between the terrestrial and aquatic systems?	**SSQ 1-5.** What are the important pathways that link lower trophic levels with fish and how will they link to dam operations?	
94	5, A or B		6.5.2	What dam operations (Category A), or other management actions (Category B), have the potential to increase or decrease the distribution and abundance of nonnative species?	**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?	Monitoring conducted consistent with CMINs.
95	5, A		6.6.2	Which seeps and springs are culturally important or occupied by rare and endemic species?	**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? **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.	
96	5, A	5	7.1.1	What are the desired ranges of	**SSQ 3-5.** How is invertebrate flux affected by	

No.	Adaptive Management Work Group (AMWG) Sequence Number and Category	AMWG Priority	Research information needs (RIN) no.	RIN text	Strategic science questions (SSQs), relevant core-monitoring information needs (CMINs), and Science Advisor (SA) questions. Questions listed below are from the Monitoring and Research Plan (MRP).	Comments
				spatial and temporal patterns of water temperatures for the CRE?	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 nearshore 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?	
97	5, A		7.2.1	Which major ions should be measured? Where and how often?	**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 nearshore 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?	
98	5, A		** SIN 7.2.1	How do the hydrodynamics and stratification of Lake Powell influence the food base or fisheries downstream?	**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	These are several related quality-of-water questions that require the Lake Powell project to be linked with the Integrated Downstream Quality-of-Water project. This integrated synthesis topic should be approached as a new research and modeling

No.	Adaptive Management Work Group (AMWG) Sequence Number and Category	AMWG Priority	Research information needs (RIN) no.	RIN text	Strategic science questions (SSQs), relevant core-monitoring information needs (CMINs), and Science Advisor (SA) questions. Questions listed below are from the Monitoring and Research Plan (MRP).	Comments
					determine mainstem and nearshore 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? **SSQ 5.5.** Will increased water temperatures increase the incidence of Asian tapeworm in HBC or the magnitude of infestation, and if so, [*then*] what is the impact on survival and growth rates?	initiative in the Lake Powell and downstream efforts and focused using advanced conceptual modeling (Phase II).
99	5, A		7.2.2	Which nutrients should be measured? Where and how often?	**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 nearshore 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?	Both this and RIN 7.2.1 should be combined and dealt with as one topic.
100	5, A		7.3.1	Develop simulation models for Lake Powell and the Colorado River to predict water quality conditions under various operating scenarios, supplant monitoring efforts, and elucidate understanding of the effects of 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 nearshore water temperatures throughout the CRE?	The temperature model developed for flow analysis that is currently being refined addresses one important component of this information need. Physical scientists at the GCMRC do not concur with the idea of using a model to "supplant" monitoring.

No.	Adaptive Management Work Group (AMWG) Sequence Number and Category	AMWG Priority	Research information needs (RIN) no.	RIN text	Strategic science questions (SSQs), relevant core-monitoring information needs (CMINs), and Science Advisor (SA) questions. Questions listed below are from the Monitoring and Research Plan (MRP).	Comments
				climate, and basin hydrology on Colorado River water quality.		
101	5, A	3	7.4.2	What is the desired pattern of seasonal and annual flow dynamics associated with powerplant operations, BHBFs, HMFs, or other flows to meet GCDAMP Goals and Objectives?	All of the MRP SSQs Under Priority 3, 4 and 5.	This is a case in which the SSQs contained in the MRP are actually more detailed than the RIN that preceded them.
102	5, A	4	8.1.1	What is the longitudinal variability of fine-sediment inputs, by reach?	**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?	This is part of what is needed to answer SSQ 4.1 with respect to the systemwide sand mass flux (inputs). This is mostly known with respect to the major tributaries and fairly well known for the lesser tributaries with regard to coarse and fine sediment.
103	5, A	4	8.1.2	What is the temporal variability of fine-sediment inputs, by reach?	**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?	This is part of what is needed to answer SSQ 4.1 with respect to the systemwide sand mass flux (inputs). This is mostly known from various publications with respect to both the seasonality and decadal-scale variability.
104	5, A	4	8.1.3 8.2.1 8.3.1 8.4.1 8.5.6	What fine sediment abundance and distribution, by reach, is desirable to support GCDAMP ecosystem goals? (Note: Definition of "desirable" will	**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	Managers need to define targets for sediment and other resources. Physical scientists at GCMRC prefer to use the concept of spatial and

No.	Adaptive Management Work Group (AMWG) Sequence Number and Category	AMWG Priority	Research information needs (RIN) no.	RIN text	Strategic science questions (SSQs), relevant core-monitoring information needs (CMINs), and Science Advisor (SA) questions. Questions listed below are from the Monitoring and Research Plan (MRP).	Comments
				be derived from targets for other resources and managers goals.)	decadal time scales? **SSQ 4.2.** 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 HBC) associated with high flows?	temporal "evaluation criteria" rather than "targets" for addressing this RIN.
108	5, A	4	** SIN 8.5.2	What is the relationship between the fine-sediment budget and turbidity?	**SSQ 4.1e.** Can we develop a relationship between suspended sediment concentration and turbidity to support fisheries research?	This is subquestion "e" under SSQ 4.1 as reported in the 2005 KAR.
109	5, A	4	8.5.4	What is the significance of aeolian processes in terrestrial sandbar reworking?	**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?	This question was at least partially addressed by the work of Rubin and Draut in their 2003–06 research, including the 2004 BHBF test.
110	5, A	4	** SIN 8.5.5	How can the ongoing fine sediment supply be managed to achieve sustainable habitats?	**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?	This is partially answered within existing reports: Rubin and others, 2002; Wright and others, 2005; Topping and others, 2006, etc.
112	5, A		9.3.1	What is the desired target level of camping beaches by reach?	None proposed.	Managers need to define targets for camping beaches and other

No.	Adaptive Management Work Group (AMWG) Sequence Number and Category	AMWG Priority	Research information needs (RIN) no.	RIN text	Strategic science questions (SSQs), relevant core-monitoring information needs (CMINs), and Science Advisor (SA) questions. Questions listed below are from the Monitoring and Research Plan (MRP).	Comments
						GCDAMP resources. Geographic Information Systems (GIS) atlas project (FY2007–08) may provide information useful to determining appropriate target.
113	5, A	3	10.1.2	What would be the effects on the CRE and marketable capacity and energy of increasing the upramp and downramp limit?	**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)?	This is an EIN that presumably will be addressed in the LTEP.
114	5, A	3	10.1.3	What would be the effects on the CRE and marketable capacity and energy of raising the maximum power plant flow limit above 25,000 cfs?	**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)?	This is an EIN that may be addressed in the LTEP.
115	5, A		10.3.1	What are the effects of providing financial exception criteria?	**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)?	This is an EIN that may be addressed in the LTEP.
116	5, A	2	11.1.1.a	What and where are the geomorphic processes that link loss of site integrity with dam operations as opposed to dam existence or natural processes?	**SSQ 2-1.** Do dam controlled flows increase or decrease rates of erosion and vegetation growth at arch sites and TCPs, and if so, how? **SSQ 2-2.** How do flows impact OHWZ terraces in the CRE, 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 terraces?	

No.	Adaptive Management Work Group (AMWG) Sequence Number and Category	AMWG Priority	Research information needs (RIN) no.	RIN text	Strategic science questions (SSQs), relevant core-monitoring information needs (CMINs), and Science Advisor (SA) questions. Questions listed below are from the Monitoring and Research Plan (MRP).	Comments
					SSQ 2-3. If flows contribute to arch site/TCP erosion, what are the optimal flows for minimizing impacts to these cultural resources? **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 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 those resources? **CMIN 11.1.1** (SPG revised). Determine the condition and integrity of prehistoric and historic sites in the CRE through tracking rates of erosion, visitor impacts, and other relevant variables. Determine the condition and integrity of TCPs in the CRE.	
117	5, A	2	11.1.1.b	What are the terrace formation processes and how do dam operations affect current terrace formations processes?	**SSQ 2-2.** How do flows impact OHWZ terraces in the CRE, 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 terraces?	
118	5, A	2	11.1.1.c	Determine if and where dam operations cause accelerated erosion to historic properties?	**SSQ 2-1.** Do dam controlled flows increase or decrease rates of erosion and vegetation growth at arch sites and TCPs, and if so, how? **SSQ 2-2.** How do flows impact OHWZ	

No.	Adaptive Management Work Group (AMWG) Sequence Number and Category	AMWG Priority	Research information needs (RIN) no.	RIN text	Strategic science questions (SSQs), relevant core-monitoring information needs (CMINs), and Science Advisor (SA) questions. Questions listed below are from the Monitoring and Research Plan (MRP).	Comments
					terraces in the CRE, and what kinds of important information about the historical ecology and human history of are being lost due to ongoing erosion of the Holocene terraces? **SSQ 2-3.** If flows contribute to arch site/TCP erosion, what are the optimal flows for minimizing impacts to these cultural resources? **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 those resources?	

No.	Adaptive Management Work Group (AMWG) Sequence Number and Category	AMWG Priority	Research information needs (RIN) no.	RIN text	Strategic science questions (SSQs), relevant core-monitoring information needs (CMINs), and Science Advisor (SA) questions. Questions listed below are from the Monitoring and Research Plan (MRP).	Comments
119	5, A	2	11.1.1.d	What are the potential threats to historic properties relative to integrity and significance?	**SSQ 2-1.** Do dam controlled flows increase or decrease rates of erosion and vegetation growth at arch sites and TCPs, and if so, how? **SSQ 2-2.** How do flows impact OHWZ terraces in the CRE, 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 terraces? **SSQ 2-3.** If flows contribute to arch site/TCP erosion, what are the optimal flows for minimizing impacts to these cultural resources? **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 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 those resources? **CMIN 11.1.1** (SPG revised). Determine the condition and integrity of prehistoric and historic sites in the CRE through tracking rates of erosion, visitor impacts, and other relevant variables. Determine the condition and integrity of TCPs in the CRE.	

No.	Adaptive Management Work Group (AMWG) Sequence Number and Category	AMWG Priority	Research information needs (RIN) no.	RIN text	Strategic science questions (SSQs), relevant core-monitoring information needs (CMINs), and Science Advisor (SA) questions. Questions listed below are from the Monitoring and Research Plan (MRP).	Comments
120	5, A	2	11.1.2.b	How do specific sites meet National Register Criteria for Evaluation?		This is a management decision, not a science question.
121	5, A	2	11.1.2.c	Identify GCDAMP activities that affect National Register eligible sites?	**CMIN 11.1.1** (SPG revised). Determine the condition and integrity of prehistoric and historic sites in the CRE through tracking rates of erosion, visitor impacts, and other relevant variables. Determine the condition and integrity of TCPs in the CRE.	The NPS can make this determination through their project review process. Monitoring will provide some relevant data.
122	5, A	2	11.1.3.a	Determine the necessary information to assess resource	**CMIN 11.1.1** (SPG revised). Determine the condition and integrity of prehistoric and	Research and development studies for core-monitoring development can

No.	Adaptive Management Work Group (AMWG) Sequence Number and Category	AMWG Priority	Research information needs (RIN) no.	RIN text	Strategic science questions (SSQs), relevant core-monitoring information needs (CMINs), and Science Advisor (SA) questions. Questions listed below are from the Monitoring and Research Plan (MRP).	Comments
				integrity.	historic sites in the CRE through tracking rates of erosion, visitor impacts, and other relevant variables. Determine the condition and integrity of TCPs in the CRE.	provide data that assist in determining the most appropriate answer, but science cannot resolve differences of opinion among managers about what constitutes adequate integrity.
123	5, A	2	11.2.4	What changes are occurring in cultural resource sites, and what are the causes of those changes?	**SSQ 2-1.** Do dam controlled flows increase or decrease rates of erosion and vegetation growth at arch sites and TCPs, and if so, how? **SSQ 2-2.** How do flows impact OHWZ terraces in the CRE, 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 terraces? **SSQ 2-3.** If flows contribute to arch site/TCP erosion, what are the optimal flows for minimizing impacts to these cultural resources? **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 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 those resources? **CMIN 11.1.1** (SPG revised). Determine the	

No.	Adaptive Management Work Group (AMWG) Sequence Number and Category	AMWG Priority	Research information needs (RIN) no.	RIN text	Strategic science questions (SSQs), relevant core-monitoring information needs (CMINs), and Science Advisor (SA) questions. Questions listed below are from the Monitoring and Research Plan (MRP).	Comments
					condition and integrity of prehistoric and historic sites in the CRE through tracking rates of erosion, visitor impacts, and other relevant variables. Determine the condition and integrity of TCPs in the CRE.	
124	5, A		12.3.2	What are the differences between western science and tribal processes for design of studies and for gathering, analyzing, and interpreting data used in the adaptive management program? How well do research designs and work plans incorporate tribal perspectives and values into the standard western science paradigm? Is it more beneficial to keep the perspective separated?	**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 those resources? **CMIN 11.2.1** (SPG revised). Determine the condition of traditionally important resources and locations using tribal perspectives and values.	
125	5, A		12.3.3	How effective is the GCDAMP in addressing the EIS statement "Long-term monitoring and research are … implemented to measure how well the selected alternative meets resource management objectives"?	None proposed.	Partially addressed through the State of the Colorado River Ecosystem in Grand Canyon (SCORE) report. Annual and 5-year assessments conducted by GCMRC and GCDAMP are components of the planning process in the MRP.
126	5, A		12.5.1	What are the most effective means to build GCDAMP	None proposed.	A possible POAHG project.

No.	Adaptive Management Work Group (AMWG) Sequence Number and Category	AMWG Priority	Research information needs (RIN) no.	RIN text	Strategic science questions (SSQs), relevant core-monitoring information needs (CMINs), and Science Advisor (SA) questions. Questions listed below are from the Monitoring and Research Plan (MRP).	Comments
				public support through effective public outreach?		
127	5, A		12.5.2	What are the most effective means to attain and maintain effective communication and coordination with other resource management programs in the Colorado River basin to ensure consideration of their values and perspectives into the GCDAMP and vice versa?	None proposed.	The 2008 Science Symposium will be held jointly with sponsors of other restoration/science programs in the Colorado River Basin. In addition, the FY2007 GCDAMP effectiveness workshop may help to address this information need.
128	5, A		12.5.4	What is the most effective way to distribute information to our stakeholders and the public in a secure and accessible fashion?	None proposed.	A possible POAGH issue. The MRP recommends a study to assess the feasibility of using decision support tools to improve use of science information in the GCDAMP process. The FY2007 GCDAMP effectiveness workshop may help to address this information need.
129	5, A		12.7.1	How effective are the current strategies to achieve tribal consultation?	None proposed.	Policy topic for the Cultural Resources ad hoc Group (CRAHG) and programmatic agreement (PA) to discuss and resolve.
130	5, A		12.7.2	How well do the current strategies to achieve tribal consultation meet legal and GCDAMP protocols?	None proposed.	Policy topic for the CRAHG and PA to discuss and resolve.
131	5, A		12.8.1	How well does current tribal participation in the GCDAMP research and long-term monitoring programs meet tribal needs and desires?	None proposed.	FY2007 GCDAMP effectiveness workshop may help to address this information need.

No.	Adaptive Management Work Group (AMWG) Sequence Number and Category	AMWG Priority	Research information needs (RIN) no.	RIN text	Strategic science questions (SSQs), relevant core-monitoring information needs (CMINs), and Science Advisor (SA) questions. Questions listed below are from the Monitoring and Research Plan (MRP).	Comments
132	5.5, A		1.2.4	What are the habitat characteristics between GCD and the Paria River that most affect benthic invertebrates? How are these characteristics affected by GCD operations?	**SSQ 1-5.** What are the important pathways that link lower trophic levels with fish and how will they link to dam operations? SSQ 5-2. Is invertebrate flux affected by water quality (e.g., temperature, nutrient concentrations, turbidity) and dam operations?	
133	5.5, A		1.3.1	How are the composition and biomass of primary producers in the CRE below the Paria River affected by flow and water quality (including nutrients, temperature, light regime, toxins, dissolved oxygen), and waterborne diseases, or other factors?	**SSQ 1-5.** What are the important pathways that link lower trophic levels with fish and how will they link to dam operations? **SSQ 5-2.** Is invertebrate flux affected by water quality (e.g., temperature, nutrient concentrations, turbidity) and dam operations?	
134	5.5, A		1.4.3	How do top-down effects (grazing and predation) affect the abundance and composition of benthic invertebrates?	**SSQ 1-6.** Are fish populations, trends, or indicators from fish, such as growth, condition, and body composition, correlated with patterns in invertebrate flux?	
135	5.5, A		1.5.1	How are the composition and biomass of drift in the CRE affected by flow and water quality (including nutrients, temperature, light regime, toxins, dissolved oxygen), and waterborne diseases, or other factors?	**SSQ 1-5.** What are the important pathways that link lower trophic levels with fish and how will they link to dam operations? SSQ 5-2. Is invertebrate flux affected by water quality (e.g., temperature, nutrient concentrations, turbidity) and dam operations?	
136	5.5, A		4.2.4	What is the target population size of RBT appropriate for the Lees Ferry reach that limits	**SSQ 3-6.** What GCD operations (ramping rates, daily flow range, etc.) maximize trout fishing opportunities and catchability?	This will be one of the subjects addressed by the RBT PEP in 2007.

No.	Adaptive Management Work Group (AMWG) Sequence Number and Category	AMWG Priority	Research information needs (RIN) no.	RIN text	Strategic science questions (SSQs), relevant core-monitoring information needs (CMINs), and Science Advisor (SA) questions. Questions listed below are from the Monitoring and Research Plan (MRP).	Comments
				downstream emigration?	**CMIN 4.1.2.** Determine annual proportional stock density of RBT in the Lees Ferry reach. **CMIN 4.1.4.** Determine annual standard condition and relative weight of RBT in the Lees Ferry reach.	
137	5.5, A		6.3.1	How has the abundance, composition, and distribution of the OHWZ community changed since dam closure (1963), high flows (1984), interim flows (1991), and the implementation of ROD operations (1996)?	**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? **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.	
138	5.5, A		6.7.5	What is the need, feasibility, and priority of maintaining habitat suitability for southwestern willow flycatcher in the CRE?	None proposed.	The NPS is taking the lead for this resource in conjunction with USFWS. Not a GCDAMP priority at this time.
139	5.5, A		8.5.2	What is the reach-scale variability of fine-sediment storage throughout the main channel?	**SSQ 4.1.** (See above.)	This information has been previously reported in synthesis final reports by Schmidt and others (2004); Grams and others (2003); Grams and others (in press) and in FIST ongoing reporting, at least upstream of river mile 87.
140	5.5, A		8.5.5	What are the historic and ongoing longitudinal trends of fine-sediment storage, above	**SSQ 4.1.** (See above.)	This information has been previously reported in synthesis final reports by Schmidt and others (2004); Grams

No.	Adaptive Management Work Group (AMWG) Sequence Number and Category	AMWG Priority	Research information needs (RIN) no.	RIN text	Strategic science questions (SSQs), relevant core-monitoring information needs (CMINs), and Science Advisor (SA) questions. Questions listed below are from the Monitoring and Research Plan (MRP).	Comments
				25,000 cfs?		and others (2003); Grams and others (in press) and in FIST ongoing reporting, at least upstream of river mile 87.
141	5.5, A		** SIN 8.5.7	What are the limiting factors that regulate substrate availability and its distribution?	**SSQ 4.1.** (See above.)	The limiting factors are a combination of tributary sediment supply, influence of dam operation, and larger tributary floods.
142	5.5, A		9.4.1	Identify the elements of wilderness experience specific to the CRE.	**SSQ 3-7.** How do dam controlled flows affect visitor experiences, and what are the optimal flows for maintaining a high quality recreational experience in the CRE? **SSQ 3-8.** What are the drivers for recreational experience in the CRE, and how important are flows relative to other drivers in shaping recreational experience? **SSQ 3-12.** How do flow 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 NPS defined key elements of wilderness experience in the CRE, with public input (e.g., the Colorado River Management Plan [CRMP]). Indirectly, this issue will be addressed in the recreation tradeoff study proposed for FY2008–09.
143	5.5, A		10.1.4	What would be the effects on the CRE and marketable capacity and energy of lowering the minimum flow limit below 5,000 cfs?	None proposed.	This is an EIN that may be addressed by the LTEP.
144	5.5, A		11.1.2.d	Identify NPS permitted	None proposed.	NPS addresses this RIN through their

No.	Adaptive Management Work Group (AMWG) Sequence Number and Category	AMWG Priority	Research information needs (RIN) no.	RIN text	Strategic science questions (SSQs), relevant core-monitoring information needs (CMINs), and Science Advisor (SA) questions. Questions listed below are from the Monitoring and Research Plan (MRP).	Comments
				activities that affect National Register eligible sites.		internal project permit review process.
145	5.5, A		11.1.5	What are appropriate strategies to preserve resource integrity?	**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?	Science can determine whether preservation strategies work or not; managers and stakeholders need to define what is "appropriate."
146	6, A		1.1.3	How do top-down effects (grazing and predation) on primary producers affect food base productivity?	**SSQ 1-5.** What are the important pathways that link lower trophic levels with fish and how will they link to dam operations? **SSQ 5-2.** Is invertebrate flux affected by water quality (e.g., temperature, nutrient concentrations, turbidity) and dam operations?	
147	6, A		1.2.3	How do top-down effects (grazing and predation) affect the abundance and composition of benthic invertebrates?	**SSQ 1-5.** What are the important pathways that link lower trophic levels with fish and how will they link to dam operations? **SSQ 5-2.** Is invertebrate flux affected by water quality (e.g., temperature, nutrient concentrations, turbidity) and dam operations?	
148	6, A		1.3.3	How do top-down effects on primary producers (grazing and predation) affect food base productivity?	**SSQ 1-5.** What are the important pathways that link lower trophic levels with fish and how will they link to dam operations? **SSQ 5-2.** Is invertebrate flux affected by water quality (e.g., temperature, nutrient concentrations, turbidity) and dam operations?	
149	6, A		1.3.4	What are the habitat characteristics in the CRE below the Paria River that most affect primary productivity? How are these characteristics	**SSQ 1-5.** What are the important pathways that link lower trophic levels with fish and how will they link to dam operations? **SSQ 5-2.** Is invertebrate flux affected by water quality (e.g., temperature, nutrient	

No.	Adaptive Management Work Group (AMWG) Sequence Number and Category	AMWG Priority	Research information needs (RIN) no.	RIN text	Strategic science questions (SSQs), relevant core-monitoring information needs (CMINs), and Science Advisor (SA) questions. Questions listed below are from the Monitoring and Research Plan (MRP).	Comments
				affected by GCD operations?	concentrations, turbidity) and dam operations?	
150	6, A		1.4.4	What are the habitat characteristics in the CRE below the Paria River that most affect benthic invertebrates? How are these characteristics affected by GCD operations?	**SSQ 1-5.** What are the important pathways that link lower trophic levels with fish and how will they link to dam operations? **SSQ 5-2.** Is invertebrate flux affected by water quality (e.g., temperature, nutrient concentrations, turbidity) and dam operations?	
151	6, A		2.2.11	What are the impacts of current recreational activities on mortality, recruitment and the population size of HBC?	None proposed.	The NPS planned to fund a study on this topic in FY2006–07 through their CRMP funding sources. Current status of the project is unknown. This issue will be brought up for discussion in the FY2008 PEP.
152	6, A		2.6.3	What are the physical and biological characteristics of habitats that enhance recruitment of FMS, BS, and SD populations in the CRE?	**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?	
153	6, A		*IN 6.1	Develop GIS coverages of natural communities in the CRE to use in identification of status and trends.	**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? 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.	This information need is being addressed by vegetation mapping, monitoring and synthesis projects in FY2006–07 and beyond. It will also be a focus of the shoreline habitat study.
154	6, A		*IN	How is the abundance of	**SSQ 1-5.** What are the important pathways	

No.	Adaptive Management Work Group (AMWG) Sequence Number and Category	AMWG Priority	Research information needs (RIN) no.	RIN text	Strategic science questions (SSQs), relevant core-monitoring information needs (CMINs), and Science Advisor (SA) questions. Questions listed below are from the Monitoring and Research Plan (MRP).	Comments
			6.3	vertebrate consumers affected by seasonal shifts in food base abundance in the CRE?	that link lower trophic levels with fish and how will they link to dam operations? **SSQ 5-2.** Is invertebrate flux affected by water quality (e.g., temperature, nutrient concentrations, turbidity) and dam operations?	
155	6, A		** SIN 7.3.1	Measure appropriate water quality parameters to determine the influence of these parameters on biological resources in the CRE.	**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 nearshore water temperatures throughout the CRE?	
156	6, A		** SIN 8.5.8	What is the total area of different aquatic habitat types (cobble, gravel, sand, talus, etc,) in the CRE?	None proposed.	This information need is being addressed by a shoreline habitat study initiated in FY2007 as well as other remote-sensing methods (e.g., side-scanning sonar, underwater microscope, etc.) that come from the FIST research and development project.
157	6, A		** SIN 8.5.9	How are sandbar textures related to cultural site stability?	None proposed.	This SIN is a legitimate science question and should be pursued as support becomes available.
158	6, A		10.1.1	What would be the effects on the CRE and marketable capacity and energy of increasing the daily fluctuation limit?	**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)?	This RIN will be addressed through the LTEP.

No.	Adaptive Management Work Group (AMWG) Sequence Number and Category	AMWG Priority	Research information needs (RIN) no.	RIN text	Strategic science questions (SSQs), relevant core-monitoring information needs (CMINs), and Science Advisor (SA) questions. Questions listed below are from the Monitoring and Research Plan (MRP).	Comments
159	6, A		10.4.1	What are the effects on the CRE and marketable power and energy of increasing Automatic Generation Control at GCD?	**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)?	This RIN may be addressed through the LTEP.
160	6, A		12.5.3	To what extent does the public understand and support the GCDAMP?	None proposed.	A possible task for the POAGH.
161	6.5, A		5.1.1	What constitutes population viability for KAS at Vaseys Paradise?	None proposed.	Mostly a policy and management question; data to help support this question are collected consistent with the monitoring described in CMINs.
162	6.5, A		5.2.3	How can remote sensing technologies be used to less intrusively and more cost effectively characterize and monitor KAS habitat at Vaseys Paradise (vegetation type and distribution)?	None proposed.	Not a current high AMWG priority.
163	6.5, A		*IN 6.2	Develop or adopt an existing ecological community classification system. The system should describe the composition and frequency of vascular plants, vertebrates, arthropods, and mollusks to an appropriate taxonomic level.	**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? **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.	
164	6.5, A		7.2.4	What are the waterborne pathogens that are a threat to human health? How should	**SSQ 3-7.** How do dam controlled flows affect visitors' recreational experiences, and what are the optimal flows for maintaining a high	

No.	Adaptive Management Work Group (AMWG) Sequence Number and Category	AMWG Priority	Research information needs (RIN) no.	RIN text	Strategic science questions (SSQs), relevant core-monitoring information needs (CMINs), and Science Advisor (SA) questions. Questions listed below are from the Monitoring and Research Plan (MRP).	Comments
				they be monitored? Where and how often?	quality recreational experience in the CRE? **SSQ 3-11.** How do varying flows positively or negatively affect visitor safety, health, and navigability of the rapids? **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 CRE.	
165	6.5, A		8.6.1	How do ongoing inputs of coarse-sediment from tributaries influence storage of fine sediment within pools, runs, and eddies throughout the CRE?	None proposed.	Work published by Webb and others, 2001, and Melis, 1997, already provide some information about this topic (see section on sand storage in USGS Fact Sheet FS 019-01). (No additional SSQ because of relatively low AMWG priority.)
166	7, A		9.5.1	What effects do administrative trips, including research and monitoring activities have on recreational users?	**CMIN 9.5.**1 Determine and track the frequency and scheduling of research and monitoring activity in Glen and Grand Canyons.	CRMP research sponsored by NPS may be addressing this issue at some level.
167	7, A		* IN 10.1	Determine and track the impacts to power users from implementation of ROD dam operations and segregate those effects from other causes such as changes in the power market.	**SSQ 3-3.** What are the hydropower replacement costs of the MLFF (annually, since 1996?) CMIN 10.1.1 Determine and track the marketable capacity and energy produced through dam operations in relation to various release scenarios.	

No.	Adaptive Management Work Group (AMWG) Sequence Number and Category	AMWG Priority	Research information needs (RIN) no.	RIN text	Strategic science questions (SSQs), relevant core-monitoring information needs (CMINs), and Science Advisor (SA) questions. Questions listed below are from the Monitoring and Research Plan (MRP).	Comments
168	7.5, A		7.3.1.a	Determine the status and trends of chemical and biological components of water quality in Lake Powell as a function of regional hydrologic conditions and their relation to downstream releases.	(No additional SSQ because of relatively low AMWG priority.)	The annual Lake Powell monitoring program is collecting these data. Need for an assessment of historical quality-of-water (physical and biological) data collected within Lake Powell reservoir has been identified since the late 1990s but has yet to be published. The data exist and should be first published, then described and synthesized within a major interpretive report. This project should be completed as soon as funding is available. The program will be assessed in PEP in FY2009.
169	7.5, A		** SIN 8.5.10	How are sandbar textures related to recreational site stability?		This SIN is a legitimate science question and should be pursued as support becomes available.
170	8, A		1.3.2	What is the estimated primary productivity in the CRE below the Paria River? (Note: If the cost of obtaining these data, relative to the benefit of the information suggests the information is not worth the expense, this RIN will not be pursued.)	**SSQ 1-5.** What are the important pathways that link lower trophic levels with fish and how will they link to dam operations? **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	

No.	Adaptive Management Work Group (AMWG) Sequence Number and Category	AMWG Priority	Research information needs (RIN) no.	RIN text	Strategic science questions (SSQs), relevant core-monitoring information needs (CMINs), and Science Advisor (SA) questions. Questions listed below are from the Monitoring and Research Plan (MRP).	Comments
					determine mainstem and nearshore water temperatures throughout the CRE? **SSQ 5-2.** Is invertebrate flux affected by water quality (e.g., temperature, nutrient concentrations, turbidity) and dam operations?	
171	8, A		1.4.2	What is the estimated productivity of benthic invertebrates in the CRE below the Paria River? (Note: If the cost of obtaining these data, relative to the benefit of the information suggests the information is not worth the expense, this RIN will not be pursued.)	**SSQ 1-5.** What are the important pathways that link lower trophic levels with fish and how will they link to dam operations? **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 nearshore water temperatures throughout the CRE? **SSQ 5-2.** Is invertebrate flux affected by water quality (e.g., temperature, nutrient concentrations, turbidity) and dam operations?	
172	8, A		2.5.4	What is the feasibility and advisability of augmenting RBS in the CRE to attain a viable population including technical/legal/policy constraints?	None proposed.	Not a high GCDAMP priority.
173	8, A		6.7.1	What is the function of the CRE as a migratory corridor for southwestern willow flycatcher (SWWF)?	None proposed.	SWWF issues are currently being managed by NPS with USFWS.

No.	Adaptive Management Work Group (AMWG) Sequence Number and Category	AMWG Priority	Research information needs (RIN) no.	RIN text	Strategic science questions (SSQs), relevant core-monitoring information needs (CMINs), and Science Advisor (SA) questions. Questions listed below are from the Monitoring and Research Plan (MRP).	Comments
174	8, A		6.7.2	What is the food base that supports SWWF and other terrestrial vertebrates?	None proposed.	SWWF issues are currently being managed by NPS with USFWS.
175	8, Done		6.7.3	What constitutes suitable SWWF habitat?	None proposed.	This has been determined by USFWS; it is not a GCDAMP decision.
176	8.5, A		6.6.3	How has the composition, abundance and distribution of seep and spring communities changed since dam closure (1963), high flows (1984), interim flows (1991) and the implementation of ROD operations (1996)?	**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? **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.	This is being addressed by vegetation synthesis project in FY2007 and beyond.
177	9, A		1.1.2	What is the estimated productivity for the reach between GCD and the Paria River? (Note: If the cost of obtaining these data, relative to the benefit of the information suggests the information is not worth the expense, this RIN will not be pursued.)	**SSQ 1-5.** What are the important pathways that link lower trophic levels with fish and how will they link to dam operations? **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 nearshore water temperatures throughout the CRE? **SSQ 5-2.** Is invertebrate flux affected by water quality (e.g., temperature, nutrient concentrations, turbidity) and dam operations?	

No.	Adaptive Management Work Group (AMWG) Sequence Number and Category	AMWG Priority	Research information needs (RIN) no.	RIN text	Strategic science questions (SSQs), relevant core-monitoring information needs (CMINs), and Science Advisor (SA) questions. Questions listed below are from the Monitoring and Research Plan (MRP).	Comments
178	9, A		2.5.5	What are the genetic and ecological criteria for reintroducing RBS into the CRE?	(No additional SSQ because of relatively low AMWG priority.)	Not a current high priority of GCDAMP.
179	9, A		4.1.2	What is the minimum quantity and quality of spawning substrate necessary for maintaining a wild reproducing RBT population in the Lees Ferry reach?	**SSQ 3-6.** What GCD operations (ramping rates, daily flow range, etc.) maximize trout fishing opportunities and catchability?	Currently this is being addressed most directly (but not completely) by Korman's work. Current monitoring consistent with CMINs for this resource.
180	9, C		5.1.7	What is the historic range of Oxyloma haydeni? Can this range be determined from subfossil or fossil evidence? (NOTE: This is intended to determine if this is a relict species and the initial work would be done at Vaseys Paradise, South Canyon and other probable sites within the CRE.)	(No additional SSQ because of relatively low AMWG priority.)	Completed KAS review by USFWS may answer this information need. Current monitoring is consistent with CMINs for this resource.
181	9, A		6.6.1	How is seep and spring habitat affected by variation in dam operations, variation in seep or spring flow, and variation in water quality? How do flow rates and water quality parameters at seeps and springs compare with historic measurements?	**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?	Current vegetation projects address species composition and distribution, but no projects are looking at effects of flow rates or water quality. The effects of experimental flows on vegetation will be a component of the LTEP, but specifics of the experiment have not yet been determined. Current monitoring is consistent with CMINs for this

No.	Adaptive Management Work Group (AMWG) Sequence Number and Category	AMWG Priority	Research information needs (RIN) no.	RIN text	Strategic science questions (SSQs), relevant core-monitoring information needs (CMINs), and Science Advisor (SA) questions. Questions listed below are from the Monitoring and Research Plan (MRP).	Comments
						resource.
182	9, A		6.6.4	What is the distribution, patch size, total area, and composition of seep and spring communities and the flow rate and water quality of all seeps and springs within the CRE?	None proposed.	Current vegetation projects address species composition and distribution, but no projects are looking at effects of flow rates or water quality. Effects of experimental flows on vegetation will be a component of the LTEP, but specifics of the experiment have not yet been determined. Current monitoring is consistent with CMINs for this resource.
183	9, A		6.7.4	How has the abundance, distribution and reproductive success of SWWF changed since dam closure (1963), high flows (1984), interim flows (1991) and the implementation of ROD operations (1996)?	None proposed.	SWWF issues are currently being managed by NPS with USFWS.
184	9, A		7.3.3	How do dam operations affect reservoir limnology?	(No additional SSQ because of relatively low AMWG priority.)	This is a legitimate science question that potentially warrants further study in the LTEP.
185	9, A		** SIN 8.5.1	How do sandbar textures influence biological processes?	(No additional SSQ because of relatively low AMWG priority.)	This SIN is a legitimate science question and should be pursued as support becomes available.
186	9.5, C		3.1.1	What information (including technical, legal, economic, and policy issues) should be considered in determining the	None proposed.	Policy and management question. If restoration of one or more of these species is a priority, then GCMRC can provide scientific support.

No.	Adaptive Management Work Group (AMWG) Sequence Number and Category	AMWG Priority	Research information needs (RIN) no.	RIN text	Strategic science questions (SSQs), relevant core-monitoring information needs (CMINs), and Science Advisor (SA) questions. Questions listed below are from the Monitoring and Research Plan (MRP).	Comments
				feasibility and advisability of restoring pikeminnow, bonytail, roundtail chub, river otter, or other extirpated species?		
187	9.5, A		8.5.3	What is the pre- and postdam range of grain-size in fine-sediment deposits, by reach?	None proposed.	See several publications containing information on this topic: Howard and Dolan, 1981; Schmidt and Graf, 1990; Topping and others 2005; Topping and others, 2000a and 2000b.
188	10, A		4.1.1	What is the target proportional stock density (i.e., tradeoff between numbers and size) for RBT in the Lees Ferry reach?	None proposed.	To a large degree, the target is a management decision, but current monitoring efforts provide supporting information.
189	10, A		4.1.4	How does the genetics or "strain" of RBT in the Lees Ferry reach influence the average size of fish creeled by anglers?	(No additional SSQ because of relatively low AMWG priority.)	This information need is not currently being addressed.
190	11, A		2.5.1	If RBS were stocked into the CRE, what is the risk that hybridization with FMS would compromise the genetic integrity of either species?	(No additional SSQ because of relatively low AMWG priority.)	RBS are not a high GCDAMP priority at this time.
191	11, A		2.5.2	How do existing RBS and FMS affect the genetic integrity of either species? What are the factors contributing to this ongoing hybridization?	None proposed.	RBS are not a high GCDAMP priority at this time. (This question is well addressed in a paper by D.G. Buth and others, 1987, which suggests that the native level of

No.	Adaptive Management Work Group (AMWG) Sequence Number and Category	AMWG Priority	Research information needs (RIN) no.	RIN text	Strategic science questions (SSQs), relevant core-monitoring information needs (CMINs), and Science Advisor (SA) questions. Questions listed below are from the Monitoring and Research Plan (MRP).	Comments
						hybridization was not detrimental to either species.)
192	11, C		2.5.6	What are the measurable criteria that would need to be met to remove jeopardy for RBS in the CRE?	None proposed.	Policy question.
193	11, A		7.3.2	How accurately can modeling predict reservoir dynamics and operational scenarios?	None proposed.	Not a high GCDAMP priority. Outside funding for modeling Lake Powell is identified in the MRP. The Bureau of Reclamation has developed a model for Lake Powell reservoir, but it has not been published in the peer reviewed literature to date. Therefore, the answer to this question remains unknown.
194	11, A		9.1.1	What are the attributes of a quality river experience? (How do you define a quality river experience?)	**SSQ 3-7.** How do dam controlled flows affect visitors' recreational experiences, and what 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? (See also SSQ 3-9, 3-10, 3-11, and 3-12.)	This is largely an NPS management decision. Social science studies can provide data on what the public considers to be a quality river experience, but ultimately NPS must determine what type of experience they are managing for.
195	11, A		9.1.2	Determine the appropriate carrying capacity for recreational activities within the CRE.	None proposed.	Appropriate carrying capacity is dependent on the type of recreational experience that the river corridor is being managed for and amount of crowding NPS is willing to allow;

No.	Adaptive Management Work Group (AMWG) Sequence Number and Category	AMWG Priority	Research information needs (RIN) no.	RIN text	Strategic science questions (SSQs), relevant core-monitoring information needs (CMINs), and Science Advisor (SA) questions. Questions listed below are from the Monitoring and Research Plan (MRP).	Comments
						therefore, this RIN must be addressed by NPS managers in consultation with the public. Once target levels for crowding and encounter rates have been established, we can provide data on how flows are changing social encounters and campable area in relation to those targets.
196	11, A		9.1.3	How do ongoing inputs of coarse-sediment from tributaries diminish or enhance navigability of rapids throughout the CRE?	**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?	This was to be addressed as a component of the safety study proposed for FY2007, and now deferred to FY2008 or FY2009.
197	11, A		12.1.2	What are the use (e.g., hydropower, trout fishing, rafting) and nonuse (e.g., option, vicarious, quasi-option, bequest and existence) values of the CRE?	None proposed.	A question for the socioeconomic PEP to consider.
198	11, A		12.1.3	How does use (e.g., hydropower, trout fishing, rafting) and nonuse (e.g., option, vicarious, quasi-option, bequest and existence) values change in response to an experiment performed under the ROD, unanticipated event, or other management action?	**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)?	
199	11.5, A		7.3.1.b	Determine stratification,	None proposed.	Some aspects of this RIN are

No.	Adaptive Management Work Group (AMWG) Sequence Number and Category	AMWG Priority	Research information needs (RIN) no.	RIN text	Strategic science questions (SSQs), relevant core-monitoring information needs (CMINs), and Science Advisor (SA) questions. Questions listed below are from the Monitoring and Research Plan (MRP).	Comments
				convective mixing patterns, and behavior of advective currents in Lake Powell and their relation to GCD operations to predict seasonal patterns and trends in downstream releases.		addressed by current modeling by Reclamation. No new SSQ because of low AMWG priority.
200	11.5, A		7.4.1	What is the desired range of seasonal and annual flow dynamics associated with powerplant operations, BHBFs, and habitat maintenance flows, or other flows that meet GCDAMP goals and objectives?	None proposed.	This is what the entire GCDAMP is supposedly trying to answer and is a focus of the current LTEP EIS.
201	11.5, A		10.1.5	How do power-marketing contract provisions affect GCD releases?	None proposed.	Not a GCDAMP priority at this time.
202	11.5, A		12.1.1	What is the economic value of the recreational use of the CRE downstream from GCD?	None proposed.	Not a GCDAMP priority at this time.
203	No Sequence Order, A		* IN 12.2	Determine what information is necessary and sufficient to make recommendations at an acceptable level of risk.	None proposed.	Ultimately managers will need to decide what level of risk they are willing to accept.

APPENDIX C. Monitoring and Research Plan Acronym Glossary

AMPSP	Final Draft GCDAMP Strategic Plan
AMWG	Adaptive Management Work Group
ASMR	Age-structured mark recapture
AZGFD	Arizona Game and Fish Department
BHBF	Beach/habitat-building flows
BHS	Bluehead sucker
CEM	Conceptual ecosystem model
CMINs	Core monitoring information needs
CRAHG	Cultural Resources ad hoc Group
CRE	Colorado River ecosystem
CREDA	Colorado River Energy Distributors Association
CRMP	Colorado River Management Plan
DASA	Data Acquisition, Storage, and Analysis Program
DOI	Department of the Interior
EIS	Environmental impact statement
FIST	Fine-grained Integrated Sediment Team
FMS	Flannelmouth sucker
GCD	Glen Canyon Dam
GCDAMP	Glen Canyon Dam Adaptive Management Program
GCMRC	USGS Grand Canyon Monitoring and Research Center
GCRA	Grand Canyon National Park
GIS	Geographic Information Systems
HBC	Humpback chub (*Gila cypha*)
HMF	Habitat maintenance flow
IQW	Integrated quality-of-water
IRP	Independent Review Panels
ISA	Energy Tracking Database
KAR	Knowledge Assessment Report
KAS	Kanab ambersnail
LCR	Little Colorado River
LSSF	Low summer steady flows
LTEP	Long-Term Experimental Plan
MLFF	Modified low fluctuating flow
MRP	Monitoring and Research Plan
NAU	Northern Arizona University
NGS	National Geodetic Survey
NHPA	National Historic Preservation Act
NPS	National Park Service
OHWZ	Old high water zone
PCMP	Provisional Core Monitoring Plan
PEP	Protocols evaluation panel
PIT	Passive integrated transponder
POAGH	Public Outreach ad hoc Group
RBS	Razorback sucker
RBT	Rainbow trout
RINs	Research information needs
ROD	Record of Decision
SA	Science Advisors
SBSC	Southwest Biological Science Center
SCORE	Colorado River ecosystem in Grand Canyon
SD	Speckled dace
SEDS	Sediment transport modeling review
SIN	Supporting Information Need
SPG	Science Planning Group
SSP	Strategic Science Plan
SSQs	Strategic science questions
STARS	Sediment transport and river simulation
TCD	Temperature control device
TCPs	Traditional cultural properties
TEM	Terrestrial ecosystem monitoring
TWG	Technical Work Group
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
USU	Utah State University
WAPA	Western Area Power Administration
YoY	Young-of-year