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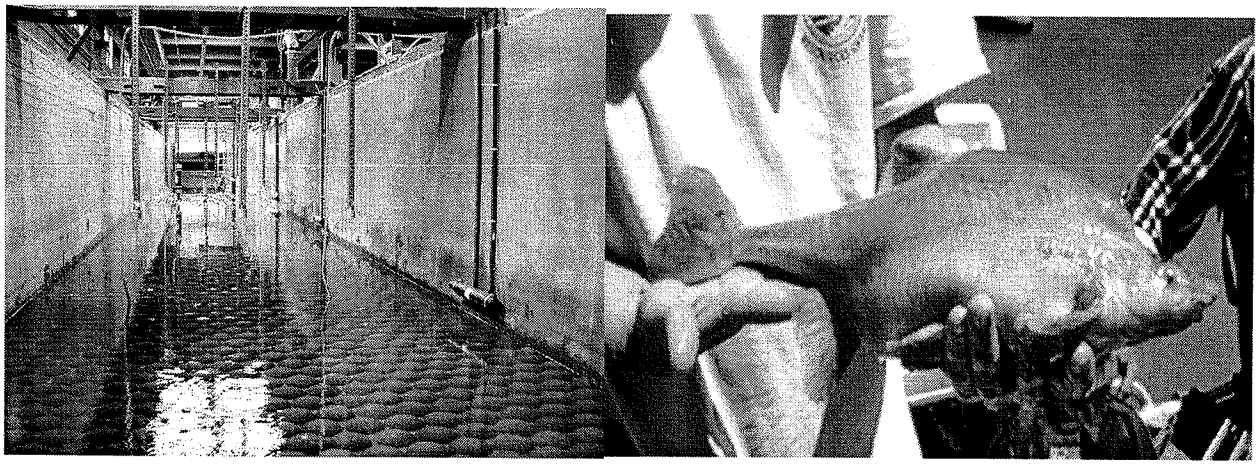
Grand Canyon Monitoring and Research Center Monitoring and Research Plan to Support the Glen Canyon Dam Adaptive Management Program: 2007-2011

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 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 Monitoring and Research Plan (MRP) has been developed by the U.S. Geological Survey Grand Canyon Monitoring and Research Center (GCMRC) in cooperation with the AMP Science Planning Group (SPG) to specify research and monitoring programs consistent with the strategies and priorities in the:

- 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, principles, goals, management objectives, information needs, and management actions.

- **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.

The **GCMRC Biennial Work Plan (BWP)** identifies the scope, objectives, and budget for the 2-year monitoring and research projects consistent with the MRP. A transitional Annual Work Plan will be developed for FY 07 while consideration is given to the development of the Long Term Experimental Plan, a funding plan for a Temperature Control Device (TCD and development of a recovery program for humpback chub (HBC) in the Grand Canyon.

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 shall formally synthesize new scientific information and knowledge in the form of an updated State of the Colorado River in the Grand Canyon (SCORE) report (Gloss and others, 2005), Knowledge Assessment Report (KAR) (Melis and others, 2006) and/or other reports, as appropriate. Priority information needs and science questions will be evaluated by scientists and managers to determine what program revisions are needed. This includes development of revised SSP and MRP documents.

The MRP also incorporates information from appropriate agency/AMP plans such as the National Park Service (NPS) Colorado River Management Plan (CRMP), the humpback chub comprehensive plan, the Provisional Core Monitoring Plan (PCMP), and the Long-term Experimental Plan (LTEP). GCMRC will attempt to provide science information that is consistent with and supports these plans as appropriate and practical.

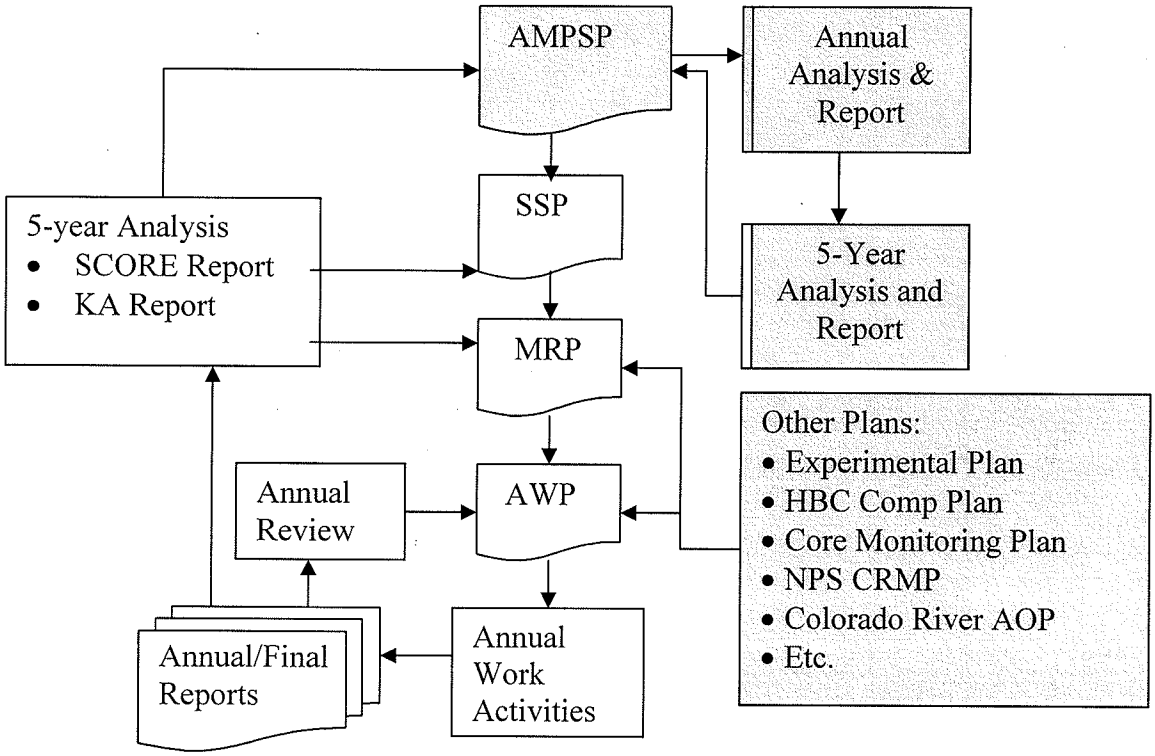
PURPOSE

The purpose of the Monitoring and Research Plan is to describe the scope and objective of a 5-year monitoring and research 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 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

Figure 1.1. Collaborative science planning and implementation process. The AMP and Department of Interior (DOI) have lead responsibility for the shaded boxes. GCMRC has lead responsibility for the boxes that are not shaded.



ELEMENTS OF THE RESEARCH AND MONITORING PLAN

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

1. **Long Term Experimental 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, through monitoring and research, 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 the condition and trend of priority AMP resources (HBC, sediment, food base, etc.).

3. **Research and Development Element:** Research projects aimed at (a) addressing specific hypotheses or information needs related to a priority AMP resources and/or (b) developing/testing new technologies or monitoring procedures.

These elements 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 A). 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.

Long Term Experimental Element

The MRP will be consistent with and implement the Long Term Experimental Plan developed through the AMP and endorsed by the Department of the Interior. The AMP has embraced the concept of a "***Hybrid***" experimental design which incorporates assessments of both management actions and experimental treatments. 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 2003-2006 research program have been proven effective at reducing the 2003-2006 abundance and distribution of rainbow trout within treatment reaches near the confluence of the Little Colorado River. As such, further GCMRC research on this activity is not included in the MRP. Future implementation of this action should be carried out primarily by the appropriate land and resource management agencies.

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 LTEP will be implemented following approval by the Secretary of the Interior and completion of appropriate environmental compliance (e.g., National Environmental Policy Act, Endangered Species Act). GCMRC will provide scientific information to support the environmental compliance process, as requested.

A component of the LTEP will include research to test various hypotheses associated with different experimental flows from GCD such as, evaluating the effects of different ramping rates on downstream resources, evaluating alternate triggers for steady flows, or the effects of short duration flow spikes on aquatic productivity or drift. One area of emphasis will be further research on the use of controlled floods, or Beach Habitat Building Flows (BHBF), to build sand bars that support several AMP goals, such as providing camping beaches, fish habitat and riparian habitat. BHBFs are triggered by predetermined target levels of natural deposits of sediment in the mainstem Colorado River below the Paria River and Little Colorado River (LCR). The evaluation of the BHBF conducted in FY 04 cost approximately $1.2M. In the FY 07-11 period, GCMRC anticipates two additional BHBF tests. GCMRC estimated costs for the research and monitoring associated with the BHBF tests is $1.5M per test. The current balance of the experimental fund at the end of the FY06 is anticipated to be approximately $500K. An additional $500K will be set aside by GCMRC annually in an account at the Bureau of Reclamation (Reclamation) to fund the BHBF tests so they can be conducted without financially impacting other ongoing aspects of the science program. Deposits to the experimental account will cease upon completion of the second BHBF test or when the balance reaches $2.5M. GCMRC will develop a BHBF work plan in consultation with the AMP consistent with the available funds that describes the hypotheses that will be conducted to test those hypotheses. BHBF studies will be coordinated with ongoing projects to maximize cost-effectiveness.

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." (Draft 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 generally involves the establishment of Protocol Evaluation Panels (PEP) for each key resource area, followed by several 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 got underway in 1998 and is in progress for many elements of the program today (e.g., terrestrial ecosystems, archaeological and tribal resources, aquatic food base, recreation, and fisheries). Other factors 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

A Provisional Core Monitoring Plan (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 formally adopted by the Technical Work Group (TWG)/AMWG, nor 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 monitoring projects associated with various AMP resources (e.g., sediment, native fishes, trout, archaeology, tribal resource values, etc.) will be subjected to an evaluation by GCMRC in cooperation with the TWG/SPG. 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 projects to core monitoring following the technical evaluation. 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 BWP to incorporate new information, findings or monitoring techniques that may improve their effectiveness. A more comprehensive review will be conducted each 5 years.

Implementation of the Core Monitoring Element has significant budget implications for the science program which could limit the flexibility of GCMRC and the AMP to respond to high priority research needs such as the evaluation and testing of the operation of a Selective Withdrawal Structure, evaluating the benefits of alternative GCD operations on Colorado River Ecosystem (CRE) resources, etc. Consequently, in FY 07 GCMRC will conduct a comprehensive review of the potential long term core monitoring projects to determine priorities and the level of funding that should be dedicated to core monitoring by resource area. Results of this review could constrain the scope of core monitoring projects described below.

The initial focus 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 and their anticipated review schedule include:

- Downstream surface water discharge and stage measurements (FY 07)
- Downstream quality of water for a limited suite of parameters, such as temperature, specific conductivity, and suspended sediment (FY 07)
- Status of Lees Ferry rainbow trout (FY 07)
- Status of humpback chub in the Colorado River (FY 08)

In addition, the following projects will be tested and refined as components of the Research and Development (R&D) element during FY 07-11 with the goal of moving them to core monitoring by FY 11.

- Sand storage monitoring and camping beaches monitoring (FY 07)
- Terrestrial Ecosystem Monitoring (FY 07)
- Lake Powell quality of water (FY 09)
- Kanab ambersnail habitat and population monitoring (FY 09)
- Cultural site monitoring (archeological, Traditional Cultural Properties (TCPs)) (FY 10)
- Aquatic food base (FY 10-11)

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.

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

The tribes are being funded by the AMP in FY06 to define their monitoring projects and associated methods and metrics for evaluating the resources and places of specific tribal interest in the CRE. These projects are scheduled to be brought forward to the TWG for review and discussion in FY07. If the methods and rationales for these proposed monitoring projects are shared with the AMP and subjected to peer review, then they may fit within the AMP science program as currently defined. Otherwise, the information derived from the tribal monitoring effort may be more appropriately incorporated into the AMP decision-making process via ongoing consultation between the tribes, AMWG/TWG stakeholders, and the DOI agencies. GCMRC will describe the tribal monitoring component of the 5-year science program with more specificity after the tribal monitoring needs are defined and brought forward for TWG review in FY 06- FY 07.

Research and Development Element

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

1. Link whole-system carbon cycling to 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.
6. Laboratory experiments to evaluate HBC habitat preferences.

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.

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. **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 managing and supervising day-to-day operations at GCMRC 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 pursue specific integrated interdisciplinary ecosystem science strategies such as the application of the CRE conceptual model to science planning and project design, and the evaluation and implementation of decision support tools to improve the application of science information in the AMP process (see below). The efficacy of hiring the visiting scientist will be reviewed based on the Science Advisors (SAs) proposed FY 07 evaluation/recommendations related to opportunities for incorporating an ecosystem science approach into the current science program (see below).

2. **Enhancing the conceptual ecosystem model to identify critical ecosystem interactions and data gaps.**

   In 1998, Walters and others (2000) conducted a workshop to assist Grand Canyon scientists and managers in development of a conceptual model of the CRE affected by GCD operations. The model proved to be useful for helping to understand the relationship among various ecosystem components and identify knowledge gaps and predict the response of some ecosystem components to policy change. However, it lacked the capability to predict the effects of policy decisions on several key areas such as long term sediment storage, fisheries response to habitat restoration, and 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 SAs to identify and incorporate more robust integrated interdisciplinary science approaches into its overall program effort. The SA review will address practical approaches and opportunities to improve the ability of GCMRC to address priority AMP information needs using an integrated interdisciplinary science approach. A specific objective of the SA's review will be to evaluate redesign and expansion of the conceptual CRE model. A preliminary list of priority expansions of the CRE model include:

- Expanding the fishery elements to address cold and warm water fish predation on HBC, young-of-year (YoY) HBC habitat use, etc.
- Modeling outcomes of non-flow management activities (i.e., operation of a temperature control device, mechanical removal of non-natives, translocation efforts for HBC, tributary triggers for BHBFs)
- Linking Lake Powell and downstream temperature simulations to fine-sediment, food web, and fisheries sub-models
- Expanding the model to provide a broader landscape perspective by incorporating Lake Powell, the LCR, and Paria River and addresses relationships to terrestrial habitats in the CRE
- Enhancing the use of climatic input data and simulations
- Recreational use and campsite size/abundance/distribution
- Cultural site change and protection strategies (archeological sites, TCPs)
- Financial impact simulations coupled to the flow/dam operations sub-models

3. 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 some archaeological sites in close proximity to the river. Sand bars also 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 provided sediment triggers are reached. A

focus of these experiments and the BHBF work plan will be to determine the relationships between creation and maintenance of sand bars and these AMP resources.

4. Planning and Evaluation of a GCD Temperature Control Device.

The evaluation and possible construction of a TCD for GCD has been identified as a priority activity for the AMP in the FY 07-11 period. The objective of the TCD would be to allow for regulation of temperatures and other water quality parameters (e.g., dissolved oxygen) of water released from GCD. The primary goal would be to create mainstem water temperature conditions that promote natural reproduction and recruitment of humpback chub in the mainstem of the Colorado River. Other potential benefits or impacts of a TCD may include:

- Increased aquatic productivity
- Increases in the distribution and abundance of native fishes
- Increase in the distribution and abundance of warm and cool water non-native fishes that may compete with or prey upon native fishes
- Increased trout productivity in the Lee Ferry reach and associated improvements in the trout fishery
- Increased satisfaction of the river recreation experience
- Increased flexibility to generate hydropower at very low lake elevations

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

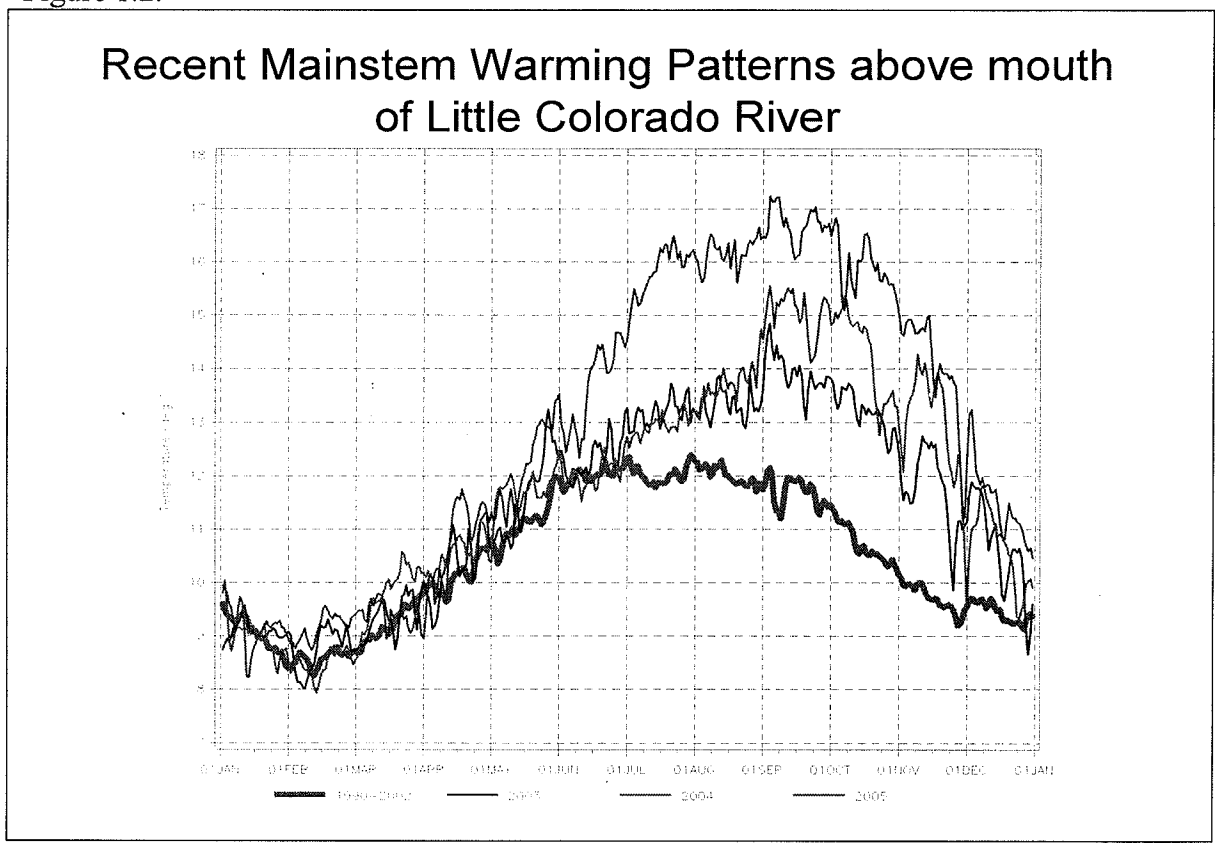
1. Evidence of mainstem spawning of HBC as indicated by the presence of YoY HBC at river mile 30 on the Colorado River;

2. Increased numbers of juvenile HBC in comparison to recent years;

3. A decline in the rainbow trout population in the Lee Ferry reach possibly owing to reductions in dissolved oxygen associated with the warmer GCD releases; and

4. Increased observations of warm water non-native fishes which may prey upon or compete with native fishes

Figure 1.2.



The natural warming of the river is expected to occur at least through WY 06 and provides a unique opportunity to study the effects of warmer water on the CRE resources prior to the possible construction of a TCD.

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

1. Development and testing of a water temperature model to better predict the effects of GCD operations on downstream water temperature and associated shoreline habitats (FY 06-07 funded with Reclamation TCD funds).

2. Synthesize water quality data for Lake Powell and link Lake Powell to the Colorado River quality of water models. (See below – funded with proposed USGS appropriations beginning in FY 08).

3. A synthesis and evaluation of currently available water temperature data focused on the Colorado River near the confluence of the LCR (ongoing-funded with Reclamation TCD funds).

4. Development and testing of a non-native fish management plan. The plan will (a) assess the implications and expected response of both the native and non-

native fisheries community to warmer water and (b) identify methods of control that will be tested/refined (FY 07-11).

5. Continue to gather and evaluate baseline data on the effects of natural warming of river temperatures on the distribution, abundance, and reproductive success of native and non-native fishes (FY 07-11).

6. In accordance with an approved HBC Genetics Management Plan, establish a refuge for HBC to avert the catastrophic declines in HBC populations associated with the proliferation of non-native fishes. (FY 07-08 – funded with Reclamation TCD funds)

7. Organize and conduct a workshop to develop a comprehensive science plan to address the operation of a TCD (FY 07--funded with Reclamation TCD funds).

CRITICAL RESEACH AND MONITORING NEEDS OUTSIDE THE AMP

The uses of AMP funds are currently focused on addressing the impacts of dam operations on resources in the immediate Colorado River corridor downstream of Glen Canyon Dam to Lake Mead. As a result, some potentially significant external threats to CRE resources that are relevant to the AMP mission and goals are not being addressed. 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 have been identified by U.S. Fish and Wildlife Service (FWS) as a significant threat to the endangered HBC in the LCR/Grand Canyon. FWS has identified the need to develop 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 and 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 a TCD that will allow for regulating the temperature and other water quality characteristics of releases from GCD. While extensive physical and biological data on Lake Powell water quality have been collected for over two decades, the data have not been synthesized, or subjected to extensive analysis and advanced modeling to simulate both temperature and dissolved oxygen characteristics for GCD operations and resulting releases. 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 GCD (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 TCD at GCD. These assessments could significantly advance knowledge of potential future water quality in Lake Powell and the appropriate design and operation of the TCD. This study would be carried out in partnership/ cooperation with the Bureau of Reclamation.

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 hydropower production in the Colorado River Basin and the conservation of natural resources in Grand Canyon and elsewhere in the Basin. Run-off 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 need predictive capability for climate change and related drought forecasting over annual-to-decadal time spans. However, the causal mechanisms of drought are not presently well enough understood to make accurate predictions to meet the needs of managers at even seasonal-to-annual scales. In addition, continued climate change and long term drought will have potentially significant implications for several identified 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 how new emerging climate information could be used by water and other resource managers in the GCD AMP program. The specific focus would be on: 1) how climate forecast information could be used in decisions related to the operation of GCD and other Colorado River Storage Project operations, and 2) the role of climate variability and hydrological variance (upper basin runoff versus the flood frequency of major tributaries below GCD) in ecosystem responses and their relationship to operation of GCD. This study 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

Proposed science activities for FY 2007-11 are summarized in Table 2.1. These activities are categorized as Core Monitoring, Long Term Experimental, and Research and Development and are related to both GCD AMP goals and AMWG priorities.

The following section summarizes the Core Monitoring, Long Term Experimental, and Research and Development elements for each major AMP Goal (i.e., Goals 1-12). Also, the efforts to link and integrate research and monitoring activities across goals is discussed within each goal, illustrating how specific science elements of individual goals are integrated across several goals. Strategic science questions that will be addressed are a product of the Strategic Science Plan and 2005 Knowledge Assessment Workshop (KAW).

Table 2.1. Summary of projects and activities in the FY07-11 Monitoring and Research Plan

GCD-AMP Strategic Goals	AMWG Priority	Core Monitoring	Long Term Experimental	Research and Development
1. Food base	1,3,5	FY 10: Evaluate new food web monitoring program for core monitoring status	FY 07-11: Evaluate effects of experimental flows on food web.	FY 06-08: Linking whole-system carbon cycling to quantitative food webs in the Colorado River (R&D for food base core monitoring program)
2. Humpback chub & Other Native Fishes	1,3,5	FY 08: Evaluate current HBC monitoring program for core monitoring status	FY07-11: Evaluate effects of experimental flows on HBC and other Native Fishes	FY 07-08: Gear efficiency/sampling evaluation. FY 07-11: Non-invasive monitoring gear development FY 07-11: Warm/cold water non-native fish monitoring, removal and control: affect on native fish recruitment. FY 07-11: Statistical review of existing HBC monitoring protocols and habitat data.
3. Extirpated species	N/A	N/A	FY 07-11: Planning and design of a TCD	N/A
4. Rainbow Trout	3	FY 07-11:Lees Ferry Trout Monitoring	FY 07-11: Evaluate effects of experimental flows on RBT	FY 07-11: Downstream dispersal of RBT below Lees Ferry.
5. KAS	3	FY 09-11: KAS Habitat Monitoring; evaluate for core monitoring status	N/A	FY 07: Evaluation of alternative survey methods of KAS habitat.
6. Springs/Riparian	4	FY 07-11: Evaluate terrestrial ecosystem monitoring for core monitoring status	FY 07-11: Evaluate allochthonous contribution during BHBF tests	FY 07-11: Vegetation synthesis project FY 07: Vegetation monitoring PEP

Table 2.1. Summary of projects and activities in the FY07-11 Monitoring and Research Plan

GCD-AMP Strategic Goals	AMWG Priority	Core Monitoring	Long Term Experimental	Research and Development
7. Quality-of-Water (QW)	1,3,5	FY 09: Lake Powell monitoring PEP FY 09-11 Lake Powel Monitoring Downstream Integrated Quality-of-Water Monitoring	FY 07-11: Continued Evaluation of Flow Testing (BHBF, steady flows, alternative fluctuating flows, selective withdrawal structure, etc.) linked to experimental design.	FY 08-10: Lake Powell Synthesis and Modeling FY 07-11: Advanced Development of downstream flow, temperature and suspended-sediment models
8. Sediment (sand bars & debris fans/rapids)	1,2,3,4	FY 07-11: Implementation of Recommendations from the final SEDS-PEP (summer 2006) Biennial Sand-Storage Monitoring	FY 08-11 Continued Evaluation of Flow Testing (BHBF, steady flows, alternative fluctuating flows, etc.) linked to experimental design.	FY 07-11: DASA Activities: -Change-Detection of Near-Shore Habitats, relating to 2004 Biological Opinion -Legacy Data Conversion
9. Recreational Experience	3,4	FY 07-11: Campable Area Monitoring, linked to biennial sand bar monitoring (above)	FY 07-11: Evaluate effects of ramping rates and BHBFs on campsites, visitor safety, and visitor health	FY 07-08: Complete campsite inventory and GIS atlas FY 07-08: Evaluate campable area monitoring results using measured field data vs. remotely sensed data FY 07 or FY 08: Compile and analyze existing safety data in anticipation of conducting future safety studies under experimental flows.

Table 2.1. Summary of projects and activities in the FY07-11 Monitoring and Research Plan

GCD-AMP Strategic Goals	AMWG Priority	Core Monitoring	Long Term Experimental	Research and Development
				FY 08-09: Evaluate relative importance and potential effects of different flows on recreation exp qualities FY 09: Evaluate vegetation encroachment on campsites; revisit Weeder survey data FY 10-11: Update regional recreation economic studies.
10. Hydropower	3	FY 07-11: Monitor of flows and power generation re: changing market values	FY 08-11: Effects of experimental flows on power and Basin Fund	FY07-08: Implement highest priority recommendations of socioeconomic PEP
11. Cultural	2,3,4	FY 08-10: Integrated Archaeological Site Monitoring Pilot (See R&D)	FY 08-11: Evaluate effects of BHBF, steady and fluctuating flows on sediment supply and deposition at arch sites and traditional cultural properties (TCPs).	FY 07: Research & Development towards Core Monitoring (of arch sites and TCPs) FY 08-10: Implement CR monitoring project on a pilot basis FY 08-10: Geomorphic Model of Archaeological Site Vulnerability FY 10: Cultural PEP II
12. High quality Monitoring, Research and AEAM				

Table 2.1. Summary of projects and activities in the FY07-11 Monitoring and Research Plan

GCD-AMP Strategic Goals	AMWG Priority	Core Monitoring	Long Term Experimental	Research and Development
DASA	1,2,3,4,5	FY 07-11 Remote Sensing (preparation, acquisition, & storage of 2009 terrestrial resource monitoring data)	FY 07-11 No additional remotely sensed data proposed beyond the 2009 monitoring mission	FY 07-11: -Legacy Analog Data Conversion (DASA) -Integrated Analysis and Modeling – Shoreline Habitat and Change Detection Mapping in support of 2004 Biological Opinion
Logistics Support of Field Activities	1,2,3,4,5	Ongoing as related to monitoring projects	Ongoing, as needed to support experimental design	Ongoing, as needed
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 08-10: 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 08-10: 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 10 Workshops

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)
- Estimate baseline of standing crop of algae and diatoms through measurement of basal food resources, such as primary productivity, and submerged aquatic vegetation. Future monitoring will allow for estimation of how the standing crops change over time

Research and Development

AMWG Priority and Strategic Science Questions Addressed

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?

3-5. 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 core monitoring, as outlined below. Core monitoring protocols will be developed with the assistance of a protocol evaluation panel of experts, currently scheduled for FY 2010.

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 (FY 07 only) will assemble and synthesize stomach content, drift sample, and environmental data collected during the mechanical removal of trout project. Taken together these three projects will greatly improve understanding of how primary and secondary production of the Colorado River is incorporated into the aquatic food web. Special emphasis is given to the Lees Ferry and Little Colorado River inflow reaches of the river because of the fish populations of special interest to the AMP (see AMWG Goals 2 and 4) that are found in these reaches. Concurrent study of the whole Colorado River, the Lees Ferry reach, and the LCR reach allow for analysis of the hypothesis that the Glen Canyon Dam/Lees Ferry reach provides a large proportion of the food available to rainbow trout, humpback chub, and other fishes.

The first project objectives are to identify basal carbon sources and food web linkages for the whole system, particularly below the Paria River. The project is testing the hypothesis developed in Walters and others (2000) that "the whole downstream aquatic ecosystem appears to be driven by changes in aquatic primary productivity, particularly in the upper reaches". This hypothesis was developed from previous research (Angradi, 1994; Stevens and others, 1997a, b). The submerged aquatic vegetation (SAV) mapping project would supplement the basal carbon source and food web project by providing more detailed information that the scope and budget of Project 1 does not permit, i.e., the scale of Project 1 considers the whole river, while this project is focused in Glen Canyon. If, in fact, standing crop in the tailwaters plays a significant role not only in the Lees Ferry trout fishery but downstream, then quantifying the amount and types of SAV becomes clearly important as a monitoring tool associated with secondary production of both trout and native fishes. The SAV project provides support for the Lees Ferry trout management program by quantifying standing crop, food availability and identifying YoY and juvenile cover areas. The management of the trout in Lees Ferry is confounded at times by being unable to determine if fish condition factor is affected by food availability or density dependence factors. This project would provide information about food availability, while the trout monitoring provides information about fish densities. The integration of these data supports management of the blue ribbon fishery.

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

This project was initiated in 2005 to identify energy pathways and quantifying basal resources through multiple approaches. The project incorporates stable isotope and diet analysis of invertebrates and fish to identify trophic pathways. Flux along trophic pathways will be quantified by calculating invertebrate densities and estimating production and growth. 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 FY 09, will contribute to the development of a core monitoring program for the Grand Canyon food base in subsequent years.

Project:
BIO 1.R1.07: Aquatic Food Base

2. Mapping submerged aquatic vegetation, 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 07. 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 Arizona Game and Fish Department (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.

Project:
BIO.1.R2.07: Submerged Aquatic Vegetation (SAV)

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 effort to remove trout from the Little Colorado River inflow reach of the Colorado River in Grand Canyon. Some of the tasks associated with these projects have been completed, including field work, sample enumeration, 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. Only preliminary analysis has been conducted to date and results have not been documented. This project is a one year effort for FY 2007 to complete the database, including quality control, and to synthesize the data in the form of reports and/or manuscripts. Synthesis of the available information provides value to the AMP by increasing understanding of trout diets in the Colorado River, information that is valuable to managers as they utilize the primary productivity information generated by the first two projects for this goal, above.

Project:
BIO 1.R3.07: Complete diet, drift, and predation studies

Integration

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 nonnative 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. Comparison to trout diets assessed during the mechanical removal will be possible. Quantifying the submerged aquatic vegetation in the Lee's Ferry reach and associating these measures with available food resources helps managers determine carrying capacity of the Lees Ferry reach for rainbow trout (AMWG Goal 4). Completing the stomach content analysis of samples taken during the mechanical removal project helps managers evaluate what rainbow trout in the removal reach have been eating and how this may or may not impact HBC entering and exiting the LCR.

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. Seek methods that reduce, eliminate, or control limiting factors

- Identify habitat characteristics that are most important to all life stages of humpback chub. Seek methods that 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, including sampling design, gear selection, and development of remote monitoring methods. The method(s) developed and selected should be consistent with the latest edition of the Colorado River Endangered Fishes Recovery Goals. (The FWS has scheduled revision of the Goals to be initiated 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 Grand Canyon

- Increase integration among biological sub-disciplines and between physical, cultural and recreational disciplines in order to improve knowledge of the interrelationships between sciences in support of management decision-making. Efforts to address this objective include:

    - Integrate results of food base, aquatic vegetation, and diet investigations of native fishes

    - Utilize results of terrestrial vegetation studies to determine 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; utilize multivariate statistics to analyze available physical and biological information for indications of how dam operations and natural resources affect native fishes

Razorback sucker are not currently regularly observed in Grand Canyon, and so are considered under Goal 3 which addresses extirpated species. The objectives above will be addressed as follows:

Research and Development Element - Monitoring

AMWG Priority and Strategic Science 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. 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 non-native species.

1-4. Can long-term decreases in abundance of rainbow trout in Marble and eastern Grand Canyons be sustained with a reduced level of effort of mechanical removal or will re-colonization from tributaries and from downstream and upstream of the removal reach require that mechanical removal be an ongoing management action? This question also applies to future removal programs targeting other non-native species.

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

1-8. How can native and non-native fishes best be monitored while minimizing impacts from capture and handling or sampling?

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.

Managers and researchers studying the humpback chub in Grand Canyon stress the importance of monitoring the population in and near the Little Colorado River, especially for gaining an accurate assessment of the population numbers, which supports future evaluations of the population's current jeopardy status. Monitoring of the LCR, conducted with four separate mark-recapture trips, will be maintained in FY 2007 and 2008. The timing of mainstem monitoring will be altered to coordinate more closely with the existing LCR sampling efforts. One more, shorter, mainstem sampling effort will be conducted in the mainstem to provide a total of three annual concurrent sampling efforts as described by Otis (D. Otis, Iowa State University, personal communication, 2006), a member of the 2003 Kitchell panel (Kitchell and

others, 2003). The two longer mainstem sampling trips will be conducted the length of the mainstem, using electroshocking and hoop nets, from Lees Ferry to near Lake Mead (i.e., below Diamond Creek). The shorter mainstem sampling trip will be timed to coincide with the second spring sampling trip in the LCR as well as the standardized sampling in the lower 1,200 meters of the LCR. Monitoring of the recently introduced humpback chub population above Chute Falls will be continued in 2007 and 2008 to assess the success of that population segment. All monitoring of humpback chub will be the subject of PEP in FY 2008. Resulting guidance from the PEP should initially be implemented in FY 2009.

Balancing substantial information needs and regulatory responsibilities with limited budgets continues to challenge the creativity of scientists and managers studying fishes in Grand Canyon. Extensive field studies may provide important information that cannot be obtained in any other manner, but some existing monitoring protocols include relatively frequent handling at relatively high cost. Some newer technologies seem to hold promise for providing at least some of the necessary population monitoring information, but will require field testing before implementation. The FY 2007-2008 work plan and budget proposed by GCMRC:

- Coordinates concurrent monitoring of humpback chub in the LCR and mainstem in support of both scientific rigor and management evaluation
- Links two mainstem monitoring events with sampling below Diamond Creek
- Utilizes two mainstem monitoring events (spring and fall) as the primary monitoring of the Colorado River fish community
- Reduces use of trammel nets and increases use of hoop nets to reduce stress on native fishes
- Conducts one Kanab ambersnail trip annually, instead of two, to be shared with a mainstem backwater seining trip that monitors YoY and small-bodied fishes
- Conducts research on the following gears: trammel nets, remote PIT tag readers, sonic tags, and the DIDSON (sonic) camera (see Monitoring Research)
- Collects additional data to support a PEP in 2009 (see Monitoring Research)

It is anticipated that GCMRC will continue to rely heavily on permanent FWS and AZGFD personnel for their expertise, knowledge, and creativity. The projects proposed above may reduce, but not eliminate, the need for technicians, seasonal personnel, volunteers, and consultants.

Projects:
BIO 2.R1.07: Little Colorado River Humpback Chub Monitoring Lower 15km
BIO 2.R2.07: Little Colorado River Humpback Chub Monitoring Lower 1,200m
BIO 2.R3.07: Humpback Chub Monitoring Above Chute Falls
BIO 2.R4.07: Monitoring mainstem fishes (includes below Diamond Creek)

Mechanical removal. One of the biotic factors thought to be limiting to native fishes is predation by and/or competition with non-native fishes. This threat has been addressed during fiscal years 2003-06 with the mechanical removal of rainbow trout and other non-native fish using boat electrofishing. 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. The DIDSON camera may be deployed along with some gear types to help evaluate efficacy.

Projects:
BIO 2.R5.07: Non-native Control Planning
BIO 2.R6.07: Non-native Control Pilot Testing

Modeling populations. As managers and scientists strive to manage and conserve the natural resources of the Grand Canyon, it is important to characterize the population size of the resident humpback chub population and the trend of the population over years. The GCMRC has been taking the lead in estimating the population size and trend and 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, especially the monitoring and the aging study. Associated projects include development of a bio-energetic model of the Grand Canyon fish community to help predict anticipated changes in the fish communities in response to environmental changes, and development of abundance estimation procedures for non-native fishes.

Projects:
BIO 2.R7.07: Stock Assessment of Native Fish in Grand Canyon (model development)
BIO 2.R8.07: Abundance Estimation Procedures
BIO 2.R9.07: Bio-energetic Modeling
BIO 2.R10.07 PEP Preparation (Sampling analysis)

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 (Paukert and others, 2005. Potential negative effects of capture and study, especially of endangered fishes, have lead researchers to seek less invasive methods for evaluating the populations. 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:
BIO 2.R12.07: Remote PIT Tag Reading
BIO 2.R13.07: Test Sonic Tags
BIO 2.R14.07: Test DIDSON Camera
BIO 2.R15.07: Trammel Net Effects

Other Research and Development

AMWG Priority and Strategic Science 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 emigrate from Glen to Marble and eastern Grand Canyons, and if so, during what life stages? To what extent do Glen Canyon emigrants 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?

4-2. How important are backwaters and vegetated shoreline habitats to the overall growth and survival of YoY and juvenile native fish? Does the long-term benefit of increasing these habitats outweigh short-term potential costs (displacement and possibly mortality of young HBC) associated with high flows?

Habitat. The literature regarding HBC habitat use is modest but is increasing. The published assumptions regarding which habitats are optimum and available for different life stages of HBC 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 identified from available data, protected, and replicated. These data will be referenced to date, river flows, and Glen Canyon Dam operations to help avoid improper assumptions, i.e., to avoid concluding fish prefer a habitat when it may be the only one available. 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.

Laboratory experiments could be employed to address fish habitat preferences and performance in those habitats. These experiments would be of particular value if young humpback chub could be made available for experimentation, but could also be conducted with closely related species such as bonytail. While the conclusions of experimental results must be carefully assessed when extrapolating to the natural environment, experimental results may be used to suggest what

factors are most limiting to growth and recruitment. Such experiments may be more specifically defined and proposed during the 2007-2011 planning period.

Projects:
BIO 2.R11.07: Native Fishes Habitat Data Analysis

Long Term Experimental Element

AMWG Priority and Strategic Science 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 BHBFs.

During FY 2007-08, the GCMRC staff and its science cooperators shall undertake efforts at mapping and detecting changes in the distribution and abundance of sand bars and related near-shore habitats throughout the CRE. This effort is an experimental support activity associated with the collection of May 2005, digital, remotely sensed imagery (system-wide data were also collected in 2002 and 2004) and is directly related to conservation measures for HBC, as associated with recent high-flow sediment testing (BHBF). The objective of the project is to identify changes in shorelines and near-shore habitats (such as change in abundance, distribution, and size of backwaters) that resulted from a High-Flow test release of 41,000 cfs for a duration of 60 hours in November 2004.

Project:
DASA 12.D6.07: Integrated Analysis and Modeling – Mapping Shoreline Habitat Changes

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 non-native 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 GCD release regimens. Additional details of integration strategies and products are provided above and in the Biennial Work Plan.

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

2007-11 Science Objectives

- Identify species responses that may be expected in response to warmer water as may be provided by climate change and/or a 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 pikeminnow 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.

Long Term Experimental Element

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.

AMWG 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.

2007-11 Science 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).

Core Monitoring Element

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.

AMWG Priority and Strategic Science Questions Addressed

3-6. What GCD operations (ramping rates, daily flow range, etc.) maximize trout fishing opportunities and catchability?

Project:
Bio 4.M1.07: Status and Trends of Lees Ferry Trout

Research and Development Element

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).

Long Term Experimental Element

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.

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

2007-11 Science 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:

Core Monitoring Element

AMWG Priority and Strategic Science Questions Addressed

Not one of AMWG's Top 5 Priorities.

Other Strategic Science Questions Addressed

The following science questions were identified in the KA for the CRE (Melis et al, 2006). The following question could be applied to Vasey's Paradise as it relates to seep and spring issues, and cultural sites. Because the association between snails and vegetation composition is somewhat specific, understanding vegetation composition, density, and distribution responses to flow is important.

1. How do physical processes (e.g., magnitude, duration and frequency of discharge, sediment flux) influence riparian vegetation structure and composition, and habitat quality (e.g., expansion of invasive species)?

2. What is the contribution of riparian vegetation (springs) to the Colorado River carbon budget, secondary production, and its linkage with the aquatic system?

3. How does the type and aerial extent of riparian vegetation affect cultural resources (e.g., sand transport, campsite area encroachment, wilderness experience, TCPs)?

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).

Project;
BIO 5.R1.07: Monitor Kanab ambersnail and humpback chub in backwaters

Research and Development Element

Testing alternative methods for determining population size, variability, 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 FWS in 2006 to contribute to determination of population size and variability information regarding this endangered species that is acceptable to the FWS.

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.

Long Term Experimental Element

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 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.

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

2007-11 Science Objectives

- Determine the extent of vegetation communities 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 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

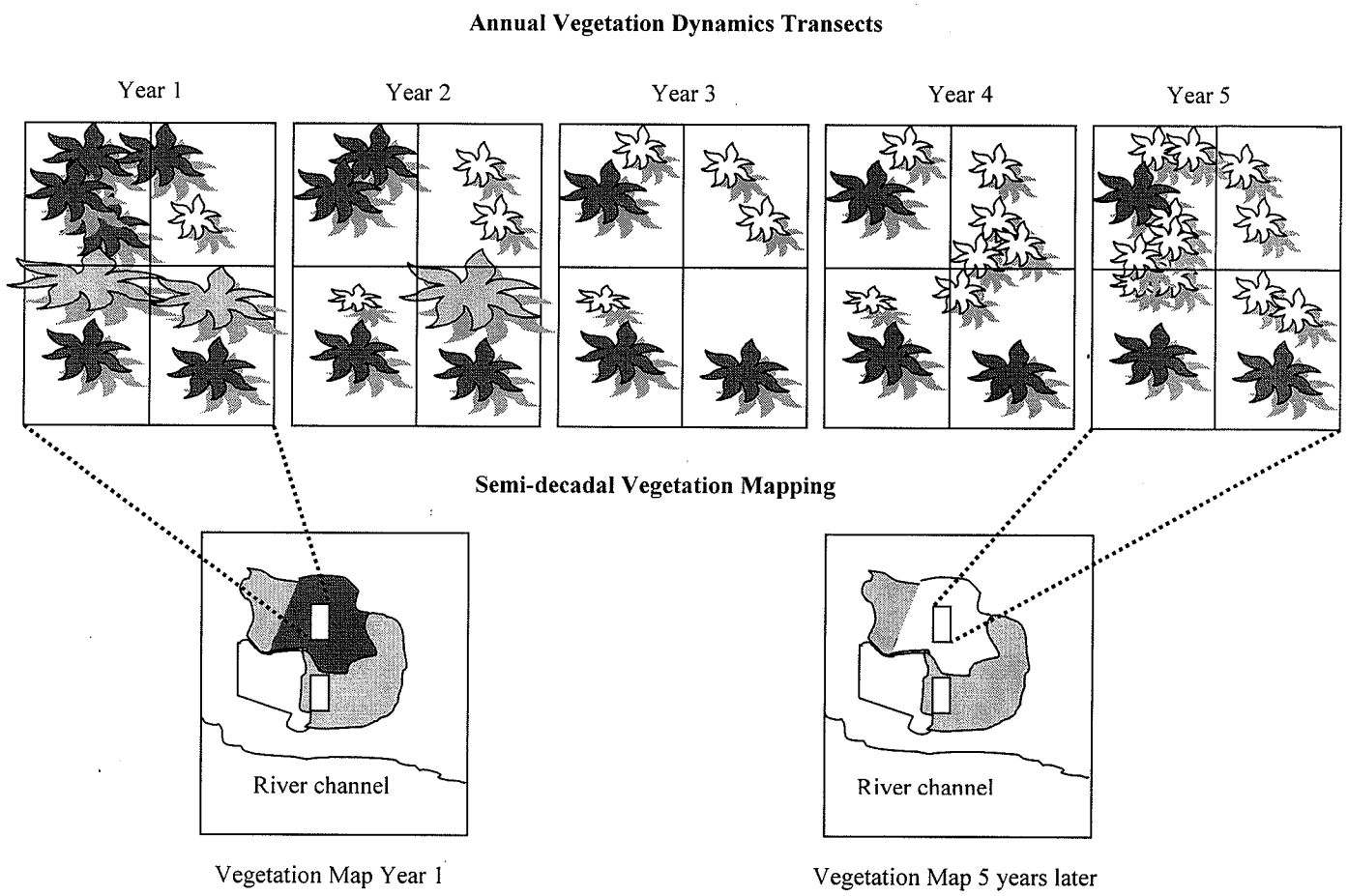
Core Monitoring Element

AMWG Priority and Strategic Science Questions Addressed

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?

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 07.



Schematic illustrating the differences in scale and information obtained from annual transect and semi-decadal vegetation mapping. The annual surveys show a decline in species diversity through time and a decline in cover through year three. Cover increases after year 3, but species diversity remains reduced. The vegetation map records a change in the vegetation class but no change in polygon area. Cover values would be similar for both incidents. The annual surveys capture smaller scale changes within a community, in this case perhaps recording rate of invasive colonization, whereas the vegetation mapping effort would record dominant cover changes and quantify total area covered by dominant species. A vegetation synthesis would incorporate local scale information associated with yearly sampling, like river stage elevation changes and landscape scale information like patch changes to explain riparian habitat shifts that have occurred along the CRE.

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

Projects:
BIO 6.R1.07: Vegetation Mapping
BIO 6.R2.07: Vegetation Transects

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

The results of the pilot program for Terrestrial ecosystem monitoring suggested focusing on vegetation, avifauna, and arthropods was based on trade-offs between economic costs vs. information gained. The investigators suggested that linkages between vegetation cover and composition and faunal abundances are possibly more manageable for monitoring that emphasized vegetation, arthropods and birds, rather than for small mammals and reptiles or amphibians. The logistic and field hours required to monitor mammals and herpetofauna within the river corridor makes monitoring prohibitive. The authors identified arthropods as a direct link between vegetation and higher trophic levels. Their densities can be correlated with plant species types, and plant species types and plant cover are variables most influential on bird abundance and diversity (Sogge 1998, Holmes et al 2005). Furthermore, invertebrate densities may be utilized in the aquatic food base program as a monitoring tool, pending results of the aquatic food base study. Recommendation from the authors of the pilot study will be reviewed on FY 07 in association with a follow-up PEP associated with Terrestrial Monitoring. The table below provides a proposed survey schedule for multiple resource monitoring. Mammals and herpetofauna might be surveyed on a semi-decadal time frame. The proposed schedule is presented for informational purposes rather than a recommendation for implementation in FY 2007.

Annual survey schedule			
Trip (timing)	Group	Survey Methods	Output
Spring 1 (Early May) 14 days	Breeding Birds Vegetation Density	Point counts with distance sampling Vegetation volume for all patches	Breeding bird density 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	Ground-dwelling insects (beetles,

		Sweep net (with ladders)	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

Research and Development Element

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.

Our understanding of how riparian vegetation changes as a result of dam operations is well developed for marsh species (see Stevens et al. 1995). The authors related decadal changes in operations, geomorphic reach and distance from the dam to area cover and species composition. Our knowledge regarding this community was reaffirmed in the KAW summarized in Melis et al. (2006) in which the color green was assigned to marsh vegetation. As one moves upslope from the channel, our understanding of how operations influence vegetation change is less conclusive, hence the purpose of the synthesis (i.e., proposed research). We do know, as a result

of the vegetation transects completed from 2000 - 2004 that operations affect vegetation cover, richness and diversity up to the 35 kcfs river stage elevation, while the local environment appears to affect vegetation above this elevation. We do not know, however, how short duration high flows (i.e., discharges greater than 31 kcfs), may change riparian vegetation. These questions would be considered within the scope of the vegetation synthesis.

Project :
BIO 6.R3.07: Vegetation synthesis:
Part I – local processes and system-wide change synthesis. FY07-09
Part II – integration with faunal and cultural components FY09-11

Long Term Experimental Element

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

Assessing changes in vegetation resulting from a high flow would be most effectively measured by focusing on seedlings and herbaceous vegetation located below the 45 kcfs surface stage elevation. Sampling could be coordinated with vegetation dynamics monitoring plots (vegetation transects) that would have been multiple years of data that incorporates both river stage/operations and limited weather/climate data. Information about sediment transport, grain size distribution, and substrate gain and loss would be obtained from the physical sciences program (IQW) and incorporated into the analysis related to observed changes in vegetation. Vegetation structure and changes in area of woody species would be captured in semi-decadal mapping efforts.

Integration

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 is 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.

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

2007-11 Science Objectives

Lake Powell

- 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.

AMWG Priority and Strategic Science Questions

3-5: 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?

Project:
BIO 7.R1.07: Water Quality Monitoring of Lake Powell and the Glen Canyon Dam Tailwater

Core Monitoring

Lake Powell

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, and selective withdrawal structure and related downstream thermal modeling efforts.

Research and Development Element

Lake Powell

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 on the quality of Glen Canyon Dam releases and its suitability to downstream aquatic resources.

Integration

Monitoring and modeling of Lake Powell and Glen Canyon Dam release water quality will integrate with aquatic resource programs in Grand Canyon. Reservoir and tail water monitoring efforts will link directly with downstream quality-of-water monitoring (suspended-sediment transport, temperature, specific conductivity, dissolved oxygen) to provide consistent methodology and data management to ensure a cost-effective and reliable monitoring program. Integration with the aquatic food base program will provide necessary information on temperature, nutrients, plankton, organic carbon, and other parameters in GCD 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 GCD releases that directly affect life history, recruitment, health and behavior of downstream native and non-native fish populations.

Downstream Integrated Quality-of-Water Program:

2007-2011 Monitoring & Research Objectives

- Monitor and report real-time data of release pattern of Glen Canyon Dam (stage and discharge, as measured at the Colorado River gage near Lees Ferry and key points downstream)

- Monitor and report real-time Quality-of-Water data for downstream segments of the Colorado River ecosystem that focus on managers' needs and supports modeling efforts below Glen Canyon Dam (temperature, specific conductivity, etc. in the main channel and selected tributaries)

- Monitor and report estimates for (measurements and modeling) sand and silt/clay volumes (with grain sizes) delivered by major and lesser tributaries below Glen Canyon Dam (ecosystem's influx of fine sediments)

- Monitor and report estimates for (measurements and modeling) sand and silt/clay volumes (and grain sizes) transported by the Colorado River downstream below Glen Canyon Dam (ecosystem's efflux of fine sediments)

- Experimental flow support - collect, as need arises, additional similar data in support of experimental flows released from Glen Canyon Dam

- Ongoing Research & Development - through focused synthesis and research, promote ongoing integration of quality-of-water program in support of other interrelated resource management goals, such as aquatic productivity, fisheries, sandbars and related habitats and recreation

These objectives will be addressed as follows:

Integrated Quality-of-Water Monitoring, Modeling & Experimental Flow Research

Two strategic science questions related to physical resources were recently developed (summer 2005 Knowledge Assessment Workshop) relating to flow and quality-of-water through a process of knowledge assessment workshops conducted in 2005, relating to Goal #7. Those two questions were later combined into a single question (see Appendix A) that is focused primarily on the temperature of Glen Canyon Dam releases and the need for managers to predict how water temperature evolves as flows are translated through the Colorado River ecosystem after leaving the dam:

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?

As part of science efforts between 2007 and 2011, the GCMRC shall continue development of a downstream model for temperature (initiated in 2006). Temperature monitoring along the main channel is proposed to be expanded to include continuous measurements in selected near-shore environments, such as backwaters (return-current channel) within Marble and Eastern Grand Canyons.

During 2007 and 2008, GCMRC scientists and cooperators conducting research on nutrient dynamics related to the ecosystem's aquatic productivity and the quality-of-water program are scheduled to continue collaborative efforts to define future monitoring activities. One objective of the food web research is to help the GCMRC identify elements of downstream monitoring that might be of interest to managers. Strategies for expanding downstream quality-of-water measurements and integrating new protocols with existing measurements shall be explored during the remainder of the food web research.

During the 2005 KAW, additional strategic science questions (Appendix A) were also identified for fine sediment transport (Goals #7) and sand bars (Goal #8) and were related to need for future experimental flow efforts that are intended to focus on relating flow and suspended-sediment dynamics to aquatic and terrestrial habitat characteristics:

3-1: Is there a "Flow-Only" operation (i.e. a strategy for dam releases, including managing tributary inputs with BHBFs, without sediment augmentation) that will restore and maintain sandbar habitats over decadal time scales?

Efforts to resolve the above question were initiated in March 1996, and again with testing in November 2004. Sediment scientists at the 2005 Knowledge Assessment meetings, suggested that additional field and modeling efforts are needed to further resolve this complicated issue of sand conservation using existing downstream sand supplies if additional tests of the Beach/Habitat-Building Flow concept under tributary sand enriched conditions occurs during the FY 2007-011 experimental research period.

Efforts to resolve strategic science question 3-1 above would consist of focused field and modeling efforts to further resolve this complicated issue of sand conservation using existing downstream sand supplies, presumably following the experimental field testing period. Such efforts depend upon the answer to the question of whether or not there is a "Flow-Only" operation that will restore and maintain sandbar habitats, as derived from additional tests of the BHBFs concept under tributary sand enriched conditions during the FY 2007-11 monitoring and research period.