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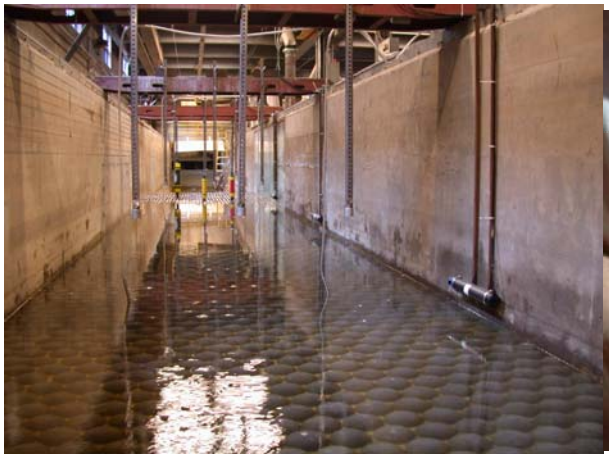
Grand Canyon Monitoring and Research Center Monitoring and Research Plan to Support the Glen Canyon Dam Adaptive Management Program: 2007-2011

Developed in cooperation with the Glen Canyon Dam Adaptive Management Program



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GRAND CANYON MONITORING AND RESEARCH CENTER
MONITORING AND RESEARCH PLAN
FY 2007-2011
DEVELOPED IN COOPERATION WITH GLEN CANYON DAM ADAPTIVE MANAGEMENT PROGRAM (GCD AMP)

CHAPTER 1. INTRODUCTION, PURPOSE, AND ELEMENTS OF THE GRAND CANYON MONITORING AND RESEARCH CENTER'S (GCMRC) MONITORING AND RESEARCH PLAN

INTRODUCTION

The Glen Canyon Dam Adaptive Management Program (AMP) has adopted a science planning process to develop a credible, objective science program that is responsive to the goals and priority needs of the AMP. The major components of the science planning process include:

1. The Final Draft **AMP Strategic Plan (AMPSP):** A long-term plan drafted by AMP participants in cooperation with GCMRC in August 2001 that identifies the Adaptive Management Work Group's (AMWG) vision and mission statement, principals, goals, management objectives, information needs, and management actions.

2. **The GCMRC Strategic Science Plan: (SSP):** Developed by GCMRC in cooperation with AMP participants to identify 5-year strategies for providing science information to respond to goals, management objective, and priority questions of the AMP participants, consistent with the AMPSP.

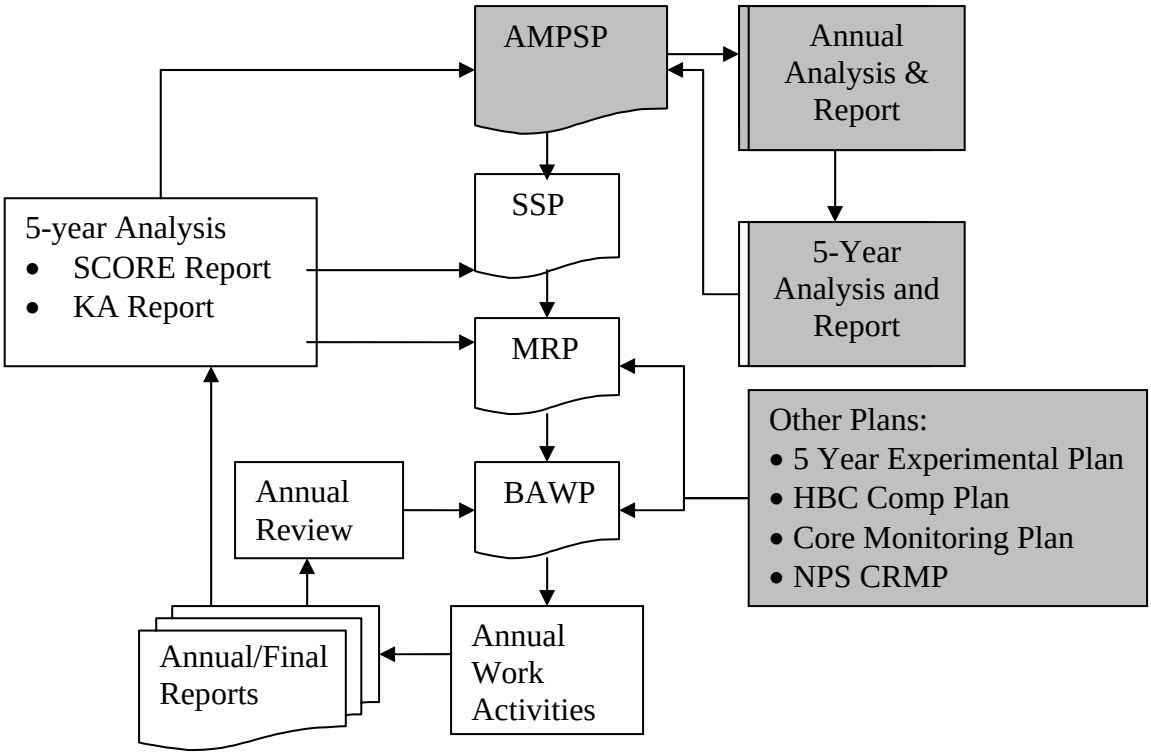
3. The **GCMRC Monitoring and Research Plan (MRP):** Developed by GCMRC in cooperation with the AMP Science Planning Group (SPG) to specify 5-year research and monitoring programs consistent with the strategies and priorities in the SSP. The MRP will identify the objectives associated with each strategic science question and related monitoring, experimental research, and research and development projects.

4. The **GCMRC Biennial Work Plan: (BAWP):** Developed by GCMRC in cooperation with the AMP Science Planning Group to identify the scope, objectives, and budget for the 2-year monitoring and research projects consistent with the MRP.

Figure 1.1 depicts the flow of information in the science planning and implementation process. Annually, GCMRC will report on accomplishments related to projects included in the biennial work plan and evaluate how science has advanced knowledge relative to AMP goals and management objectives. At 5-year intervals, GCMRC will formally synthesize new scientific information in the form of an updated The State of the Colorado River Ecosystem in Grand Canyon (SCORE) report (Gloss and others, 2005) and or/a Knowledge Assessment (KA) Report (Melis and others, 2006) will be revised to identify knowledge gaps related to the effects of various treatments/management actions on resources of interest to the AMP (e.g., the effect of dam operations on humpback chub (HBC) recruitment). Information from one or both of these reports will be used to identify key strategic questions associated with priority AMP information needs or questions.

Priority information needs and science questions will be evaluated by scientists and managers to determine what revisions to the science program are needed. This includes development of revised SSP and MRP documents and a new experimental research plan. The planning process is designed to be carried out collaboratively by GCMRC and AMP participants working through the AMWG, Technical Work Group (TWG), and the Science Advisors Board (SAB).

Figure 1.1. Collaborative science planning and implementation process. The AMP and Department of Interior (DOI) have leaded responsibility for the shaded boxes. GCMRC has lead responsibility for the un-shaded boxes.



PURPOSE

The purpose of the Monitoring and Research Plan is to describe the scope and objective of a 5-year experimental, research and monitoring program to address priority goals, questions, and information needs specified by the AMP. The plan will identify specific priority science needs for years one and two of a 5-year planning period; more general needs will be defined for years three through five.

The MRP is designed to be consistent with and implement both the AMP Strategic Plan and the GCMRC SSP. In summary, the SSP emphasizes:

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

ELEMENTS OF THE RESEARCH AND MONITORING PLAN

The FY 2007-2011 monitoring and research program will include three principle elements:

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

These elements, while treated separately for the purposes of the MRP, are designed and carried out in an integrated interdisciplinary fashion as discussed below.

The AMP has, since inception, attempted to insure appropriate science and management program continuity and balance across all goals adopted by the program. The current focus is on strategic science questions associated with high priority AMWG information needs (Appendix B). Other AMP goals will still be pursued, but with less intensity, until priority issues of concern are resolved and monies can be reprogrammed or obtained through alternate sources. In the MRP, at least one project will be proposed to address each AMP goal.

Experimental Research Element

The MRP will be consistent with and implement the Experimental Research Program developed through the SPG and endorsed by the AMWG. The experimental program design embraces the concept of a "***Hybrid***" experimental design. This design incorporates assessments of both management actions and treatments in experimentation.

A component of the Hybrid design is the identification of management actions. Management actions are those actions that provide proven resource benefits that no longer require further research. For example, cold water fish control methods developed in the 2003-2005 research program have been proven effective at reducing the abundance and distribution of rainbow trout within treatment reaches near the confluence of the Little Colorado River. In addition, in FY 04 a methodology to mitigate the effect of Beach Habitat Building Flows (BHBF) on Kanab ambersnail (KAS) habitat loss was developed, tested, and proven effective. These actions will be considered management actions in the MRP. As such, future implementation of these actions will be primarily a responsibility of the appropriate land and resource management agencies.

The use of controlled floods, otherwise known as BHBFs, are triggered by unpredictable natural deposition/accumulation of sediment in the mainstem Colorado River below the Paria River and Little Colorado River (LCR). The evaluation of the BHBF conducted in FY 04 cost

approximately $1.2 million. In the FY 07-11 period, GCMRC anticipates conducting up to two additional BHBF tests at a cost of approximately $1M per test. Approximately $350K will be set aside from GCMRC annually in an account to fund the BHBF tests so they can be conducted without financially impacting other ongoing projects of the MRP. Deposits to the experimental account will cease when the balance reaches $2M. A BHBF work plan will be developed that describes the hypotheses that will be tested and the studies that will be conducted to test those hypotheses. BHBF studies will be coordinated with ongoing projects to maximize cost-effectiveness.

NOTE: The complete final experimental flow and non-flow option scheduled for FY 2007-2011 have yet to be finalized by the AMP. Information will be included once it is available.

The experimental research program will be implemented following approval by the Secretary of DOI and completion of appropriate National Environmental Policy Act (NEPA) and Endangered Species Act (ESA) compliance requirements. GCMRC will provide scientific information to support the environmental compliance process, as requested.

The Monitoring Program

A comprehensive monitoring program has existed in the overall GCMRC science program for over a decade. However, the AMP has felt that improved assessments be made of the various monitoring programs and projects so that determinations could be made for termination of selected programs deemed not effected or not needed, and assignments of programs deemed critical to a special category “Core Monitoring”. Other programs would also be placed in selected categories.

Core Monitoring Element

“Core Monitoring: Consistent, long-term, repeated measurements using scientifically accepted protocols to measure status and trends of key resources to answer specific questions. Core monitoring is implemented on a fixed schedule regardless of budget or other

circumstances (e.g., water year, experimental flows, temperature control, stocking strategy, non-native control, etc.) affecting target resources." (AMP Strategic Plan, 2000)

The need for a long-term core monitoring plan for the AMP has been identified as a critical program need since its inception in 1996. However, completion of a long-term core monitoring plan has remained an elusive goal for a variety of reasons. First, the process for the systematic development of monitoring programs involves the establishment of Protocol Evaluation Panels (PEP) for each key resource area, followed by 4-5 years of pilot testing of monitoring protocols, then a period of analysis, synthesis, and revaluation, culminating in the implementation of long-term monitoring protocols. This process, which requires approximately 5-6 years of Research and Development for each key resource, got underway in 1998, and is still in progress for some elements of the program today (e.g., terrestrial ecosystems, archaeological and tribal resources, aquatic food base, recreation, and socio-economic.) Other factors that have hindered rapid progress in the development of a core monitoring plan include:

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

All of these issues continue to limit progress on the development and implementation of a core monitoring plan for the AMP. A Provisional Core Monitoring Plan (PCMP) (Fairley and others, 2005) was drafted by GCMRC in cooperation with an AMP 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/AMWG, or finalized. Nevertheless, the PCMP represents the best information that is currently available to guide the development of the core monitoring plan for FY 07-11.

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

- Lake Powell quality of water
- Downstream surface water discharge and stage measurements
- Downstream quality of water for a limited suite of parameters, such as temperature, specific conductivity, and suspended sediment
- Status of Lees Ferry rainbow trout
- Status of humpback chub in the Little Colorado River

Each of these monitoring programs will be subjected to an evaluation by GCMRC in cooperation with the TWG/SPG using agreed upon procedures and criteria. The criteria and procedures included in the PCMP (Appendix B) will be used as the starting point for developing an efficient and practical evaluation process. A formal recommendation will be made to the TWG for movement of recommended programs to core monitoring. Formally approved Core Monitoring projects will receive first consideration for funding each year and will not undergo the same competitive review as other projects. Core Monitoring projects will be reviewed annually during the development of the BAWP to incorporate new information/findings or monitoring techniques that may improve their effectiveness. A more comprehensive review will be conducted each 5 years.

In addition to the above described core programs, the following projects will be tested and refined during FY 07-11 with the goal of moving them to core monitoring by FY 11.

- Aquatic food base
- Archaeological site monitoring
- KAS habitat and population monitoring
- Camping beaches monitoring

These projects will be subjected to the same evaluation process cited above prior to forwarding them to the TWG for approval as Core Monitoring projects.

Research and Development Element

The Research and Development (R&D) element incorporates short-term research projects aimed at (a) addressing specific hypotheses or information needs related to a priority AMP resource(s) and/or (b) developing/testing new technologies or monitoring procedures. Examples of R&D projects included in the MRP:

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

In the MRP, R&D projects will focus on addressing specific information needs and hypotheses related to the AMWG priority strategic science questions, and the development and refinement of monitoring protocols. As noted above, a period of R&D is generally required to develop a scientifically credible core monitoring program.

INTEGRATED INTERDISCIPLINARY SCIENCE

The GCMRC will provide increased emphasis on using an interdisciplinary integrated science approach over the next 5 years. An interdisciplinary integrated approach is the only practical way to link the physical, biological, and socio-cultural components of the CRE. The MRP is structured around overarching strategic science questions (Appendix A) which will provide the framework for the appropriate integration of science activities across disciplines. An integrated interdisciplinary approach will be emphasized in the following areas:

1. **Linking flow-sediment dynamics to priority AMP resources.** Sediment and sand supplies are critical to the long term maintenance of several priority AMP resources. High elevation sand bars provide camping beaches, support riparian habitat and associated wildlife, and are a source of aeolian sand that affords protection for archaeological sites in close proximity to the river. Low elevation sand bars provide backwater habitats that are warmer than main channel habitats and are believed to be important to the growth and survival of HBC and other native fishes.

As part to the experimental program, two BHBF experiments are planned for the FY 07-11 period to enhance sand dynamics and related resources. A focus of these experiments will be to determine the relationships between creation and maintenance of sand bars and these AMP resources.

2. Enhancing the conceptual ecosystem model to identify critical ecosystem interactions and data gaps. In 1998, Walters and others (2000) conducted an Adaptive Environmental Assessment and Management Workshop to assist Grand Canyon scientists and managers in development of a conceptual model of the Colorado River Ecosystem (CRE) affected by GCD operations. The model proved to be useful at helping to understand the relationship among various ecosystem components and identify knowledge gaps and predict the response of some ecosystem components to policy change. However, it was lacking in its ability to predict the effects of policy decisions on several key areas such as long term sediment storage, fisheries response to habitat restoration, and socio-economic effects. Expanded design, development, and use of the conceptual ecosystem model is needed to increase its utility in ecosystem science planning and management processes, to make it more user friendly to scientists and managers, and to provide information that is relevant to each high priority AMWG goal/question.

In FY 2007-2008, GCMRC will work with the Science Advisors (SA) to identify and incorporate more robust integrated ecosystem science approaches into its overall program

effort. The first step will be to evaluate redesign and expansion of the CRE model. Possible refinements are:

- Capture social system components not currently encompassed in the model and improve information for adaptive management and agency decision processes
- Moving to landscape scale; i.e., linking Lake Powell, LCR, and Paria to CRE and include additional terrestrial components
- Additional fishery elements (cold and warm water fish predation on HBC, pathogen impacts on HBC, etc.)
- Modeling to predict outcomes of non-flow management activities (mechanical removal of non-natives, native fish refugia or grow-out programs, check dams, translocation efforts for HBC, tributary triggers for sand, fine-sediment augmentation, etc.)
- Terrestrial vegetation changes
- Coupled Lake Powell and downstream temperature simulations linked to fine-sediment, food web, and fisheries sub-model
- Enhanced use of climatic input data and simulations
- Recreational use and campsite size/abundance/distribution
- Cultural resource change and protection strategies
- Financial impact simulations coupled to operation flow sub-models

3. Aligning GCMRC staffing/organization to facilitate integrated interdisciplinary science

In FY 06, GCMRC staff will be realigned to create a Deputy GCMRC Chief position that will be responsible for day-to-day management and supervision of the Science Program and assuring that integrated/interdisciplinary methods and procedures are utilized in the science program. In addition, in FY 08, GCMRC proposes to recruit a part-time/visiting ecosystem scientist/ ecologist to work with GCMRC staff and cooperators to develop and implement an integrated interdisciplinary ecosystem science program. The efficacy of this action will be reviewed based on the Science Advisors above proposed FY 07 evaluation/recommendations related to opportunities for incorporating an ecosystem science approach into the current science program (see below).

CRITICAL RESEACH AND MONITORING NEEDS OUTSIDE THE SCOPE OF THE AMP

The use of AMP funds are currently restricted to addressing the impacts of dam operations on resources in the immediate Colorado River corridor downstream of Glen Canyon Dam to the western boundary of Grand Canyon National Park. As a result, scientists and managers are constrained from evaluating some potentially significant external threats to CRE resources that are relevant to the AMP mission and goals. USGS will seek outside AMP funding in FY 08 to address three critical needs:

1. **Little Colorado River Threats:** The lower reach of the LCR, just above its confluence with the main Colorado River, is a 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 within the scope of the AMP. Potential hazardous material spills and/or potential water quality contamination in upstream areas of the LCR watershed has been identified by Fish and Wildlife Service (FWS) as a significant threat to the endangered HBC in the LCR/Grand Canyon. FWS is developing a hazardous material spill response plan to help avert the catastrophic loss of the HBC population. The existing stream gage in the lower section of the LCR needs to be enhanced to include water quality sampling consistent with the existing Colorado River Main Stem Quality-of-Water Program. There is an immediate need to assess the risk of contamination from various sources in the LCR or provide a capability to provide early detection of changes in LCR water quality resulting from contamination or hazardous materials in the upper watershed. Also, there is a need to synthesize existing/historical information for the LCR basin related to hydrology, sediment transport, water quality, and changes in land use in relation to changes in the HBC population that reside in lower reaches of the LCR.

2. **Lake Powell Water Quality:** The primary determinant of water quality in the Colorado River below Glen Canyon Dam is the water released from Lake Powell. In addition, the water quality characteristics and dynamics of Lake Powell have significant implications

for the design and operation of Bureau of Reclamation's (BOR) proposed Selective Withdrawal Structure (SWS) that will allow for regulating the temperature and other water quality characteristics of releases from Glen Canyon Dam. While extensive physical and biological data on Lake Powell water quality have been collected for over two decades, the data have not been synthesized, or subjected to extensive analysis and advanced modeling to simulate both temperature and dissolved oxygen characteristics for Glen Canyon Dam operations and resulting releases. Synthesis of historical Lake Powell data would be aimed at summarizing trends in quality of water data, and linking dam operations, basin hydrology, and climate variability with biological data both in the reservoir and downstream of Glen Canyon Dam (aquatic productivity and both non-native and native fish trends). Information from such syntheses would be incorporated into efforts to model both Lake Powell quality-of-water and downstream release characteristics for projected use and testing of a SWS at Glen Canyon Dam. These assessments could significantly advance knowledge of potential future water quality in Lake Powell and the appropriate design and operation of the SWS.

3. **Effects of Climate Change and Drought on the AMP:** Long term drought and climate change have significant implications for decisions about future water management and hydro power production in the Colorado River Basin and the conservation of natural resources in Grand Canyon and elsewhere in the Basin. Runoff in 2000-2004 in the Upper Colorado River Basin was the lowest in the period of record and Lake Powell is currently (2006) less than 50 percent full. Water managers increasingly want to know the predictability of climate and its effects on water resources over annual and decadal time spans, yet the linkage between climate, drought, and stream flow is poorly understood. Climate change and long term drought will have potentially significant implications for several identified flow strategies for the operation of GCD to attain a variety of AMP goals (e.g., native fishes, sediment, cultural resources, and recreation). Basin-scale climate studies would focus on: 1) how climate forecast information could be used in decisions related to the operation of Glen Canyon Dam and other Colorado River Storage Project operations, 2) how new emerging climate information could be used by water and other resource managers in the GCD AMP program, and 3) the role of climate variability

and hydrological variance (upper basin runoff versus the flood frequency of major tributaries below GCD) in ecosystem responses and their relationship to operation of GCD. This study would be carried out in partnership/ cooperation with the National Oceanic and Atmospheric Administration and the Bureau of Reclamation.

CHAPTER 2: THE PROPOSED 2007-2011 EXPERIMENTAL, RESEARCH, AND MONITORING SCIENCE PROGRAM.

An overview of proposed science activities for FY 2007-11 is summarized in Table 2.1. These activities are categorized as monitoring, experimental research, and non-experimental research and are related to both GCD AMP goals and AMWG priorities.

GCD-AMP Strategic Goals	AMWG Priority	Monitoring	Experimental Research	Non-Experimental Research
1. Food base	1,3,5	FY09-11: Implement new food web monitoring program.	FY07-11: Evaluate effects of experimental flows on food web	FY06-08: Linking whole-system carbon cycling to quantitative food webs n the Colorado River (R&D for food base core monitoring program) FY10: Aquatic foodbase PEP II
2. Humpback chub & Other Native Fishes	1,3,5	FY07-11: LCR monitoring for humpback chub. FY07: Evaluate current LCR HBC program for core monitoring status	FY07-11: Evaluate effects of experimental flows on HBC and other Native Fishes	FY07-08: Gear efficiency/sampling evaluation. FY07-11: Non-invasive monitoring gear development FY07-11: Warm/cold water non-native fish monitoring, removal and control: affect on native fish recruitment. FY07-11: Statistical review of existing HBC monitoring protocols and habitat data. FY08: Fish monitoring PEP
3. Extirpated species	N/A	N/A	N/A	N/A
4. Rainbow Trout	3	FY07-11:Lees Ferry Trout Monitoring	FY07-11: Evaluate effects of experimental flows on RBT	FY07-11 Downstream dispersal of RBT below Lees Ferry.
5. KAS	3	FY07-11: KAS Habitat Monitoring; Evaluate for Core Monitoring status	N/A	FY07 Evaluation of alternative survey methods of KAS habitat.

6. Springs/Riparian	4	FY07-11: Vegetation monitoring	FY07-11: Evaluate allochthonous contribution during BHBF tests	FY08-10: Vegetation synthesis project FY 07: Vegetation monitoring PEP
7. Quality-of-Water (QW)	1,3,5	FY07-11: Lake Powell Monitoring (forebay & lakewide) Downstream Integrated Quality-of-Water Monitoring	FY07-11: Continued Evaluation of Flow Testing (BHBF, steady flows, alternative fluctuating flows, selective withdrawal structure, etc.) linked to experimental design.	FY08-10: Lake Powell Synthesis & Modeling FY07-11: Advanced Development of downstream flow, temperature and suspended-sediment models FY 09: Lake Powell monitoring PEP
8. Sediment (sand bars & debris fans/rapids)	1,2,3,4	FY07-11: Implementation of Recommendations from the final SEDS-PEP (summer 2006) Biennial Sand-Storage Monitoring	FY08-11 Continued Evaluation of Flow Testing (BHBF, steady flows, alternative fluctuating flows, etc.) linked to experimental design.	FY07-11 DASA Activities: -Change-Detection of Near-Shore Habitats, relating to 2004 Biological Opinion -Legacy Data Conversion
9. Recreational Experience	3,4	FY07-11: Campable Area Monitoring, linked to biennial sand bar monitoring (above)	FY07-11: Evaluate effects of ramping rates and BHBFs on campsites, visitor safety, and visitor health	FY07-08: Complete campsite inventory and GIS atlas and repeat the 1973 Weeden assessments. FY07-08: Evaluate campable area monitoring results using measured field data vs. remotely sensed data and evaluate role of vegetation encroachment on campsite area loss. FY07: compile and analyze existing safety data in anticipation of conducting future safety studies under experimental flows.

				FY08-09: Evaluate relative importance and potential effects of different flows on recreation exp qualities FY10-11: Update regional recreation economic studies.
10. Hydropower	3	FY07-11: Monitor of flows and power generation re: changing market values	FY07-11: Effects of experimental flows on power and Basin Fund	FY07-08: Implement highest priority recommendation of socioeconomic PEP
11. Cultural	2,3,4	FY08-10: Integrated Archaeological Site Monitoring	FY07-11: Evaluate effects of BHBF, steady and fluctuating flows on sediment supply and deposition at arch sites and TCPs.	FY06-07: Research & Development towards Core Monitoring (of arch sites and TCPs) FY08-10: Geomorphic Model of Archaeological Site Vulnerability FY10: Cultural PEP II
12. High quality Monitoring, Research and AEAM				
DASA	1,2,3,4,5	FY07-11 Remote Sensing (preparation, acquisition, & storage of 2009 terrestrial resource monitoring data)	FY07-11 No additional remotely sensed data proposed beyond the 2009 monitoring mission	FY07-11 -Legacy Analog Data Conversion (DASA) -Integrated Analysis and Modeling – Shoreline Habitat and Change Detection Mapping in support of 2004 Biological Opinion
Logistics Support of	1,2,3,4,5	Ongoing as related to monitoring projects	Ongoing, as needed to support experimental design	Ongoing, as needed

Field Activities				
Support Science Planning	1,2,3,4,5	Activities related to completion of long-term monitoring plan	FY2007 Complete experimental planning, develop science plan for Selective Withdrawal Structure Testing and Evaluation	Activities related to HBC Comprehensive Plan, etc.
Decision Support Systems	1,2,3,4,5	FY 2008-2010 New initiative to assess monitoring information needed by managers	FY 2008-2010 New initiative to assess experimental research information needed by managers	FY 2008-2010 New initiative to assess non-experimental research information needed by managers
Advanced Conceptual Modeling Activities	1,2,3,4,5	FY 2008-2010 Assessment of monitoring information needs and findings from DSS	FY 2008-2010 Assessment and incorporation of recent experimental research findings into GCM – w/ move to landscape scales	FY 2008-2010 Assessment and incorporation of recent non-experimental research findings into GCM – w/ move to landscape scales
Knowledge Assessment	1,2,3,4,5	N/A	N/A	FY 2010 Workshops

The following section summarizes the experimental, research, and monitoring programs for each major AMP Goal (i.e., Goals 1-12). Also, the necessity to link and integrate research and monitoring activities across goals is discussed within each goal, to clarify how specific science elements of individual goals are integrated across several goals.

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

2007-2011 Science Objectives:

- Determine the important energy sources and pathways that support fishes, especially native species and trout
- Quantify the basal resources, using a carbon budget framework, to determine potential available energy for higher trophic levels
- Identify variable food availability in the drift (flux) along trophic pathways
- Incorporate knowledge into bioenergetics model and trophic basis for production calculations
- Document primary production and drift of fish food items in response to varying flow regimens
- Develop core monitoring strategies for the aquatic food base in the Colorado River from Glen Canyon Dam to Diamond Creek
- Develop core monitoring strategies for submerged aquatic vegetation and associated epiphytic algae and invertebrates in the Glen Canyon Reach (See also Goal 4)

Related Strategic Science Questions:

1-5. 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?

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?

3-6. How is invertebrate flux affected by water quality (e.g., temperature, nutrient concentrations, turbidity) and dam operations?

Managers of native and non-native fishes need to understand the amounts and quality of aquatic food resources that are available to fishes to help direct management actions. Managers need to understand how different flow regimens affect the aquatic food base. The objectives and questions above will be addressed through research projects, to support development of long-term core monitoring, as outlined below:

Research: There are three areas of study associated with food resources for higher trophic resources in FY07-08. The scope of one of the projects addresses the whole river ecosystem and was initiated in 2005, while the second project focuses on the fishery above Lees Ferry. The third project will assemble and synthesize available data collected during the mechanical removal of trout project.

1. Linking whole-system carbon cycling to quantitative food webs in the Colorado River

A project that focuses on identifying energy pathways and quantifying basal resources through multiple approaches was initiated in 2005. 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. Whole stream metabolism and terrestrial litter and biomass estimates will be determined to assess basal resources. Lastly, these data will be incorporated into a bioenergetics model for the aquatic ecosystem. Results from this work, scheduled to end in FY08, will contribute to the development of a core monitoring program for the Grand Canyon food base in subsequent years.

2. Mapping submerged aquatic vegetation (SAV), and determining the distribution of associated epiphytic diatoms and invertebrates, in the Glen Canyon Reach of the Colorado River.

The second project is a proposed new start for FY 2007. The objective of this project is to develop a map of SAV within the Glen Canyon Reach of aquatic macrophytes and green algae. The map, in combination with Hess samples and dredges of SAV types, will be used to determine how density and species composition of ephiphytic diatoms and invertebrates vary among SAV. The project will be coordinated with AZGFD trout monitoring schedule to assess how fish abundance and distribution is affected by SAV type and density. The project is directed at information needs associated with food availability and habitat complexity. The product would be a baseline data set that could be used to detect changes in SAV associated with changes dam operations, installation of a selective withdrawal structure, or species invasions, for examples. The project would be done in collaboration with the first food base project.

3. Complete diet, drift, and predation studies associated with mechanical removal of rainbow trout.

Rainbow and brown trout diet, food resource availability, and incidence of piscivory were areas of investigation associated with the mechanical removal of trout from the Colorado River in Grand Canyon. Some of the tasks associated with these projects have been completed, including field work, sample enumeration and biomass determination, and data entry. However, the data from these projects have not been assessed for data omission, data entry errors, nor have the data been completely compiled into a database design. Only preliminary analysis has been conducted to date and results have not been documented in the form of reports or manuscripts. This effort will address separate tasks required to complete each of the three study projects. A sequential order is suggested for completing each of the necessary tasks, specific to each project. The food resource availability and the non-native fish diet projects will be completed first, since the findings are important in the analysis and inferences used in assessing and completing the incidence of piscivory project.

Integration with related projects

Physical Sciences. Five of our seven study reaches in the whole-system carbon cycling project are FIST (Fine-grained Integrated Sediment Transport) and Integrated Water Quality monitoring sites which will facilitate integration of the physical environment data with the standing mass, distribution, and production of basal resources and invertebrates, further

supporting a long-term core monitoring program. The temperature model that is being developed by the Physical Sciences program will be a valuable tool for estimating system-wide growth rates of algae and invertebrates—temperature is the most important determinant of invertebrate growth rates.

Fisheries. Ongoing fisheries monitoring data on the distribution and relative density of common native and non-native fishes will be used to determine rates of energy flow to fishes in the system. Where possible, the cooperators will also rely on existing fisheries monitoring efforts to obtain the fish stomachs and tissue samples required for gut content and stable isotope analysis, respectively.

AMWG 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.

2007-2011 Objectives:

- Elucidate critical physical and biotic factors that may be limiting to, or supportive of, the humpback chub and other native fish populations in Grand Canyon. Reduce, eliminate, or control limiting factors.
- Identify habitat characteristics that are most important to all life stages of humpback chub. Maintain, and possibly replicate, suitable habitats.
- Determine and refine the most appropriate method(s) for estimating the population size of humpback chub and other Grand Canyon fishes, consistent with Colorado River Endangered Fishes Recovery Goals, scheduled for revision in 2007.
- Improve understanding of dam operations on young of year and juvenile humpback chub survival and habitat use.
- Establish core monitoring protocols for humpback chub in the Little Colorado River.

- Develop effective coordination with other disciplines to support conservation of humpback chub and other native fish populations in Grand Canyon. Areas of coordination will include:
    - Integrate results of food base investigations with effects on native fishes
    - Utilize results of terrestrial vegetation studies to investigate interrelationships with native fishes, especially the degree to which allochthonous inputs provide food supply to native fishes
    - Integrate results of previous habitat studies with knowledge of humpback chub distribution; identify areas of needed additional research
    - Utilize multivariate statistics to analyze available physical and biological information for indications of how dam operations and natural resources affect native fishes

These objectives will be addressed as follows:

Core Monitoring

Strategic Science Questions addressed:

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

3. Can long-term decreases in abundance of rainbow trout in Marble and eastern Grand Canyons be sustained with a reduced level of effort of mechanical removal or will re-colonization from tributaries and from downstream and upstream of the removal reach require

that mechanical removal be an ongoing management action? This question also applies to future removal programs targeting other nonnative species.

SA HBC 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?

Monitoring of native and non-native fishes.

Balancing substantial information needs with limited budgets is an exercise that continues to challenge the creativity of scientists and managers studying fishes in Grand Canyon. Extensive field studies may reveal important information that cannot be obtained in any other manner, but at relatively high cost. Some newer technologies potentially hold promise for providing at least some of the necessary population monitoring information, but will require field testing that will take resources away from established monitoring efforts (see Monitoring Research, below). The FY 2007-2008 budget proposed by GCMRC seeks to strike a balance by reducing the level of effort for some ongoing monitoring while increasing the level of effort dedicated to testing remote monitoring technologies for application in Grand Canyon. Most notably, the proposed budget and associated work plan call for the following changes:

- One fall trip to monitor HBC in the LCR, instead of both one in the spring and one in the fall
- An alternating one year on, one year off schedule for two efforts: mainstem downstream monitoring and monitoring below Diamond Creek
- One monitoring trip only for the rainbow trout population below Glen Canyon Dam
- One KAS trip annually, instead of two, to be shared with a mainstem backwater seining trip
- Research on the following gears: trammel nets, remote PIT tag readers, sonic tags, and the DIDSON (sonic) camera
- Completion of the diet and predation studies using samples (stomach contents) collected by the rainbow trout mechanical removal program (FY 2007 only)

This approach is expected to have two primary effects on personnel. First, it will reduce funding for contractors (SWCA). Two, it will reduce the funding available for agencies to hire technicians and seasonal personnel. It is anticipated that GCMRC will continue to rely heavily on permanent US Fish and Wildlife Service (USFWS) and Arizona Game and Fish Department (AZGFD) personnel for their expertise, knowledge, and creativity in other aspects of the AMP fisheries program.

Continued monitoring of the native fish population in the Grand Canyon is necessary for addressing question 1 above, ideally leading to increased understanding of the status of these populations and identifying population trends. Monitoring is particularly important for providing status and trend information for humpback chub to evaluate the species against recovery goal targets. Because the LCR is the primary location where humpback chub spawn and where young fish mature during their first few months of life, continued monitoring of this critical tributary is fundamental to addressing question 1.

Monitoring in the mainstem is currently in place. This monitoring samples known, smaller, aggregations of HBC and also conducts stratified random sampling at additional locations in the mainstem each year. All of this monitoring contributes to the current state of knowledge of native fish population status and trends and provides some baseline against which some changes may be observed should these occur, especially if large population changes occur. This baseline provides a starting point for general evaluation in the case of changing flow regimens.

Projects:
Little Colorado River humpback chub monitoring
Lower 1200 m of LCR monitoring
Downstream fishes monitoring
Power analysis of Little Colorado River humpback chub monitoring

Monitoring Research

Questions addressed:

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?

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

7. Which tributary and mainstem habitats are most important to native fishes and how can these habitats best be made useable and maintained?

8. How can native and non-native fishes best be monitored while minimizing impacts from capture and handling or sampling?

Monitoring technology research. The native fish population of the Grand Canyon is handled regularly as part of multiple efforts to understand the population size trends and during mechanical removal. Electroshocking and netting of fish can cause stress to, and reduce the growth of, these animals, especially when they are handled repeatedly. Potential negative effects of capture and study have lead researchers to seek less invasive methods for evaluating the populations. Some available 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.

Projects:
Documenting trammel net impacts
Investigate remote PIT tag reading technology
Investigate sonic tag technology

Investigate DIDSON (acoustic) camera for applications to fish monitoring

Studying gear efficiencies. The efficiency with which existing gear types sample wild fish populations is not well known. In other words, researchers cannot be certain what percentage of the existing population is sampled when they capture fishes in the Grand Canyon. Improved understanding of the effectiveness of various types of gear is critical to being able to draw conclusions regarding the fish community composition and any changes in this composition that may occur. Independent estimates of population sizes need to be developed using different gear types and acoustic and remote PIT tag technologies to help determine what percentage of the available population is sampled by a given gear type so that capture rates can be more accurately linked to population estimates. Acoustic imaging technologies can contribute to these studies. Remote monitoring of populations can help provide improved characterization of fish habitat use because it is independent of handling by humans and therefore may be expected to yield more natural, unbiased results.

Projects:
Documenting trammel net impacts
Investigate remote PIT tag reading technology
Investigate sonic tag technology
Investigate DIDSON (acoustic) camera for applications to fish monitoring

Mechanical removal. One of the biotic factors thought to be limiting to native fishes is predation by and/or competition with nonnative fishes. This threat has been addressed during FY 2003-06 with the mechanical removal of (boat electrofishing for) rainbow trout. With warming of the Colorado River in the Grand Canyon the non-native fish species posing the greatest threat to natives may change to species more adapted to warmer water. The threats from non-native species will be addressed in a comprehensive non-native species control plan to be developed over the fiscal years 2007-2010. This time period will be utilized to implement pilot projects, assess their value, and then refine the techniques.

Projects:

Cold water and warm water non-native control plan
Pilot testing

Research and Development

Questions addressed:

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?

1-2. Does a decrease in the abundance of rainbow trout and other cold and warm water non-natives in Marble and eastern Grand Canyons result in an improvement in the recruitment rate of juvenile humpback chub to the adult population?

1-3. 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?

1-7. Which tributary and mainstem habitats are most important to native fishes and how can these habitats best be made useable and maintained?

4-3. 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?

Habitat. The literature regarding HBC habitat use is modest but is increasing. The published assumptions regarding where different life stages of HBC can be found need to be tested, but potentially serve to direct long-term monitoring and population modeling efforts and selection of flow regimens. To the extent possible, the characteristics of habitats (physical, water

quality), particularly in the mainstem Colorado River, that are most important to native fishes need to be identified, protected, and potentially replicated. Habitat characteristics needed by YoY and juvenile HBC are most important to identify and protect because of the endangered status of this species. The GCMRC will review available literature and information from the upper basin regarding HBC habitat usage and preferences to see if such habitats can be protected and replicated. Where possible these data will be related to Glen Canyon Dam operations. A multivariate statistical method for linking environmental variables to fish populations will be tested for potential value in defining important habitat characteristics, including river flows, water quality characteristics, and physical habitat.

Projects:
Habitat selection literature synthesis
Linking capture locations with habitat parameters
Multivariate analysis of physical and biotic factors affecting humpback chub
Modeling of aquatic habitat and water quality in response to dam operations and climate

Aging humpback chub. Scientists studying humpback chub rely on an estimate of captured animals' ages based on their size (length). This information is especially important for modeling the population (see next paragraph). A standardized curve has been developed that describes the relationship of observed size to presumed age. However, HBC are known to grow at variable rates. Additional work is needed to better characterize the length/age relationship, especially the anticipated variability. This work would be contracted out to a qualified researcher using, at least initially, museum and existing agency specimens.
Project:
Revision of humpback chub age/length curve

Modeling populations. As managers and scientists strive to manage and conserve the natural resources of the Grand Canyon, it is important to characterize the population size of the resident HBC population and the trend of the population over years. The GCMRC has been taking the lead in estimating the population size and trend and expects to continue to lead this

effort in the future. Characterization and modeling of the population is dependent on some of the other projects described above.

Project:
Refinement of the Age-Structured Mark-Recapture model for HBC in Grand Canyon

Trout movement. One of the managers' concerns is whether the rainbow trout from below Glen Canyon Dam are drifting into the LCR inflow reach of the Colorado River where they are thought to have negative impacts on native fish populations through predation and competition. Evaluation of rainbow trout size in Glen, Marble, and eastern Grand canyons suggests that there is drift because the farther downstream the sample is taken the larger the population of rainbow trout, evidence that little or no reproduction takes place downstream (Korman). By marking rainbow trout in the Glen Canyon/Lees Ferry reach and then monitoring fishes downstream will be able to clearly document whether or not rainbow trout migration is occurring, at least under the prevailing flow regimen(s). Genetic markers of Glen Canyon rainbow trout will be developed and utilized in future years, if necessary, to see if young trout found in eastern Grand Canyon are the offspring of rainbow trout from Glen Canyon.

Projects:
Rainbow trout marking in Glen Canyon
Rainbow trout genetic profiles

Experimentation
Questions addressed:

5-3. To what extent do temperature and fluctuations in flow limit spawning and incubation success for native fish?

5-4. 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?

As experimental flows are determined it will be critical to evaluate the effects of these flows on fishes. Of particular importance will be the impacts on YoY and juvenile native fishes and their habitats. At a minimum, relative population and habitat densities should be determined in advance of and following experimental releases, especially beach habitat building flows.

Integration

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

Monitoring and characterization of the fish community of Grand Canyon will be integrated with monitoring and modeling of physical habitat and water quality parameters, especially in relation to various Glen Canyon Dam release regimens.

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

2007-2011 Objectives

- Identify species responses that may be expected in response to warmer water as may be provided by climate change and/or a Temperature Control Device (TCD) (a.k.a., Selective Withdrawal Structure), focusing on historic species no longer found in Grand Canyon.

This Goal has not been addressed by any current AMP prioritizations or Strategic Science Questions. Efforts to model and monitor river temperatures in response to various dam operations help support possible future efforts to more actively address this Goal, as at least some of the extirpated species, e.g., Colorado pike minnow and potentially razorback sucker, are

thought to be more adapted to a warmer flow regimen. Because of the low prioritization of this Goal and due to funding limitations, this Goal will not be actively addressed in the 2007-11 work plan cycle.

Experimental

Monitor water temperature changes in response to climate, experimental flows, and a TCD. Model river water temperatures in response to these factors, as data become available, and relate these results to the report on potential reintroductions of extirpated species.

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.

2007-2011 Objectives:

- Monitor the rainbow trout population below Glen Canyon Dam to monitor responses to various flows
- Develop a monitoring tool for submerged aquatic vegetation and associated epiphytic algae and invertebrates in the Glen Canyon Reach (See Goal 1).

Strategic Science Questions:

3-7. What GCD operations (ramping rates, daily flow range, etc.) maximize trout fishing opportunities and catchability?

These questions and objectives will be addressed as follows:

Monitoring

Continue to monitor the rainbow trout population and document population changes and condition factors. Utilize electrofishing and compare catch per unit effort and fish condition among trips and years.

Research

Develop methods for evaluating the extent of submerged aquatic vegetation to estimate available fish habitat, especially for young fish. Using vegetation estimates and the results of the food base study, estimate available food for fish (see Goal 1).

Experimental

Monitor fish population and fish habitat responses to various flow regimens. The results of such monitoring, the population sizes and condition factors of three or more size classes of rainbow trout, would contribute to understanding what flow regimens best support and maintain the rainbow trout present below Glen Canyon Dam.

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

Objectives:

- To determine the areal extent of available habitat for use by KAS at Vasey's Paradise
- To provide density estimates of snails within the designated KAS habitat
- To test alternative habitat survey methods that are less invasive than traditional survey approaches
- Establish KAS monitoring as a CORE monitoring effort

These objectives will be addressed through monitoring and research projects as outlined below:

Monitoring

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

Estimates for snail populations are extremely variable between seasons and as a result confidence intervals around population estimates are considered to be statistically unreliable, so additional research is needed (see below).

Research and Development

Testing alternative methods for determining population size and variability and areal extent and composition of KAS habitat at Vasey's Paradise. Surveying in Vasey's Paradise to determine the extent of the habitat can be invasive. Remote technologies that include oblique orthorectified imagery and land based LiDAR may be two methods that can be used to determine area cover and plant heights of dominant plants without the need for a person to step into the habitat. Alternative methods will be tested beginning in FY 07 to assess alternative survey and monitoring approaches for incorporation into long-term monitoring. GCMRC will participate in the 5-year status review initiated by the USFWS in 2006 to contribute to determination of population size and variability information regarding this endangered species that is acceptable to the USFWS.

Genetic research of *Oxyloma* species. Current genetics research of the *Oxyloma* species has been supported by AMP funds through GCMRC; results of this research are expected in 2007 and are expected to contribute to the species status review.

Experimental Flows

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

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

Objectives:

- Determine the extent of vegetation communities identified by the AMWG throughout the river corridor at an appropriate time frequency
- Determine the effect of changes in dam operations on annual and perennial grasses and herbs on an annual basis in association with stage discharge patterns utilizing remote monitoring techniques
- Determine the status of southwestern willow flycatchers along the river corridor in coordination with the National Park Service (NPS)
- Periodically survey for small mammals, riparian birds and herpetofauna to determine relative abundance
- Complete a synthesis of riparian vegetation to evaluate long-term change and changes in processes at multiple scales as related to operations and other resources in the CRE

Related Strategic Science Questions

2-1. Do dam controlled flows affect (increase or decrease) rates of erosion and vegetation growth at archeological sites and TCP sites, and if so, how?

5-7. How do warmer releases affect viability and productivity of native/non-native vegetation?

The objectives and questions above will be addressed with the following projects.

Monitoring

Vegetation Dynamics and Mapping: Riparian vegetation monitoring requires system-wide assessment of vegetation change at the broad scale (e.g., new high water zone) as well as at the

local scale (plot data at 25,000 cfs). While knowing how much vegetation in the river corridor exists is useful, it is equally useful to know how the species that make up the vegetation may be changing. Changes in riparian vegetation are associated with dam operations (Stevens et al, 1995; Kearsley, 2004) and can include the propagation of exotic species like tamarisk (Porter, 2002). Yearly transects assess year to year operations that can detect changes among herbaceous species, including invasives, while remotely sensed data collected at a 5-year time scale 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 a core monitoring project in FY ____.

Multiple resource surveys: The results from the Terrestrial Ecosystem Monitoring pilot (2001-2004) suggest that monitoring be directed toward vegetation, breeding birds and subsets of arthropods. Small mammal and herpetofauna results were variable and would need multiple day sampling per site to be useful. Arthropods are a link between vegetation and higher trophic levels for both terrestrial and aquatic food webs. Surveying for ground-dwelling arthropods and midges are recommended. Plant dwelling arthropods could be surveyed and limited in identification to functional groups (e.g., caterpillars, beetles, flies and spiders). Breeding bird surveys can be conducted yearly, but bird density did not respond directly to flow parameters. Rather bird density was dependent on vegetation density. Faunal monitoring could be comprised of the following, pending Protocol Review in FY07:

Annual survey schedule			
Trip (timing)	Group	Survey Methods	Output
Spring 1 (Early May) 14 days	Breeding Birds	Point counts with distance sampling	Breeding bird density
	Vegetation Density	Vegetation volume for all patches	TVV: woody and herbaceous.

Spring 2 (Late May / Early June) 14 days	Breeding Birds	Point counts with distance sampling	Breeding bird density
Spring 3 (Late May) 18 days	Arthropods	Pitfall traps Malaise traps Sweep net (with ladders)	Ground-dwelling insects (beetles, spiders), day-active flying insects (midges), and plant dwellers (caterpillars, beetles, spiders, flies) identified to those functional groups only
Spring 4 (Late June / Early July)	Breeding Birds	Point counts with distance sampling	Breeding bird density
Fall 14 days	Vegetation Dynamics	Vegetation transects with elevation. Incorporation of Marsh surveys	Cover, species richness, percent exotics by stage elevation

Projects:

Vegetation dynamics – annual monitoring of vegetation transects in fall to record changes in species cover, diversity and richness associated with operations. FY07-11

Vegetation Mapping – semi-decadal mapping to record large scale cover change and total vegetated area change with links to campable area. FY07-08

Multiple Resource Monitoring: Breeding bird surveys – late spring and summer surveys; Vegetation structure - last spring; Ground and plant arthropod sampling – late spring. Monitoring of structure and bird density will co-occur while arthropod surveys will be sampled separately to track operational effects on arthropod abundance on ground dwelling arthropods and midges. FY07-11

Research and Development

Riparian vegetation is a critical interface between aquatic and terrestrial environments around the world. Flow and sediment inputs are primary drivers of riparian vegetation, but there are multiple sub-models that the riparian community either contributes to or influences (e.g., food base, available habitat). In the CRE, the vegetation itself serves as a host for invertebrates, provides breeding and foraging habitat for birds, provides cover in the heat of the day, and may be harvested for cultural utility. Changes in the composition or structure of riparian vegetation, like expansion of an exotic species, may alter these interactions. Riparian vegetation regulates nutrient exchange between the land and water, and 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, in part, being addressed through the food base initiative. But, the linkage could be further defined through studies that focused on terrestrial productivity and processes. The Knowledge Assessment 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 progresses upslope. The outcome of the Knowledge Assessment and the science questions for riparian habitats indicate that, besides knowing the influence of flow on composition and extent of riparian vegetation, an understanding of the integrated role of riparian vegetation with other resources is needed (e.g., aquatic or cultural resources). A synthesis is a step toward filling this need.

Project:

Vegetation synthesis part I – local processes and system-wide change synthesis. FY07-09

Vegetation synthesis part II – integration with faunal and cultural components FY09-11.

Experimental

Experiments associated with riparian vegetation will be curtailed until Part I of the vegetation synthesis is completed in FY09. A potential experiment associated with riparian vegetation that could be subsequently implemented would be to remove vegetation that is subject to inundation during high flows, including low growing limbs, to determine the affect of reduced vegetation on sediment transport and deposition and to observe colonization rates in understory and open beach areas. The colonization rates would examine how native versus introduced species compete and occupy newly available space. The results would be used to test hypotheses generated in the synthesis. In the interim, annual monitoring that is correlated with stage variation will be conducted to provide a general picture of vegetation response to changes in operations associated with long-term experimental planning from FY07-11.

Integration with other resources

Physical: Flow and sediment inputs are tightly linked to riparian development. The completion of several sediment synthesis projects and instantaneous discharge records for Lees Ferry provides background information that can be incorporated into physical processes that affect riparian vegetation development and change.

Biological: Because riparian vegetation contributes to aquatic productivity (Webster and Meyer, 1997; Conner and Naiman, 1984; Vannote et al, 1992; Naiman et al,. 2005) and serves as a host to terrestrial invertebrates and higher order vertebrates (e.g., lizards, birds), knowing what the quality of these plants are can help explain changes observed in higher order vertebrate abundances, including fish species (Nakano and Murakami, 2001; Paetzold et al, 2005; Romanuk and Levings, 2003). These linkages will be further explored in FY09-11. Terrestrial arthropod surveys would also benefit aquatic food web monitoring.

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

2007-2011 Objectives:

- Complete a data report for the historical Lake Powell monitoring information
- Revise current monitoring plan to include an evaluation of current methodology and protocols, analysis of existing data, implementation of review panel recommendations, and information needs of modeling effort
- Convene subsequent protocol evaluation panel to review revised monitoring program
- Develop synthesis of historical information describing effects of climate, Glen Canyon Dam operations, and hydrodynamic processes on Lake Powell water quality and Glen Canyon Dam releases
- Model Lake Powell and Glen Canyon Dam release water quality with regard to climate variables, basin hydrology, operational effects, and potential selective withdrawal operations
- Integrate monitoring and modeling of Lake Powell and Glen Canyon Dam release water quality with downstream water quality monitoring, modeling, and aquatic resource programs

Because Lake Powell is the source of the water released from Glen Canyon Dam, questions regarding the water quality parameters of the releases are addressed by the monitoring in this project. Related **Strategic Science Questions** that are partially informed by the data generated by this monitoring include:

3-6. How is invertebrate flux affected by water quality (e.g., temperature, nutrient concentrations, turbidity) and dam operations?

5-1. How do dam release temperatures, flows (average and fluctuating component), meteorology, canyon orientation and geometry, and reach morphology interact to determine mainstem and near shore water temperatures throughout the CRE?

5-2. How is invertebrate flux affected by water quality (e.g., temperature, nutrient concentrations, turbidity) and dam operations?

5-3. To what extent do temperature and fluctuations in flow limit spawning and incubation success for native fish?

Monitoring

Maintain existing monitoring program for Lake Powell and Glen Canyon Dam release water quality to describe reservoir processes, status and trends, climatic and operational effects, and suitability for downstream resources. Revise program as necessary, based on existing data, review panel recommendations, available technology and information needs of AMP, Bureau of Reclamation, selective withdrawal program and modeling efforts.

Research

Model Lake Powell and Glen Canyon Dam release water quality parameters in response to hydrologic, climatic, and operational variables and proposed selective withdrawal structure. Use model predictions and results to supplant monitoring activities, where appropriate. Integrate these models with downstream water quality monitoring, modeling, and aquatic resource programs. Use existing data and results of modeling effort to provide a synthesis of the effects of climate and hydrology, hydrodynamic reservoir processes, and dam operations of the quality of Glen Canyon Dam releases and its suitability to downstream aquatic resources.

Integration with related projects

Monitoring and modeling of Lake Powell and Glen Canyon Dam release water quality will integrate with aquatic resource programs in Grand Canyon. Reservoir and tailwater monitoring efforts will link directly with downstream water quality monitoring to provide consistent methodology and data management to ensure a cost-effective and reliable monitoring program.

Integration with the aquatic foodbase program will provide necessary information on temperature, nutrients, plankton, organic carbon, and other parameters in Glen Canyon Dam releases that directly affect downstream primary and secondary productivity processes. Integration with native and non-native fish programs involves describing temperature, turbidity, dissolved oxygen concentrations, and the export of biotic and organic material in Glen Canyon Dam releases that directly affect life history, recruitment, health and behavior of downstream native and non-native fish populations.

Goal 8: Maintain/attain needed sediment storage.

Changes in Fine and Coarse-Grained Sediment Deposits and Related Habitat Changes Monitoring & Research Objectives

- Monitor and report biennial field measurements on status of sand bar area, volumes, and grain size characteristics at a selected sub-sample of sand bars
- Monitor and report remotely sensed measurements of sand bar areas system-wide, as derived from multi-spectral, orthorectified, digital imagery flown once every 4 years
- Monitor and report changes in the distribution and abundance of shoreline types pertaining to terrestrial and aquatic habitats of interest to managers, such as backwaters, camping areas, cultural preservation sites, etc., as derived from multi-spectral, orthorectified, digital imagery flown once every 4 years
- Monitor and report changes in the geomorphic impacts along the Colorado River ecosystem that result from tributary debris flows and stream floods
- Experimental flow support - collect, as need arises, additional similar data in support of experimental flows released from Glen Canyon Dam

These objectives will be addressed as follows:

Sand Bar Habitat Monitoring and Experimental Flow Research:

Physical Science Question #4: What are the short-term responses of sandbars to BHBFs?

Physical Science Question #5**:** What is the rate of change in eddy [sand and finer sediment] storage (erosion) during time intervals between BHBFs?

Physical Science Question #6: How does the grain-size distribution of the [sand] deposits affect sandbar stability? Main channel turbidity?

Data relating to the above questions shall be collected through a focused strategy of field measurements made before and after future tests of the BHBF concept during the research period using methods developed for sandbar monitoring during the 2000-2005 era or research and development. Measurements shall focus on areas identified as representative for eddy and sand bar responses within Glen, Marble, and Grand Canyons as reported in recent synthesis research reports. Resolving the answer to Science Question #5 assumes that at least one more BHBF test occurs in the future research period of 2007-2011 (to be compared with data from the 2004 High-Flow Test).

Physical Science Question #7: What are the effects of ramping rates on [suspended] sediment transport and sandbar stability?

Data relating to the above question shall be collected through a focused strategy of field measurements, modeling, and laboratory research efforts made before and after future tests of alternative fluctuating flows during the research period 2007-2011. This research represents a return to the types of studies that were conducted during the 1990-1994 Environmental Impact Statement (EIS) era using methods developed for sandbar monitoring during the 2000-2005 era or research and development. New methods shall also be used to further refine the information on how alternative ramping rates and daily stage ranges (relative to the ROD) influence sand bar stability and related habitats below the dam. Sand bar measurements shall focus on areas identified as representative for eddy and sand bar responses within Glen, Marble, and Grand Canyons, as reported in recent synthesis research reports. Ongoing monitoring data on suspended-sediment transport shall also be evaluated to determine how alternative fluctuating flow operations influence downstream transport (efflux) of fine sediments. Resolving the answer to Science Question #5 assumes that at least one more BHBF test occurs in the future research period of 2007-2011 (to be compared with data from the 2004 High-Flow Test).

Detection of Changes in Sand Bars and Related Near-Shore Habitats:

During FY 2007-08, the GCMRC staff and its science cooperators shall undertake efforts at mapping changes in the distribution and abundance of sand bars and related near-shore habitats throughout the Colorado River ecosystem. This effort shall be part of long-term monitoring activities related to collection of digital, remotely sensed imagery (system-wide data were recently collected in 2002, 2004, and 2005) and is a direct outcome of the November 2004 High-Flow Test.

Monitoring of Impacts of Tributary-Derived Coarse-Grained Deposits:

Over 700 tributaries have the potential to contribute coarse-grained sediment to the Colorado River ecosystem when debris flows and stream flow floods annually. 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 such changes shall be conducted on a system-wide basis through the use of remotely-sensed imagery once during 2007-2011, using imagery obtained in 2005 and 2009. Additional field activities may be scheduled for purposes of ground-truthing in support of change detection. In the event of larger debris flows that significantly alter navigational characteristics of the main channel, additional field activities may need to be conducted on a contingency basis. Monitoring data from this project shall be reported to managers at biennial science symposia and TWG meetings (on a period basis) and will be available for integration into other resource area efforts, such as food web research, cultural/recreational, and fisheries programs.

AMWG Goal 9: "Maintain or improve the quality of recreational experiences for users of the Colorado River ecosystem, within the framework of the GCD AMP ecosystems goals."

OBJECTIVES

In the 2003 AMP Strategic Plan, the GCDAMP defined five management objectives under Goal 9.

Over the next 5 years, GCMRC is proposing to conduct a program of research and monitoring to address the following science objectives that will guide the implementation of this program to meet the needs of the AMP:

- Establish a scientific basis for evaluating the effects of flow regimes on quality of recreational experience by identifying and prioritizing the critical attributes of a high quality recreational experience and the effects of flows upon them
- Provide high quality, objective monitoring data to AMP regarding changes in campable area, trout condition, and other important flow-affected physical attributes that have previously been identified as being important to maintaining high quality recreation experiences in the CRE
- Improve quality of health and safety monitoring data relative to flows
- Coordinate AMP and CRMP recreation monitoring programs to improve quality and efficiency of recreation monitoring and eliminate redundancy

Discussion of AMWG priority questions and associated science questions

Although AMWG did not identify any priority questions related to recreation at the August 2004 meeting, AMWG members recognize and acknowledge the need to maintain a high quality recreation experience in lower Glen and Grand Canyon because of the world-renown reputation of these two National Parks for water-based recreation. Furthermore, AMWG recognizes that maintaining a high quality recreation experience is a stated priority of the NPS and the DOI, and this priority is reaffirmed in the Grand Canyon Protection Act (GPCA), which specifically mentions protection and mitigation of impacts to "visitor use" values. Moreover, it is widely recognized that dam operations affect a myriad of physical and biological CRE attributes which have a direct or indirect effect on recreation in the CRE. Therefore, research and monitoring on the effects to recreation relative to dam operations will continue under the AMP to ensure that the requirements of GCPA and the goals of the AMP are fulfilled.

The KAW conducted in July 2005 concluded that while there is some scientifically peer-reviewed data with which to evaluate effects of flows on recreational experience, most available scientifically-derived information was collected during the mid-1980s and early 1990s, prior to the Record of Decision, and is now outdated. Furthermore, the KAW affirmed that there is considerable anecdotal data about effects of flows on recreation that needs to be more thoroughly evaluated through rigorous, peer-reviewed study. The KAW led to the development of numerous strategic science questions, most of which are targeted at improving our understanding of how flows affect attributes and conditions that are important to the quality of recreation experiences in the CRE. In June 2005, a Protocol Evaluation Panel (PEP) reviewed the entire recreation program and produced a final report (dated September 29, 2005), which includes numerous recommendations for improving GCMRC's recreation research and monitoring program. The recommendations provided in this report are the foundation for the FY07-FY11 recreation program described below.

Major program thrusts in FY07-FY11

Core Monitoring:

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

Prioritized Core Monitoring Information Needs Related to Recreation

1st Priority CMIN	2nd priority	3rd priority	4th priority	5th priority
CMIN 9.3.1 Determine and track the size, quality, and distribution of camping	CMIN 9.1.1 Determine and track the changes attributable to dam operations in recreational	CMIN 9.5.1 Determine and track the frequency and scheduling	CMIN 9.1.2 Determine and track the frequency and scheduling of	CMIN 9.2.2 Determine and track accident rates for visitors participating in river-related

beaches by reach and stage level in Glen and Grand Canyons.	quality, opportunities and use, impacts, serious incidents, and perceptions of users, including the level of satisfaction, in the Colorado River Ecosystem.	of research and monitoring activity in Glen and Grand Canyons.	river-related use patterns.	activities including causes and location (i.e. on-river or off-river), equipment type, operator experience, and other factors of these accidents in the Colorado River ecosystem.

A key concern of recreational rafters in Grand Canyon is the diminishing number and size of campsites along the Colorado River. In FY07-FY11, GCMRC will continue to monitor campable area at the NAU sand bar study sites, using conventional survey methods as in the past, 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). Concurrently, in FY07, GCMRC will explore options for using remote sensing data to evaluate changes in campable area in the future through a focused R& D effort (See discussion under R&D section below for more details.) A major thrust of the FY07-11 monitoring program will be to more closely integrate the campable area work with that of the sand storage monitoring program so that the latter program can inform the former with respect to the effects of changing sand bar area and morphology on campable area.

A key interest of recreational anglers in lower Glen Canyon is the quality of the rainbow trout fishery (specifically size, number, and health of fish), which is directly related to the available food supply. In FY07-11, the condition of the Lees Ferry trout fishery will be monitored through routine stock assessment procedures conducted by AZGFD. In addition, GCMRC proposes to work with AZGFD biologists to upgrade the quality of angler satisfaction data being collected through routine AZGFD 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 on angling

experience, and they also have concerns about safety issues (primarily for waders and independent shoreline fishermen) due to fluctuating flows. The role of fluctuating flows in affecting fishability and boater safety will be evaluated as part of the long term experiment (see discussion under ramping rate experiments), while effects of flows on other recreational experience attributes will be evaluated as part of a focused research effort designed to improve our current understanding about how flows effect recreational experience (discussed under research and development section below), rather than through a core monitoring program.

Experimental Activities:

Several specific studies will be initiated in conjunction with the experimental flows of FY07-11 to evaluate effects of the experiment on recreation. These studies will evaluate the effects of BHBFs and ramping rate experiments on beach morphology, beach size, and distribution (e.g. campable area), as well as affects to the Lees Ferry trout fishery and angling experience. In addition, GCMRC will work with NPS to evaluate effects of high, low, steady and fluctuating flows on human health and safety.

Research and Development Program:

The 2005 Recreation PEP recommended that GCMRC initiate several foundational research studies to provide a baseline of information against which the effects of future experiments and management actions can be evaluated and compared. Furthermore, they recommended that GCMRC invest in studies that would provide data that could be used to better predict the effects of experiments and management flows on recreation, in lieu of investing in long term visitor satisfaction monitoring programs. The following research programs will be implemented FY07-11 in response to the 2005 PEP recommendations:

1. FY 09-10: Compile Campsite Inventory and GIS Atlas. The last comprehensive campsite inventory was completed more than 20 years ago, shortly after the 1983 uncontrolled release from Glen Canyon Dam. Since that time, many of the camps identified during that survey have fallen into disuse or disappeared entirely due to sand bar changes and vegetation encroachment, whole some new ones have emerged. A new inventory is needed to evaluate changes in the CRE during the past two decades and to provide an up-to-date baseline for designing future studies.

In FY07-08, an up-to-date inventory and GIS atlas of all previous and currently available campsites in the CRE will be compiled. The atlas will include information on campsite characteristics and attributes that are known to be important to visitors (e.g., physical size, estimated size of group that can be reasonably accommodated, frequency of use, amount of open sand vs. vegetation, availability of shade, mooring attributes, etc.). This baseline inventory will define the population of campsites from which samples can be drawn to characterize system-wide changes and it will serve as a basis for evaluating recreation impacts on other CRE resources of concern, such as archaeological sites.

2. FY 07: Evaluate Campable Area Monitoring Results Using Measured Field Data vs. Remotely Sensed Data**.** A formal comparison of campable area monitoring results derived through field measurements vs. through GIS-based analysis of remotely sensed imagery and topography will be completed in FY07. A pilot effort conducted in FY05 demonstrated that estimates derived from remotely sensed data consistently over-estimated campable area compared with measurements derived from field surveys; therefore, one hoped-for outcome of the proposed study will be the development of an algorithm to allow future comparisons of previously collected campable area data (derived from field surveys) with future data derived via remotely sensed imagery. Depending on the study results, it may be possible to transition the campable area monitoring program to one based largely or exclusively on remotely sensed imagery.

3. FY 08: Compile and Analyze Existing Safety Data. 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.

4. FY 09: Quantify Vegetation Encroachment at Campsites: Vegetation encroachment rates and the relative significance of vegetation encroachment in diminishing campable area will be evaluated by comparing vegetated areas at a stratified sample of heavily used and infrequently used camps using remotely sensed imagery and analyzing these data in a GIS environment.

5. FY 10: 1973 Weeden Survey Revisited. Using graduate student labor, aerial imagery and related campsite data from the 1973 Weeden survey, the first comprehensive campsite survey to be undertaken in the CRE, will be integrated into the campsite atlas and a formal comparison of photographic images from the Weeden survey with identical images collected in 2008 will be conducted to provide a diachronic perspective on campsites change in the CRE during the past 35+ years.

6. Update Regional Recreation Economic Studies. By FY 2010, existing economic baseline studies will be 20 to 25 years old (!), so in FY10-FY11, economic valuation studies for CRE-based recreation will be repeated.

Integration of recreation program studies with other GCMRC program activities

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 creel surveys.

Changes in campable area are largely, but not exclusively, due to changes in sand bar area and volume. Other factors that may be contributing to campsite loss include changes in bar morphology (e.g., steeping of slopes under certain flow regimes) and vegetation encroachment. Evaluating the contributions of these other factors requires close coordination with other GCMRC programs. Specifically, to evaluate the role of sand bar morphology in affecting campable area requires comparisons of topographic data derived from the sand storage monitoring program (FIST) against prior campable area survey results. Evaluating the role of vegetation encroachment on campable area will require using remotely sensed vegetation data derived the 2000, 2002, and 2005 remote sensing missions and the results of the ongoing vegetation analysis effort, in combination with the data developed for the GIS atlas. In addition, flow stage modeling based on the improved STARS model will be useful for defining stage relations at camps for which survey data is not currently available. The analysis and storage of

campsite data and the creation and maintenance of the GIS atlas will require direct involvement from members of the DASA team at GCMRC.

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

No activities planned.

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

GCMRC has defined the following science objectives for Goal 11 to meet the needs of the AMP:

- Establish a scientific basis for evaluating the effects of flow regimes on cultural resources, including archaeological sites, TCPs, and ethnobiotic resources of importance to the Tribes
- Improve understanding of the various factors contributing the deterioration of archaeological sites in the CRE, and specifically the role of dam operations in affecting cultural resource condition
- Provide high quality, objective monitoring data to AMP regarding changes in cultural resource condition over time
- Coordinate AMP and CRMP monitoring programs for archaeological sites to improve quality and efficiency of CRE cultural resource monitoring programs and eliminate redundancy

Archaeologists, National Park managers, and members of the public who value the diverse cultural resources of lower Glen and Grand Canyons are concerned about how dam operations and other agents of ecosystem change are affecting the integrity of cultural resources in the CRE. Specifically, these stakeholders are concerned that the non-renewable archaeological resources in the CRE are deteriorating and disappearing due to combined effects of dam operations, natural processes, and the cumulative impacts of increasing levels of visitation. Native American tribal

partners are also concerned about how dam operations impact other traditionally significant places and biological resources in the CRE besides National Register eligible historic properties.

Past research indicates that dam-controlled flows influence archaeological site condition in a variety of ways. The hypotheses that have been advanced to date require further research, testing and refinement. At a minimum, a better understanding of how dam-controlled flows affect erosion rates at cultural sites is needed. This need can be met by designing and implementing monitoring protocols that directly measure physical change at repetitive intervals and through integrating relevant data from other program areas.

Understanding how site condition is affected by dam controlled flows is important to achieving the stated goals of the AMP and GCPA. This 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, and geomorphic and biotic processes), in addition to direct, indirect, and interactive effects of flow regimes. To address this need from an ecosystem-based perspective, in FY06 the GCMRC initiated a multi-year, multi-faceted cultural resource research and development program which will continue during the first years of this MRP. This work will be supported by compilation and analysis of existing legacy data in FY06-07.

In addition to site-specific cultural resources, the Native American tribes who participate in the AMP are concerned about how dam operations may affect traditionally valued terrestrial plants and animals in the CRE. Like the place-based cultural resources, 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, and impact the characteristics of habitats used by various faunal species. Other direct effects from dam operations relate to the redistribution of seeds and nutrients. Direct effects also include the consequences related to the timing and frequency of such inundation and flow-induced disturbance events. Indirect effects include changes to the sediment substrate from flows, changes to the water table and consequent effects to higher elevation vegetation (e.g., mesquite), and long-term changes in species composition and abundance due to the timing, frequency and discharge level of dam-controlled flows. Once

again, monitoring and evaluating the effects of flows on culturally significant plans and animals can be most efficiently and effectively achieved by more closely integrating cultural resource monitoring objectives with physical and biological program objectives.

Discussion of AMWG priority questions and associated science questions

During a workshop in August 2004, AMWG members identified the following questions concerning cultural resources as the second highest priority of the GCD adaptive management program:

"Which cultural resources, including TCPs (traditional cultural properties), are within the APE (Area of Potential Effect), which should we treat, and how do we best protect them? What are the status and trends of cultural resources and what the agents of deterioration?"

The BOR previously evaluated inventory data provided by the NPS and concluded that 323 archeological sites were potentially affected by dam operations. The EIS concluded that the exact number of sites affected by various flow regimes would likely vary depending on the specific parameters of the flow regime. Since that time, the BOR and NPS have agreed to develop a treatment plan for 161 sites that the NPS, through prior monitoring efforts, determined to be actively deteriorating due to a variety of impacting agents. Thus, part of the AMWG priority question for cultural resources ("which sites should we treat?") is currently being addressed by BOR and NPS through the current treatment planning effort. The remainder of the question -- how best to protect cultural resources, the overall status and trends of the resources in the CRE, and the relative contributions of the various agents of deterioration in affecting condition-- remain to be determined through a focused program of research and monitoring.

Discussions during the July 2005 KAW helped to frame several key science questions that respond to the stated priority questions of the AMWG about how best to protect resources and objectively assess status and trends through time.

The key science questions are:

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

2. If flows contribute to arch site/TCP erosion, what are the optimal flows for minimizing impacts to these cultural resources?
3. What other factors besides flows contribute to archeological site degradation in the CRE, and how do these factors interact with one another to affect site condition?

Supplementing these key science questions are several secondary questions:

1. How do flows impact the sedimentary matrix of the higher terrace deposits, and what kinds of important historical/legacy information about the CRE ecosystem (including human occupation and use) is being lost due to ongoing erosion of these older Holocene sedimentary deposits?
2. How effective are check dams in slowing rates of erosion at archaeological sites over the long term?
3. What are the TCPs in the CRE, and where are they located?
4. How can tribal values/data/analyses be appropriately incorporated into a western science-driven adaptive management process in order to evaluate the effects of flow operations and management actions on TCPs?
5. 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 first two supplementary questions can be addressed through applying standard scientific research practices. The last three questions require tribal partners in the AMP to make explicit value judgments and, if possible, to articulate those judgments in terms of bio-physical or social attributes that can be recognized, defined and measured, otherwise these questions are not

appropriate for consideration as part of this multiyear science plan and would be better addressed through a dialog process of government to government consultation.

Major program thrusts in FY07-FY11

Core Monitoring:

FY 08-10: Integrated Archaeological Site Monitoring and Tribal Resource Values Monitoring Programs:

These core monitoring programs are currently under development (see discussion under R&D section below). GCMRC has the lead responsibility for developing the core monitoring program for cultural resources. The archaeological site monitoring program is being developed by GCMRC in collaboration with BOR, NPS, Native American Tribes, and other AMP stakeholders to meet multiple needs for compliance with Sections 106 and 110 of the National Historic Preservation Act, as well as the mandates of the Grand Canyon Protection Act. In FY06, the tribes are being funded to develop and/or refine protocols for monitoring TCPs and other tribally valued resources. The tribal monitoring programs are being developed by the individual tribes who value these resources, but in the future the plan is to integrate tribal monitoring efforts with the archaeological site monitoring program where feasible and practical to reduce resource impacts, redundancy, and program costs. The plan calls for implementation of a revised core monitoring program for cultural resources in FY08-FY10.

Experimental Research Program:

1. FY 08-11: Evaluate Effects of BHBF Sediment Deposition at Archaeological Sites and TCPs. This focused study will assess the effects of BHBFs at historic property sites in terms of sub-aerial sediment transport rates before and after BHBFs and the effects/rates of retention of flood deposits in arroyo mouths in relation to subsequent erosion at a sample of archaeological sites. This study partially addresses EIN 11.1.1.

2. FY 08-11: Evaluate effects of steady flows and fluctuating flows (ramping rates) on archaeological site sediment supply. This study will evaluate how critical sand bars 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 bars to the archaeological sites are affected by these changes. This study partially addresses EIN 11.1.1.

3. FY 07-11: Test and Refine the Wiele Model. A model recently developed by Wiele and Torrizo (2005) predicts the response of sand bars at several critical archaeological site areas under varying flow and sediment supply conditions. This study will evaluate the accuracy of the model predictions through comparing predicted deposition at these cultural sites against actual measurements of post-flood deposits.

Research and Development Program:

In FY 07, GCMRC will continue several R&D activities initiated in FY 06 to evaluate the most appropriate core monitoring indicators and protocols for tracking cultural resource condition and the effectiveness of treatments through time. Since erosion of archaeological sites is tied directly and indirectly to dam operations, considerable effort will be devoted to refining methods for measuring and tracking erosion. However, erosion is only one of several factors affecting resource condition, so the evaluation of other indicators, such as human disturbance indicators and weather parameters, will also be pursued. In FY 07, the R&D program will include the following components:

- FY 06-07: Assessment of CRE Sites for Future Monitoring: Continue geomorphic and archaeological integrity assessments of untreated archaeological sites in the CRE to define most appropriate protocols for future monitoring
- FY 06-07: Evaluations of existing legacy monitoring data. In FY06, the emphasis will be on evaluating the accuracy, redundancy, and statistical value of existing monitoring data. FY 07 will focus on defining appropriate applications for the existing data (e.g., utility for evaluating effects of dam operations) and

evaluate utility and limitations of other legacy data, particularly the extensive photographic record that has been compiled by the NPS over the past 15+ years

- FY 06-07: Evaluate monitoring protocols for quantifying geomorphic change. This study component will compare and contrast alternative methods for measuring erosion/topographic change at a sample of sites. Specifically we will evaluate the trade offs involved in using conventional survey methods vs. ground based and airborne LiDAR in terms of field and post-field processing time, efficiency, accuracy, precision, costs, equipment limitations, and short-term and long-term resource impacts
- FY 07-08: Test and Refine Weather Monitoring Protocols. This effort will explore options for monitoring weather parameters using various technologies at a sample of intensively monitored archaeological sites distributed throughout the CRE to meet multiple needs for weather monitoring data related specifically to cultural resource monitoring programs

FY 07-08: Pilot Study to Evaluate Terrace Changes Using Remotely Sensed Imagery. In direct response to stakeholder requests to explore the utility of existing remotely sensed imagery for tracking geomorphic change at archaeological sites, in FY07-08 GCMRC will initiate a pilot study to evaluate rates of terrace retreat and arroyo erosion using digitized images of historical aerial imagery. This project hinges on completion of an ongoing FY06 effort to digitize and evaluate the accuracy of historical aerial photographs that are currently stored in hard copy format at the GCMRC library.

FY 07-08: Refine Protocols for Evaluating Erosion Control Effectiveness. In addition to refining protocols for core monitoring, in FY07-08 GCMRC proposes to continue evaluating and refining methods for measuring and tracking erosion control effectiveness at a sample of treated sites. This evaluation process will build on a pilot study initiated by USU under the treatment planning effort in FY06.

FY 09-11: Geomorphic Model of Archaeological Site Vulnerability. Another important element of the R&D program for cultural resources involves the development of a geomorphic

model to help quantify future geomorphic change at archaeological sites under various flow and climatic regimes and evaluate future site vulnerability to erosion. This model will be integrated as a sub-model of the broader CRE Conceptual Model that is proposed for development in FY 08-09. Development of the geomorphic model will build on some of the geomorphic and weather data that will be collected through the R&D program for core monitoring and experimental effects monitoring, as well as other data sources (e.g., improved STARS model for stage-discharge relations in the CRE.)

FY 10: Cultural PEP. Following completion of R&D for core and effect monitoring and the completion of a 3-year pilot monitoring program, a follow-up PEP review of the cultural program will be conducted to evaluate changes made to the program since the first Cultural PEP and to evaluate the findings resulting from the R&D studies in FY 06-10.

Integration of cultural resource program studies with other program areas

Archaeological site condition is the product of multiple interacting agents including dam operations, human visitation, weather, and various other biological and physical processes. Thus, future monitoring of cultural resource conditions will necessarily rely on data inputs from other GCMRC science programs. Integration of data from other GCMRC programs may require adjusting some of the proposed monitoring efforts to improve the utility of the resulting data for cultural resource program needs, e.g. by expanding sediment storage monitoring and modeling to include additional focus on areas above the 25,000 cfs level, by measuring change in vegetation characteristics such as cryptobiotic crust and other biophysical factors that affect rates of erosion at archaeological sites, and by monitoring visitor use levels at a sample of archaeological sites. It may also require some focused interdisciplinary research for a limited period of time (2-5 years) in order to gather physical and biological data that are relevant to cultural concerns, e.g., tracking weather parameters in proximity to a sample of archaeological sites, measuring erosion rates at intervals that allow for analysis in relation to flow releases from Glen Canyon Dam, and by relating these data to impacts that are actually measured and 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.

In addition to increasing integration with other GCMRC science programs, there is need for concurrent close coordination with relevant research and monitoring programs being conducted by Grand Canyon National Park (GRCA) under the auspices of the CRMP implementation effort. In FY06, GRCA is proposing to initiate a multiyear R&D effort to improve understanding of the interactive effects of recreational activities on the ecology and condition of natural and cultural resources in the CRE. While not directly focused on improving understanding of dam effects, these R&D efforts can help improve understanding of dam effects by evaluating the effects of recreational impacts to cultural resources. Previous research in GRCA and elsewhere shows that human visitation can adversely impact cryptobiotic crusts and vegetation cover and can lay the groundwork for future gully erosion through compacting soils and creating linear, compacted trails that channel run-off. Recreational impacts, such as trailing, may interact with dam effects such as sediment depletion, and with "natural processes" such as precipitation and soil creep, to create erosion problems that affect archaeological site integrity, so it is essential to understand and be able to quantify the contributions of human visitation to erosion as we try to evaluate the role that dam operations play in affecting cultural site condition in the CRE. GCMRC proposes to closely coordinate future monitoring and research effort 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. Integrating the information derived from these separate but related R&D efforts will be critical for minimizing future impacts to cultural resource and improving protection and preservation of cultural resources along the river in lower Glen and Grand Canyon.

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

Objectives

1. Maintain a staff of quality GCMRC managers and scientists to effectively plan, manage/coordinate, and execute an interdisciplinary science program to meet AMP needs.

2. Provide high quality and timely science support to the AMP work groups.
3. Provide timely reporting of GCMRC science project accomplishments and findings.
4. Ensure that the GCMRC science program is efficient, unbiased, objective, and scientifically sound.
5. Evaluate and implement, as appropriate, decision support tools and other mechanisms to improve the effectiveness of the AMP and the utilization of scientific information in the AMP process.
6. Provide logistical and survey support for field activities that emphasizes safety and cost effectiveness. Comply with all permitting requirements with the National Park Service and all other federal, state, and tribal agencies.
7. Provide timely support for acquisition, archiving, retrieval, and analysis of all scientific data sets and reports, including extending historical time series for resource trends back in time using legacy data, GIS mapping, data access (Oracle), and modeling as a base for decision support tools and integrated scientific investigations.

These objectives will be addressed as follows:

GCMRC Staffing

Figure 1 identifies the staff and organization structure needed to effectively plan, develop, and execute an interdisciplinary science program to meet AMP objectives based on the anticipated FY 07-11 AMP Monitoring and Research Program and science support needs of the AMWG, TWG, and related ad hoc work groups. 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 AMP by providing timely scientific reports and information to the AMP and assist the AMWG/TWG to develop and implement efficient and effective collaborative management planning and management processes. A Deputy Chief will be hired in FY 06 to provide day-to-day management and supervision of the GCMRC Science Program and facilitate the design and implementation of interdisciplinary ecosystem science projects. In FY 08, GCMRC will recruit a part-time/visiting ecosystem scientist/ ecologist to work with GCMRC staff and cooperators to develop and implement an integrated interdisciplinary ecosystem science

program. The efficacy of this action will be reviewed based on the Science Advisors proposed FY 07 evaluation/recommendations related to opportunities for incorporating an ecosystem science approach into the current science program (see below).

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

Reporting

Timely reporting of progress and study results is an essential element of effective program management and information transfer. GCMRC will publish major results/finding in peer review journal and proceedings. Final reports and papers will presented orally to the TWG/AMWG and posted on the GCMRC website for ready access by the AMP participants and interested parties. In addition, preliminary findings will be presented to the AMWG, TWG, or appropriate ad hoc work groups to facilitate timely use of the new scientific findings in the AMP process. Significant finding will also be published as USGS fact sheets or information papers in accordance with USGS policy. GCMRC will also produce an Annual Accomplishment Report in December of each year which will briefly summarize accomplishments, shortcoming for each project included in the BAWP. The Annual Accomplishment Report will also include recommendations for modification of the study, as needed. In FY 10 and 11, GCMRC will update the Knowledge Assessment and SCORE report to provide an updated synthesis of science information for use in planning the next phase of science and management activities.

Science Advisors

The Science Advisory Board will be maintained and utilized to provide independent scientific oversight and technical advice to ensure that GCMRC science programs are efficient, unbiased, objective, and scientifically sound. The SAB will be utilized in both a review and

advisory capacity during the FY 2007-2011 period to evaluate the efficacy and effectiveness of the science program. Using the SAB in an advisory capacity will be evaluated to insure that it does not affect their independence as an external independent review panel.

The SAB will be managed and operated in accordance with AMWG approved protocols adopted in October 2000. The SAB will consist of eight scientists and an executive secretary to administer, coordinate, and report on the SAB activities. In FY 2007, the SAB will evaluate the most appropriate opportunities for implementing an integrated ecosystem science and modeling approaches into the current science program and invoke greater interdisciplinary approaches in FY 2008-2011 science programs. Specifically, the SAB will by no later than September 2007 evaluate opportunities for increased use of integrated ecosystem science paradigms within GCMRC research, experimental, and monitoring programs, 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 for implementing new ecosystem strategies. The SAB recommendations will be reviewed by the AMP and implemented as appropriate in FY 08-11.

In addition to the SAB reviews, all GCMRC proposals/work plans and final reports will be subjected to independent peer review in accordance with the established GCMRC peer review process (Appendix A).

Bridging Science and Management

The success of the AMP is dependent on the GCMRC's ability to (a) produce scientific information that is relevant to management needs, and (b) effective utilization of that information by managers in the decision making process. The challenge for GCMRC scientists is to synthesize large amounts of diverse and often highly technical data into a form that is relevant to a decision (such as how to operate GCD) that has implications for multiple resources in different areas and time frames. In FY 07, GCMRC will issue a contract to assess the feasibility of utilizing decision support systems and tools to facilitate the integration and utilization scientific data and information in the AMP decision making processes including resource tradeoff analyses, risk assessments, and innovative ways to organize and display data. The feasibility

assessment will include a prioritized implementation plan, schedule, and budget. Recommendations will be implemented in FY 09-11 in accordance with established AMP/GCMRC budget priorities.

In late FY 06, GCMRC will enter into a cooperative agreement with the Environmental Policy Group (EPG) in the MIT Department of Urban Studies and Planning to conduct a 2-year assessment to improve the use of scientific information into the AMP process. The assessment would be conducted in cooperation with AMP participants and the SAB and examine the following key issues:

1. What strategies/approaches are most suitable for more effectively (a) addressing the value based conflicts reflected by the diverse interests in the AMP and (b) integrating the use of scientific information into the AMP process?
2. Is the current structure and composition of the AMP conducive to meeting program goals?
3. What improvements could be made in AMP structure, procedures, and operations (looking individually at AMWG, TWG, GCMRC, and SAB) to improve efficiency and effectiveness of the overall program?
4. Are the respective roles and responsibilities of the GCMRC, AMWG, TWG, and SAB clearly articulated and adhered to?
5. Are there clear procedures in place to resolve disagreements between various AMP entities?
6. How could the conflict resolution procedures of the AMP be improved?
7. What decision support tools are available/appropriate to assist scientists and managers to improve the use of scientific knowledge in the resource management decision-making process?
8. How should the findings and recommendations associated with the assessment above be implemented and tested?

Findings and recommendations of the assessment will be reviewed by GCMRC and the AMP in FY 08 and incorporated as appropriate into the AMP in FY 09-11.

Logistical Support

Implementation of the GCMRC mission to provide credible, objective scientific information to the AMP begins with effective coordination of all technical and logistical support of research activities. The program encompasses the integration of two elements:

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

- Logistics Operations: The GCMRC will provide complete logistical support for 30-50 research, monitoring, and administrative river trips through the Grand Canyon annually. These trips range in length from 7 to 21 days and from 4 to 36 people in size. Trips will be comprised of a variety of motor and oar powered boats operated by contracted boat operators. Projects operating in the Glen Canyon reach of the Colorado River (Glen Canyon Dam to Lees Ferry) will be supported by a variety of motor powered boats operated by GCMRC researchers and contracted boat operators. Additionally, research activities on the LCR and at other locations outside of the Grand Canyon National Park boundaries are supported by helicopter services contracted with the BOR. Ground based support for other research activities outside of the river corridor are also coordinated with the use of GCMRC leased vehicles.

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 with the use of GSA leased vehicles and contracted shuttle drivers.

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

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, salaries and permitting costs.

Data Acquisition Storage and Analysis

Elements of data acquisition, storage, and analysis are common to most of the science activities undertaken by the GCMRC. Both airborne and ground-based remote sensing activities require metadata standards and spatial positioning to be useful for mapping and detecting changes in resources of interest, such as sand bars, camping areas, near-shore habitats, etc. to ensure that data standards are achieved. The DASA's staff shall work closely with the GCMRC's survey staff, science staff, and cooperators to plan and implement future remote sensing and non-remote data collection. The administrator for the Oracle database will define not only metadata requirements, but also data delivery protocols that ensure that only quality data are added to the database. The objective of designing a high quality database is to allow staff, cooperating scientists, and manager's greater access to more data for use in focused analysis and modeling related to AMP Goals 1-11. As DASA capabilities evolve and expand, the majority of the physical holdings within the GCMRC's library shall be converted to digital files and shall be served through the Oracle database, along with other tabular data and GIS coverages. Historical imagery of the Colorado River ecosystem shall be progressively converted from analog to digital format and these legacy data shall be made available upon request as need arises. Orthorectification of the converted analog images shall be undertaken as integrated questions and analyses are identified through the science program. The DASA team shall provide increasingly more sophisticated technical and science support as the GCMRC's science

program evolves toward a more integrated ecosystem science approach and utilizes decision support tool.

Summary of proposed projects related to AMP Goal 12:

1. GCMRC program management. (FY 07-11)
2. Part-time/visiting ecosystem scientist/ ecologist to work with GCMRC staff and cooperators to develop and implement an integrated/interdisciplinary ecosystem science program. (FY 08)
3. Implement SAB recommendations related to utilizing an integrated ecosystem science and modeling approaches into the current science program. (FY 09-11)
4. Updated KA report and SCORE report. (FY 10)
5. Peer Review Panels and the Science Advisors Board. (FY 07-11)
6. Implement Findings of the Assessment AMP effectiveness and improving the use of science information in the AMP. (FY 08-11)
7. Feasibility Study of utilizing Decision Support Tools in the AMP. (FY 09)
8. Implementation of recommended Decision Support Tools. (FY 10-11)
9. Permit and Logistical support for Field activities. (FY07-11)

CHAPTER 3. FUNDING FOR THE AMP SCIENCE PROGRAM

The total anticipated funding to support GCMRC research and monitoring activities related to the AMP is shown in Table 3.1. This includes anticipated power revenues, continued BOR funding for Lake Powell monitoring, and anticipated USGS appropriations to support the AMP activities.

To respond to the expanding science needs, GCMRC and AMWG must work together in several areas as follows:

1. AMWG should periodically review and update its strategic plan including AMWG priorities and information needs, including the scope and efficacy of existing (ongoing projects) in light of new and emerging information needs.
2. GCMRC will update the knowledge assessment and propose significant program revisions at 5-year intervals to ensure that science activities are aligned with AMWG priority goals.

3. AMWG should develop greater support from the Secretary/Congress to maintain existing budget support and to expand budgets to meet critical needs that can not be addressed within current budget constraints.

4. GCMRC, with AMWG assistance, will explore expanded cooperative partnerships with AMP agencies (e.g., NPS, BOR, FWS, DOE) to expand the capacity of the AMP to address critical research and monitoring needs; etc. For example, GCMRC will work with DOI and BOR to secure the additional funds to assist evaluating and testing of a selective withdrawal structure for GCD (which is planned for construction in FY 10-11). In addition, GCMRC will work with USGS and the DOI leadership to secure additional base funding to address high priority reach and monitoring needs related to the AMP.

APPENDICIES

APPENDIX A. KEY SCIENCE QUESTIONS ADDRESSED IN THE FY 2007-2011 SCIENCE PROGRAM

APPENDIX B. CRITERIA FOR USE IN FY 2007/2008 EVALUATION OF AMP MONITORING PROGRAMS FOR INCLUSION IN AMP CORE MONITORING PROGRAMS

APPENDIX A

KEY SCIENCE QUESTIONS ADDRESSED IN THE FY 2007-2011 SCIENCE PROGRAM

The key uncertainties highlighted in the knowledge assessment matrices were helpful in framing key scientific questions that need to be resolved. There was not sufficient time at the workshop to develop a complete list of questions for each sub-model. What follows is a combined list of questions developed at the workshop as well as others developed by the authors following the meetings.

4.1 Physical Resources

1) Is there a "Flow-Only" (non sediment augmentation) operation that will restore and maintain sandbar habitats over decadal time scales?
2) Is there an optimal strategy for BHBF implementation to manage tributary inputs on an annual to inter-annual time scale?
3) What are the short-term responses of sandbars to BHBFs?
4) What is the rate of change in eddy storage (erosion) during time intervals between BHBFs?
5) How does the grain-size distribution of the deposits affect sandbar stability? Main channel turbidity?
6) What are the effects of ramping rates on sediment transport and sandbar stability?
7) *Can we develop a relationship between suspended sediment concentration and turbidity to support fisheries research? [currently underway]*
8) 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?

4.2 Hydropower

1) What are the hydropower replacements costs of the MLFF (annually, since 1996)?
2) 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)?

4.3 Food Base, Fish, and Lees Ferry Angling

4.3.1 Food Base

1) What are the important pathways, and the rate of flux along them, that link lower trophic levels with fish?
2) How is invertebrate flux affected by water quality (e.g., temperature, nutrient concentrations, turbidity) and dam operations?

3) 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?

4.3.2 Native Fish

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) To what extent does temperature and fluctuations in flow limit spawning and incubation success for native fish?
3) 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?
4) 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) associated with high flows?
5) Will increased water temperatures increase the incidence of Asian Tapeworm in HBC or the magnitude of infestation, and if so, what is the impact on survival and growth rates?
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 non-native fish abundance? To what extent could predation impacts by non-native fish be mitigated by higher turbidities?

4.3.3 Rainbow Trout in Glen Canyon

1) To what extent is the adult population of rainbow trout controlled by survival rates during incubation and YoY/juvenile rearing stages, or by changes in growth and maturation in the adult population influencing egg deposition?
2) To what extent is the size of rainbow trout in Glen Canyon controlled by density and food availability?
3) Does increased water temperature result in the occurrence of whirling disease in rainbow trout and if so, what affect will this have on population size and adult growth and condition?
4) Do rainbow trout immigrate from Glen to Marble and eastern Grand Canyons, and if so, during what life stages? To what extent to Glen Canyon immigrants support the population in Marble and eastern Grand Canyons?

4.3.4 Non-Native Fish in Marble and Eastern Grand Canyons

1) Does a decrease in the abundance of rainbow trout and other cold and warm-water non-natives in Marble and eastern Grand Canyons result in an improvement in the recruitment rate of juvenile humpback chub to the adult population?
2) Will a limited number of years of mechanical removal of rainbow trout in Marble and eastern Grand Canyons result in a long-term decrease in abundance or will re-colonization from tributaries and from below and above the removal reach require that mechanical removal be

an ongoing management action? This question also applies to future removal programs targeting other non-native species.

4.3.5 Lees Ferry Angling

1) Assuming a trade-off between trout density and size, what is the preferred combination for anglers?
2) What GCD flow constraints (ramping rates, daily flow range, etc.) maximize fishing opportunities and catchability?

4.4 Riparian Habitat

1) How do processes occurring at a variety of spatial scales (i.e., population level to community to landscape scales) interface to influence riparian habitat?
2) What is the nature and timing of terrestrial — aquatic linkages and what is their influence on the recipient habitat?
3) How do terrestrial habitat and cultural/recreation resources interface?
    i. What are the rates of vegetation encroachment (trees vs. shrubs) on camp sites?
4) How do flows, including the absence of flows (e.g., pre-dam high water zone), affect productivity and decomposition rates of riparian vegetation including the absence of flows (e.g., OHWZ)?
5) How do warmer releases affect viability and productivity of native/non-native vegetation?
6) To what extent and in what respects can BHBF's (magnitude and frequency) achieve reduction of exotic species?
7) How could monthly volumes be changed to beneficially affect riparian habitat?

4.5 Recreation

1) 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?
2) What are the drivers for recreational experience in the CRE, and how important are flows relative to other drivers in shaping recreational experience outcomes?
3) How do varying flows positively or negatively affect campsite attributes that are important to visitor experience?
4) What are the minimum size, quantity, distribution and quality of campsites to meet NPS goals for visitor experience?
5) Can changes in quality of recreational experience be quantified for single event opportunities (e.g., white water rafting, angling, camping) vs. multi-opportunity experiences (e.g. white water rafting with overnight camping)?
6) How can safety & navigability be reliably measured relative to flows?
7) How do varying flows positively or negatively affect visitor safety, health, and navigability of the rapids?

8) 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?

4.6 Cultural Resources

1) Do dam controlled flows affect (increase or decrease) rates of erosion and vegetation growth at arch sites and Traditional Cultural Property (TCP) sites, and if so, how?
2) If dam controlled flows are contributing to (influencing rates of) arch site/TCP erosion, what are the optimal flows for minimizing future impacts to historic properties?
3) How do flows impact the sedimentary matrix of the higher terrace deposits, and what kinds of important historical/legacy information about the CRE ecosystem is being lost due to ongoing erosion of these older Holocene sedimentary deposits?
4) How effective are check dams in slowing rates of erosion at archaeological sites over the long term?
5) What are the TCPs in the CRE, and where are they located?
6) How can tribal values/data/analyses be appropriately incorporated into a western science-driven adaptive management process in order to evaluate the effects of flow operations and management actions on TCPs?
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?

APPENDIX B

DEVELOPMENT OF AMP/GCMRC MONITORING PROGRAM DIRECTION FOR FY 2007-2011

During the period 2002-2004 several attempts were made by the AMP and GCMRC to evaluate the ongoing research and monitoring activities of GCMC for potential revision. At least two formal groups, the Long Term Experimental Plan (LTEP) Group and the Core Monitoring Plan (CMP) Group attempted to develop formal new approaches. Although the LTEP Group did not complete a plan they did develop a position statement that new multiple year experimental programs or experimental options should incorporate a "hybrid design" that included both "management actions" and "treatments". The CMP Group completed a draft plan that incorporated significant procedures for structuring future monitoring plans.

The LTEP and CMP Groups were subsumed in FY 2005/2006 by a formal AMP Science Planning Group (SPG) that was charged to assist GCMRC to complete all necessary GCMRC/AMP science planning documents for the period FY 2007-2011.

The CMP Group agreed to three critical principals for monitoring program development that were adopted by the SPG as follows.

1. At least one monitoring project activity would exist in 10 of the 12 AMWG goals.
2. All currently specified or active (2005) and all future proposed monitoring projects/programs should be subjected to a formal review process. Different monitoring activities would exist in the AMP including "Core" activities that would be long term and other monitoring activities of shorter term, such as those required by a specific short term experimental event.
3. Monitoring projects could not be designated as "Core" unless they are subjected to a rigorous review involving policy, science and other elements.

The SPG subsumed the activities of the CMP Group by integrating the monitoring planning direction of the group with needed planning on overall science strategies, experimental programs, research and development programs and adaptive management programs of GCMRC

and AMP. In doing so, all of the above three principals of the CMP are incorporated into the SPG monitoring planning direction as follows:

A. In FY 2007 – 2011 monitoring project and or program activities will occur in ten of the AMWG twelve goals. Only the goals related to extirpated species, and adaptive management process will not have planned monitoring activities during the period, although some may be proposed later.
B. In FY 2007-2008, a formal review will be conducted of all currently active (2006) and proposed monitoring projects for the period FY 2007-2008. The review objective is to define all monitoring projects to be implemented during the period 2009-2011.
C. Review of all current proposed GCMRC/AMP monitoring programs for 2009-2011 will be accomplished during 2007-2008. The review will be conducted according to the following guidelines.
    - Review objectives are to define "Core" monitoring and "other" monitoring projects for the period.
    - GCMRC will manage the reviews. The review will be conducted by a panel comprised of science (GCMRC, SA, external scientists) and management (AMWG/TWG, external) expertise
    - The review will incorporate policy, economic, scientific technical and management criteria.
    - Each monitoring project/program proposed for inclusion as a "Core" monitoring activity must be evaluated fully using the following and potentially additional information/criteria.

        1. Support of AMWG Goal(s); Objectives
        2. Current project category: Expermental, research, monitoring
        3. Project title
        4. Start/end dates
        5. Geographic scope
        6. GCMRC, Cooperative, or contracted science?
        7. Project goals, tasks and schedule by tasks

8. Justification for science effort; reference
9. Key science questions and managers information needs addressed
10. Contribution to ecosystem understanding and knowledge. Linkage to other resources processes, models.
11. Research and analysis methods. Sampling designs; level of data resolution; accuracy and precision assessment, etc.
12. Costs of project/program by FY
13. Expected outcomes, outputs by FY. Reports, guidelines, models, etc.