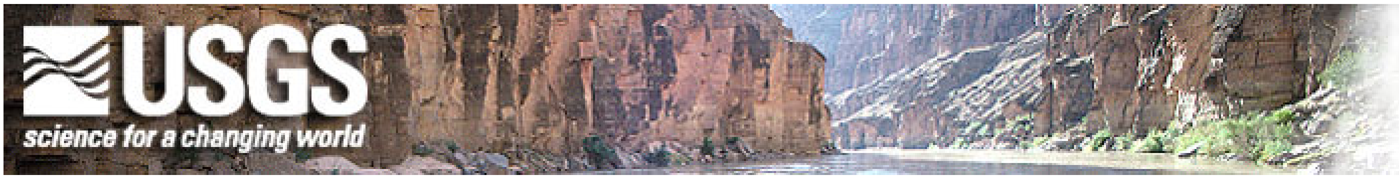

Grand Canyon Monitoring and Research Center Strategic Science Plan to Support the GCD AMP: 2007-2011

Developed in Cooperation with the Glen Canyon Dam Adaptive Management Program

Draft version: November 18, 2005

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GCMRC STRATEGIC SCIENCE PLAN FOR MONITORING AND RESEARCH PROGRAMS FOR THE GCD AMP: FY 2007-2011 IN COOPERATION WITH THE GCD AMP

I. THE GCD AMP STRATEGY FOR SCIENCE PLANNING

A. **The AMWG, GCMRC and TWG** propose a more comprehensive and responsive approach to science and management planning that incorporates all active GCD AMP groups, Including Ad Hoc Groups. The new science planning process incorporates both strategic planning for 3-5 years and operational and budget planning at two year intervals.

B. The New Science Planning Approach Develops a More Holistic and Adaptive Science and Management Planning Process

1. Incorporating all GCD AMP Groups in the planning process, i.e., GCMRC, TWG, Ad Hocs, SAs, AMWG, external science and management community.

2. Incorporating operating adaptive management principles in the planning process, i.e., rapid cycling of science and management trails new knowledge and management application within a 5 year period.

3. Applying more ecosystem based science processes, including ecosystem modeling and assessment approaches.

4. Annual evaluations of potential new knowledge application and management actions. Complete management and program assessments of potential science management changes at 3-5 year intervals and requirements for new or additional science

II. THE GCMRC MISSION AND GOALS FOR THE STRATEGIC SCIENCE PLAN

A. The Grand Canyon Monitoring and Research Center GCMRC was established by the Secretary of Interior in 1995 to develop research designs and proposals for implementing monitoring and research information needs identified by AMWG. This GCMRC Strategic Science Plan outlines the mission and objectives of the Center, the context in which the Center addresses this mission, and the FY 2007-2011 science and resource strategies the Center employs to accomplish its mission.

1. The GCMRC vision is to be the undisputed leader in providing relevant, valuable, accurate, and timely information on the effects of Glen Canyon Dam operations on the natural and cultural resources in the Grand Canyon.

2. The GCMRC Mission is:
   "To provide credible, objective scientific information to the Glen Canyon

Dam Adaptive Management Program on the effects of operating Glen Canyon Dam under the Record of Decision and other management actions on the downstream resources of the Colorado River ecosystem, utilizing an ecosystem science approach."
The Record of Decision in 1996 provided the first definitive proposals for experimental flows and non-flow management actions to be evaluated with the adaptive management and science process.

3. GCMRC's key roles and responsibilities are comprehensive, but remain focused on critical issues of stakeholders. GCMRC will:
    - Advocate quality, objective science
    - Provide scientific information for priority resources of concern
    - Support the Secretary' designee and the Adaptive Management Work Group
    - Develop research designs to implement monitoring, research and development activities
    - Coordinate ongoing science reviews with independent review panels
    - Prepare technical management recommendations and annual reports
    - Manage all data collected
    - Manage GCMRC programs, finances, and personnel

III. CONTEXT OF IMPLEMENTING THE GCMRC's VISION WITHIN ADAPTIVE MANAGEMENT AND APPLIED SCIENCE PROGRAMS IN THE CRE

A. Requirement for All Operations of Glen Canyon Dam (GCD) [photos here].

1. "The Secretary shall operate Glen Canyon Dam in accordance with the additional criteria and operating plans specified in section 1804 and exercise other authorities under existing law in such a manner as to protect, mitigate adverse impacts to, and improve the values for which Grand Canyon National Park and Glen Canyon National Recreation Area were established, including but not limited to natural and cultural resources and visitor use." (GCPA,1992).

B. Implementing Adaptive Management (GCD-AMP) in the Colorado River Ecosystem (CRE) [location map here].

1. "It is intended that the Record-of-Decision (ROD) will initiate a process of adaptive management whereby the effects of dam operations on downstream resources would be assessed and the results of those resource assessments would form the basis for future modification of dam operations." (DOI, 1995).

2. Resource assessments will determine through monitoring, and research where applicable, if modification of dam operations are effective in moving CRE resources to desired future conditions (dcfs) specified and agreed to by the AMWG. A process for determining dcfs individual resources will be

developed and incorporated in the science and management for programs in this planning period.

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C. Implementing Applied Science Programs in the CRE.

1. “The concept of adaptive management is based on the recognized need for operational flexibility to respond to future monitoring and research findings and varying resource conditions.” (DOI, 1995).

2. The GCD-AMP is structured as related in the AMWG Strategic Plan and in Figure II-10 of the GCD EIS (DOI, 1995). [organizational figure here]

3. “Monitoring and research programs should be designed by qualified researchers in direct response to the needs of management agencies.” (DOI, 1995).

4. “A process is required to coordinate and communicate management agency needs to researchers.” (DOI, 1995).

5. The Adaptive Management Work Group (AMWG) develops and communicates to the Center its goals, management objectives and information needs for the GCD-AMP (AMWG Strategic Plan, 2001). Twelve goals and over 100 information needs have been identified.

6. The Center will “develop research designs and proposals for implementing monitoring and research identified by the AMWG, and manage all monitoring and research on resources affected by dam operations.” (DOI, 1995).

7. The interactive process of scientists providing new information to managers and they implementing them as management actions is depleted in figure 1.1. Accomplished effectively it maximizes the utility of science and significantly shortens the time to realize results from a science finding and management action (insert V. Dale schematic as figure 1.1).

D. Continued Milestones in Learning in the CRE.

Gaining knowledge in the CRE has resulted from extensive management and science activities over the last 50 years by many science management and educational entities. Following is a brief listing of science inquiry.

1. 1950-1982: During this period several organized investigations took place. None were continuous over the period, and were initiated for differing reasons. They included: NPS, BOR, Dartmouth, and AG& FD as well as others. The primary findings for this period of investigation was baseline information on selected resources, such as flow changes related to wet and dry periods in the upper basin, variable sediment pulses to the CRE and changes in water quality resulting from dam construction.

2. 1982-1988 GCES Phase I: BOR science program to develop baseline information on selected resources. The Science investigation during this period developed new sampling and measurement methods for both research and monitoring projects. Improved baseline information was developed for the riparian corridor, flows and sediment dynamics. The period also marked the first continuous multiresource assessments in the CRE.

3. 1989-1995 GCES Phase II: program to establish active science studies tied to GCD releases (1990) & implementation of interim flows (1991).
   This period of science investigation focused on evaluating existing knowledge from BOR science and other studies to develop best management strategies for flows and other resources. An extensive assessment of potential flow impacts to CRE resources was completed.

4. 1996-2000: Transition Monitoring era during which time GCMRC/AMWG programs of adaptive management and ecosystem science were formerly established.
   This science period was devoted to three primary outcomes; developing the record of decision for experimental flow operations from GCD; moving the BOR GCES science program from a management agency to USDI and then USGS to increase independence and gain greater guidance for science approaches; and designing and implementing an adaptive management ecosystem science program GCMRC

5. 2001-2006: GCMRC/AMWG/TWG/BAHG/SA. Both the AMWG and GCMRC strategic management plans are developed and implementation of Active Adaptive Management is underway in 2003 with large-scale flow and non-flow experimental treatments.
   This science period accomplished significant assessments of differing flow and non-flow management actions on specific resources and/or processes; refinement of the adaptive management process; improvements in ecosystem linkage of flow impacts to various resources; and improvements in ecosystem modeling.

6. **2007-2011:** GCMRC/AMWG/TWG/BAHG/HBCCP/SPG/SA. Challenge: The next Phase of GCD-AMP programs must improve the Adaptive Ecosystem Management process and incorporate more effective ecosystem science approaches, including active experimental studies, monitoring, and developing collaborative science partnerships.

Figure 1.1. The GCD AMP Adaptive Management Process, defining process and linkage for accelerating science results into management actions.

IV. IMPLEMENTING GCDAMP SCIENCE UTILIZING ECOSYSTEM SCIENCE PARADIGM

A. Four Critical Strategies Initiated in 2007-2011, will improve implementation of ecosystem science in the GCD-AMP.

1. Expanded design, development and use of a conceptual ecosystem model. In FY 2006-2008 will upgrade the Colorado River Ecosystem Model as presented in figure 4.1. Possible additions are:

   a. Capture more social resource components and agency decision-support processes.
   b. Move into "landscape" scale incorporating multiple watersheds.
   c. Additional fishery elements.
   d. Modeling non-flow management activities.
   e. Synthesis of terrestrial vegetation changes.
   f. Downstream temperature sub-model linked to fine-sediment, food web and fisheries sub-models.
   g. Enhanced use of climatic input data and simulations, climate change.
   h. Recreational use.
   i. Cultural resource change.
   j. Financial impact simulations.
   k. Continuing stakeholder education

2. Explicit new science project designs that document system data component that specifically addresses the overarching science questions and promotes integration and linkage to other system components. (example: recent solicitations for the food web research).

   a. Explicit design of science projects to specify linkages across projects and integration of programs to a landscape level.

   b. Incorporation of "looking outward" matrix links in the ecosystem model through defined processes (Holling, 1978) to fully characterize "effectors" and impacts of processes relating various resource and process interaction.

   c. The looking outward matrix incorporated into the conceptual model would track management actions and their interactive processes to specific resource indicators and inputs to other sub-models. Figure 3.2 provides an example of mainstream temperature sub-model illustrating the linkages of management actions to indicator outcomes and inputs to other sub-models.

3. Analysis of data and evaluation of research and monitoring information from an ecosystem perspective.

a. Incorporating conceptual, simulation and/or predictive ecosystem sub-models to formulate and define critical processes/and integration of resources to enhance data analysis and evaluation of resource impact associations.

b. The use of linked physical sub-models that define how flow and fine-sediment export relates to cultural resource site erosion throughout the river corridor.

c. Flow and sediment simulations designed to evaluate optimized strategies for implementation of Beach/Habitat-Building Flows. Concepts of linear programming developed as part of a prescription for achieving sediment objectives linked to long-term monitoring of sediment and habitats.

4. Assessment of science and management interactions in adaptive management from a system perspective.

   a. Development of a CRE systems model for adaptive management using a decision support system designed and linked to the more objective ecosystem science process.

Figure 4.1. A schematic of the CRE Concept Ecosystem Model (after Walters and others, 2000).

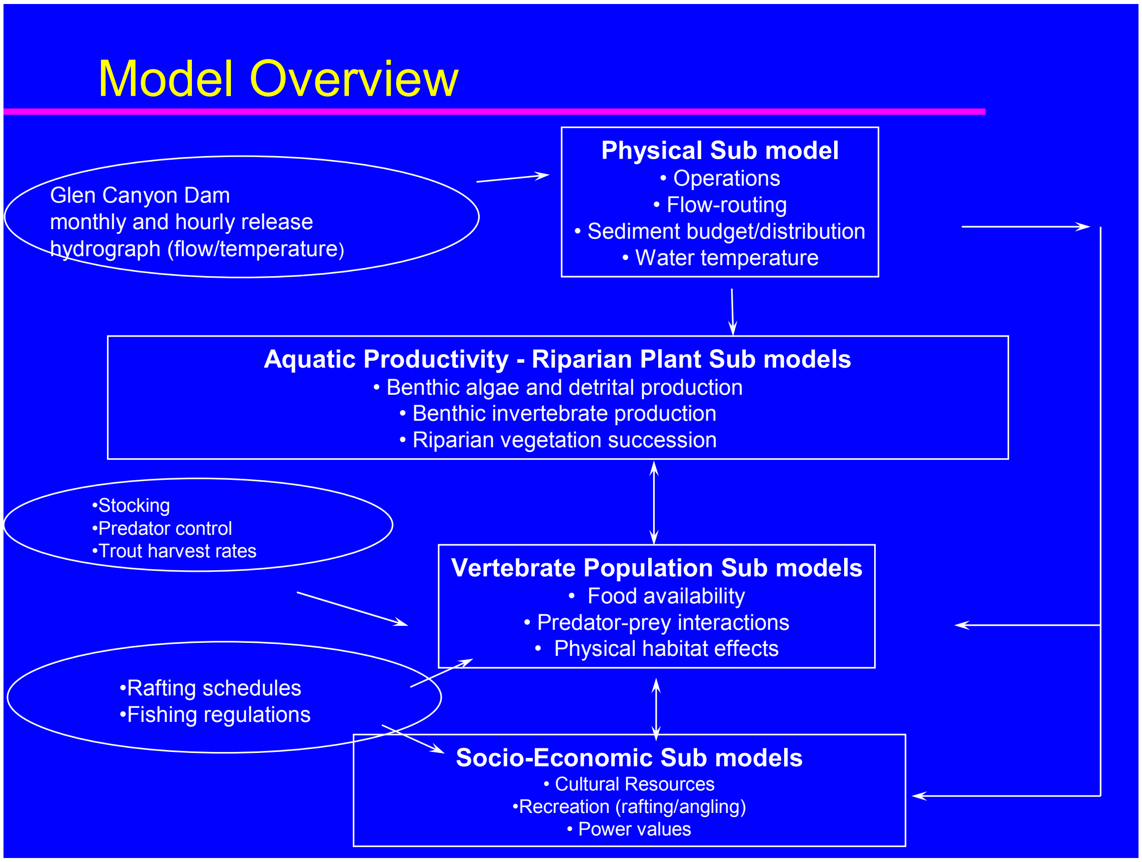
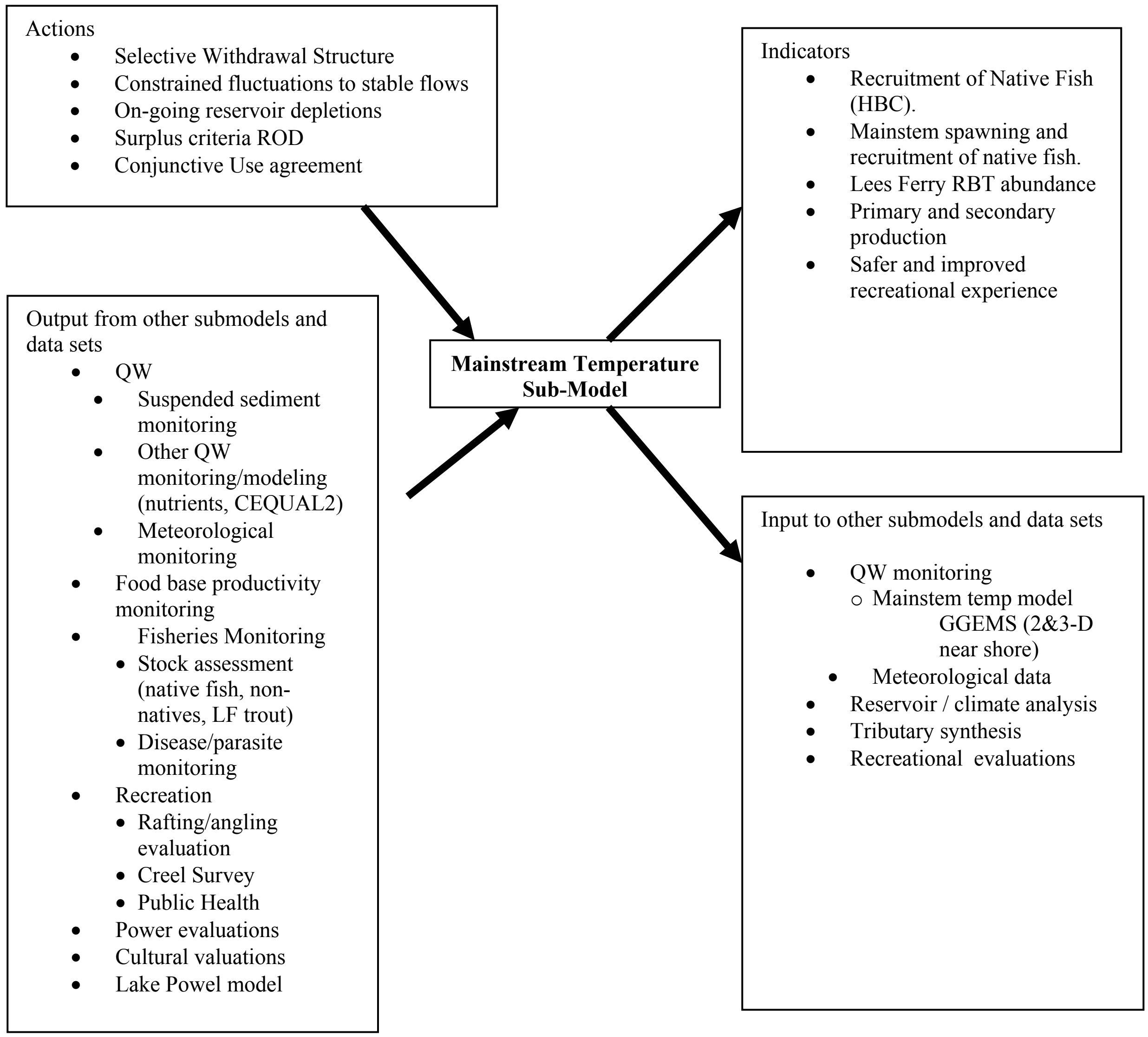


Figure 4.2. Example outward looking matrix for the mainstream temperature sub-model.



B. Using information needs, knowledge assessments and ecosystem models to enhance conceptual model effectiveness in identifying knowledge gaps and science needs.

1. Matrix assessments of system information needs across physical, biological, socio-cultural resources, strategically using knowledge assessments in context of evolving stakeholders needs to satisfy desired future conditions, and model evaluations to link learning with planning of science activities. Figure 4.3 provides an overall assessment of general information gaps identified by the knowledge assessment.

2. Outcomes focus and specify overarching and refined questions that must be resolved to address knowledge gaps.

   a. Examples of comprehensive questions that integrate science and identify how resources are linked to dam operations, other forcing influences and to each other.

V. FORMULATING SCIENCE QUESTIONS TO FOCUS RESEARCH EXPERIMENTATION AND MONITORING TO RESOLVE MANAGEMENTS MOST CRITICAL INFORMATION NEEDS

A. Development of Overarching and Refined Science Questions to Respond to Gaps in Management Information Needs and Guide the Science Inquiry Process

1. The GCD-AMP process is driven by managers specifying priority goals and information needs relating to desired future conditions of resources, many of which can be addressed by GCMRC specifying explicit questions to guide research and/or monitoring programs/projects.

2. The GCD-AMP's AMWG has specified the following general goal areas with greatest priority assigned to endangered fish, aquatic, cultural, and sand resources.
   - Fish and aquatic
   - Cultural resources
   - Sediment, with emphasis on sand
   - T&E species
   - Vegetation
   - Water
   - Power
   - Recreation
   - Adaptive process and science

3. Within each goal AMWG has specified several information needs that are expressed as Research Information Needs (RINS), Sequenced Information

Needs (SINs), or Core Monitoring Information Needs (CMINS). Generally, it is expected that CMINS would be satisfied through a monitoring program, and likewise for RINS through a research program.

4. Formal knowledge assessment processes by GCMRC (Figure 5.1) and CMIN and RIN assessments and Science Planning by GCD AMP/GCMRC in FY 2006 identified gaps in the CMINS and RINS that will be satisfied by GCMRC developed overarching and refined science questions.

5. An example of the linkage of goals and information needs to science questions and research and monitoring projects is displayed in the following hierarchical linkage of science to the goal of aquatic food base.

   AMWG Goal: Protect or improve the aquatic food base so that it will support viable populations of desired species at higher trophic levels.
   AMWG Information Need: Identify the contribution of primary and secondary productivity to the aquatic food web, and identify how operations affect productivity and food web dynamics.

   GCMRC overarching science question. What are the primary food base components and their relative contributions to the aquatic food web?

   GCMRC refined research question.
   - What are the important pathways, and the rate of flux among them that link lower trophic levels with fish?
   - How is invertebrate flux affected by water quality and dam operation?
   - Are trends in the abundance of fish populations or indicators associated with fish, correlated with patterns of food availability and/or quality?
   - What is the most effective monitoring approach to reflect the information needs for the AMP?

   GCMRC Monitoring Project. Aquatic food web monitoring (Tied to CMINS that may be subject to revision)
   This portion of the program is under development but may include:
   - Bioenergetics modeling
   - Whole river metabolism
   - Secondary producer monitoring
   - Fish diet sampling
   - Utilization of fish abundance data from fisheries monitoring.

6. The linkage of goals, information needs, over-arching and refined science questions and monitoring approaches is developed in the conceptual ecosystem model. The resources of concern are tracked through monitoring and/or research studies. For the aquatic food base, identifying the important pathways and how the components fluctuate under operations is a key information need for Goals 2 and 4 and supports recreational goals associated with angler

satisfaction. This effort represents a research element. Once these pathways and components are better understood, monitoring of changes in attributes of the food base and fish abundance and condition can more clearly be related to operations.

Figure 4.3. Conceptual portrayal of some of the information gaps identified through GCMRC knowledge assessment.

Resource Objectives Restore Sand Habitats & Warm River to Increase Native Fish	Warmer Dam Releases From (Naturally or from A Control Device)	Changing Annual Monthly Release Pattern (Lower Seasonally Adjusted Daily Peaks)	Artificial Floods to Restore Habitats (After Sediment Inputs from Downstream Tributaries)	Increased Daily Fluctuating Flows (Following Peak Energy Demand)	Sustained Low Steady Flow (Below Average Condition)	Sustained High Steady Flow (Above Average Condition)	Physical Removal of Non-Natives, (Cold Water Species Of Fishes)	Physical Removal of Non-Natives, (Warm Water Species Of Fishes)
Increase Sand in the River	(+)	(+)	(+)	(-)	(+)	(-)	**N/A**	**N/A**
Promote Backwater Habitats	(+)	(+)	(+)	(-)	(+)	(-)	**N/A**	**N/A**
Support Native Fish Recruitment	(+)				(+)	(-)		
Limit Non-Native Fishes			(+)	**(+)**			**(+)**	
Increase Near-shore Temps.	(+)	(+)	(-)	(-)	(+)	(-)	**N/A**	**N/A**
More Stable Shorelines	**N/A**	**(+)**	**N/A**	**(-)**	**(+)**	**(+)**	**N/A**	**N/A**
Benefit to Hydropower	**(-)**	**(-)**	**(-)**	**(+)**	**(-)**	**(-)**	**N/A**	**N/A**

TABLE EXPLANATION: Example of simplified Uncertainty Matrix for Colorado River Ecosystem in Grand Canyon, USA. The table depicts levels of knowledge about the flow (dam operations) and non-flow treatments with respect to some key river resources of concern, such as hydropower, endangered, native fish and physical habitats. **Notes**: 1) (+), positive response predicted relative to management objective; (o), neutral response; (-), negative response, N/A, not applicable, 2) responses assume dam operations are constrained by fixed monthly volumes, 3) suite of operational elements are contained within column "Increased Daily Fluctuating Flow," such as hourly ramp rate, flow range, peak, minimum flow, for any given monthly volume release, relative to the operational policy implemented in 1996 for the dam. **Shading**: White – scientists can predict the direction and the magnitude of resource response relative to flow or non-flow treatment, Gray – Owing to unresolved uncertainties, scientists can predict the direction, but not the magnitude of response, Black – Uncertainties are so large that a link with dam operations is suspected, but too little is known to make a prediction for resource response direction **or** magnitude of response.

VI. RESEARCH AND MONITORING PROGRAMS TO RESOLVE MANAGEMENTS MOST CRITICAL INFORMATION NEEDS.

Organization of the new GCMRC science program is around issues, goals, information needs of managers and stakeholders. Implementation of all science project efforts are within an adaptive management process using an ecosystem science paradigm driven by fundamental science questions. Research and monitoring projects are structured to respond directly to overarching and refined questions for each goal.

The new proposed research program incorporates efforts in experimentation with flow and non-flow management alternatives, research to develop needed information for managers and research to develop new monitoring procedures.

An experimentation program will evaluate, as an example, over the 2007-2011 period, the effects of high flows, warmer water, predation control, stable flows on humpback chub lifecycles, sand bars, food web, etc.

Critical research studies will evaluate, as examples, CRE food base, humpback chub translocation within the Little Colorado River, modeling sand dynamics and loss, etc.

Research studies will also be used to, for example, design new monitoring protocols for food base, warm and coldwater control of exotic fishes and assessment of gear types and efficiencies for monitoring warm water fishes, changes in pathogens in the CRE, etc.

The monitoring program is redesigned to address the core monitoring information needs of managers and stakeholders and will emphasize native fish populations, water quality, cultural resources, etc.

Strategies will be pursued so that developed data more closely tracks changes in critical resources at levels of resolution required in the advisory process associated with the GCD-AMP.

Following, are examples of research and monitoring program efforts addressing managers' information needs through the ecosystem science format:

A. Social Resources Goal: Providing Power Generation.

1. Issues of Concern: Maintaining programmed power operations; obtaining replacement power; exceeding operating criteria.

2. AMWG Goal # 10. "Maintain power production capacity and energy generation, and increase where feasible and available, within the adaptive management competing goals."

3. There are extensive ecosystem implications of flow changes to increased or

decreased power. Flow levels, ramp up and ramp down rates, flow temporal variation etc. can impact physical, biotic and socio-cultural resources. Knowledge assessment of power generation in this system indicates that wide variations in high/low daily flows and hourly ramping rates are beneficial to power and some other resources, but potentially not beneficial to other resources. The economic trade-offs to make informed decisions are known owing to abundant data and protocols to track resource change, but these data are not well documented nor accessible to all stakeholders.

4. Overarching science question:

    a. What flow regimes best mitigate cultural, sediment and recreation resource impacts, improve fishery resources, maintain or improve riparian habitat and insure acceptable power generation?

5. Proposed science program for study of power operations:

    a. Research programs:
        - Develop simulation sub-model to produce variable power and water opportunity costs for alternative flow regimes
        - Evaluate modified ramping rates and load following flows on resources in selected periods.

    b. Monitoring Program:

        - Monitor water and power variability and associated changes in other resources.

B. Physical Resource Goal: Resource effects of downstream water temperature including implications of utilizing a Selective Withdrawal Structure (SWS).

1. Issues of Concern.
   Current natural warming of the CRE (2004-2008?) offers potential for evaluating SWS. Warm water temperature could have positive effects, but also negative effects. The net effect becomes the critical issue and therefore the risk associated with SWS implementation must be fully evaluated through use of sub-model simulations. An operational downstream water temperature sub-model is needed.

2. AMWG Goal #7. "Establish water temperature, quality, and flow dynamics to achieve the adaptive management program ecosystem goals."

3. Ecosystem implication of variable water temperatures are most paramount regarding biotic resources i.e., potential enhanced humpback chub (HBC) habitat, movement of warm water predators up river. However, social resource impacts could be significant, if for example, HBC are negatively impacted by

warm water predators, or pathogens increase and impact rainbow trout (RBT) numbers or condition. A knowledge assessment identified that changing temperature would significantly impact all biology in the CRE and influence recreational experience. Some knowledge exists regarding longitudinal main channel water temperature changes, however increased knowledge is needed about the influence of tributary, LCR, and Lake Powell elevation and regional climate influences. A multi-dimensional sub-model for downstream temperature has already been developed by BOR, but needs to be more fully evaluated, verified and incorporated into the ecosystem science program, and made accessible to other scientists and fully linked to other sub-models, such as the CE-QUAL2 model for Lake Powell.

4. Two significant overarching questions relating to this resource goal are:

    a. How do dam operations, reservoir conditions, tributaries, climate, canyon orientation/aspect, and the proposed Selective Withdrawal Structure affect water temperature along the Colorado River in Grand Canyon?

    b. How does water temperature affect other water quality parameters and other resources such as the aquatic food base, fish, biological pathogens, recreation, etc?

5. Proposed science program:

    a. Research Program
        - Evaluate current warm water impacts from low reservoir conditions on CRE biology, especially HBC life stages.
        - Collaborate with BOR engineers to refine, and improve development of a water temperature predictive model and implementation of a SWS.
        - Evaluate and verify model performance and link with other sub-models through advanced conceptual modeling efforts.
        - Synthesis of Lake Powell data for the purpose of modeling and monitoring resource change.
        - Synthesis of historic tributary data (e.g., LCR).

    b. Monitoring Program
        - Data for model calibration and verification, and tracking changing boundary conditions.
        - Anticipate QW w/nutrients in support of aquatic resources.
        - Surface water and temperature measurements at discrete points.
        - HBC and RBT (Lees Ferry reach) life stage changes.

C. Physical Resource Goal: Restoring Sand Bars and Maintaining Related Habitats.

1. Issues of Concern:

Feasibility under the Record-of-Decision of restoring and maintaining sand bars at levels needed to achieve priority ecosystem objectives.

2. AMWG Goal #8: "Maintain or attain levels of sediment storage within the main channel and along shorelines to achieve the Adaptive Management Program ecosystem goals."

3. Ecosystem implications: Restoring and maintaining physical sand bar habitats and main channel sediment storage below Glen Canyon Dam can affect other physical, biotic and socio-cultural resources. Impacts to socio-cultural and biotic resources from releasing controlled floods during seasons of sediment input (summer and fall) relative to originally proposed spring timeframe. Additional socio-cultural and biotic resource impacts from constraining releases so as to retain or bank fine sediment tributary inputs until spring timing for floods. The 2005 Knowledge Assessment identified flow regimes required to bank tributary-input sand supplies (~10,000 cfs or lower) and identified that fine-sediment enrichment is required to achieve sandbar restoration. Even under supply enrichment, sand bars can only be significantly restored by elevating flows above power plant capacity. For new sand bars to persist, the deposits need to be isolated from erosion attributed by daily fluctuations.

4. Overarching Science Question: Is there a "flow-only" operating strategy for Glen Canyon Dam releases that will attain and maintain necessary levels of useable sediment?

5. Proposed science program for determining whether or not a flow-only strategy for maintaining sediment will be possible.

   a. Research Program
      - Potential replication of the 2004, high-flow sediment test, but perhaps in alternate season of winter/spring, following some monitored period of MLFF operations to redistribute new sand supplies more uniformly throughout reach of interest.
      - Flow and sediment-transport model development and refinement.

   b. Monitoring Program
      - Develop event monitoring in support of experimental research and modeling associated with both tributary sand production (Paria and Little Colorado Rivers and lesser tributaries) and mainstem suspended flux.
      - Focus monitoring around required parameters associated with boundary conditions required as input by sediment sub-models.
      - Sand bar and eddy storage data collected around controlled flood events that are required to verify the sediment sub-models.

- Stage measurements at key locations that are needed to verify flow routing sub-models.

D. Biological Resource Goal. Protection of CRE Food Base

1. Issue of Concern: Contribution of primary and secondary productivity to the aquatic food web and how dam operations affect productivity and food web dynamics.

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

3. Ecosystem implications of significant changes in aquatic food base can affect higher tropic levels such as RBT and HBC. A knowledge assessment revealed that the flux of invertebrates is expected to increase with temperature but the directional response in Grand Canyon is unknown. Higher temperatures and increase food production normally lead to increase invertebrate production and drifting rates. In Grand Canyon, it is unknown whether invertebrate production and drift rates will increase with temperature.

4. Overarching science questions exist in at least three areas as follows:

   a. What are the important pathways, and the rate of flux along them, that link lower trophic levels with fish?

   b. How is invertebrate flux affected by water quality and dam operations?

   c. Are trends in the abundance of fish populations or indicators associated with fish, correlated with patterns in food availability and/or quality?

5. Proposed science program for the aquatic food base:

   a. Research program
      - Whole river metabolism
      - Stable isotope/diet analysis
      - Carbon/energy transfer from basal level through invertebrates (secondary production)
      - Bioenergetics modeling

   b. Monitoring program – TBD but may include a combination of
      - Bioenergetics modeling input data
      - Whole river metabolism
      - Secondary producer monitoring
      - Fish diet
      - Fish abundance data from fisheries program

E. Biological Resources Goal: Maintain Lees Ferry Rainbow Trout Fishery
[photo of trout fisherman]

1. Issues of Concern: Potential impacts of Lees Ferry rainbow trout program on downstream native fishes. Inability to sustain quality RBT in a naturally reproducing fishery.

2. AMWG Goal #4: "Maintain a naturally reproducing population of rainbow trout above the Paria River, to the extent practical and consistent with the maintenance of viable populations of native fish."

3. Ecosystem implications of maintaining a naturally reproducing population of rainbow trout above the Paria River. The goal of upstream population abundance (100,000 adults) may cause downstream migration and increased downstream competition and predation on native fishes. Recreational fishing interactions could increase pathogen prominence or effect food base and/or native fish. Knowledge assessment recognized that the link between Lees Ferry and downstream RBT populations needs to be clarified.

4. Overarching Science Questions: What is the relationship between GCD flow regimes, and annual volumes, and population dynamics of rainbow trout in the Lees Ferry reach and downstream? What could be the water quality effects on RBT/Brown trout in Lees Ferry?

5. Proposed science program for Lees Ferry rainbow trout:

   a. Research program
      - Research to evaluate Lees Ferry migration downstream.
      - A research study to evaluate increased temperature effects on RBT

   b. Monitoring Program
      - Monitor changes in trout condition under differing temperature regimes
      - Stock assessment for Lees Ferry linked with downstream RBT monitoring
      - Monitoring of brown trout occurrence in L.F

F. Biological Ecosystem Resource Goal. Maintain or Enhance Native Fish Populations [photos of native fishes here]

1. Issues of concern. The two main factors likely responsible for decline of native Colorado River fishes are physical-habitat modification and interaction with non-native species. However, there are fundamental uncertainties regarding how these factors, and perhaps others, influence native fishes.

2. AMWG Goal #2: "Maintain or attain viable populations of existing native fish."

3. Ecosystem implications relating to maintaining native fish components are broad due to inter- and intraspecific interactions of fishes, trophic level linkages that involve water quality, food availability and quality, and the interactions each resource that affects native fish recruitment has with flow and temperature. The looking outward matrix identifies extensive effectors to HBC and illustrates the complex interactions that HBC have with other resources as flows change.

4. Overarching science questions. Two overarching questions must be resolved regarding HBC.

    a. What are the limiting life stages controlling population dynamics of the HBC?

    b. What are the dominant factors controlling recruitment dynamics of HBC?

5. Proposed science program for the native fish program involves extensive research and monitoring:

    a. Research program:

        - Improving monitoring technologies (gear efficiency and detection) and data analysis – field/lab based.
        - Assessment of mortality factors (habitat, predation, competition) for life history parameters – lab and controlled field experiment.
        - Evaluate increased temperature and Asian tapeworm infestation in HBC – monitoring protocol development - field experiment.
        - Exotic control efficacy – field experimentation.
        - Sampling protocol/approach for estimating YOY survivorship.
        - Relative importance of temperature, fluctuations food on survival and growth of YOY native fish. – modeling and controlled field experiment.
        - Define successful strategies of YOY and juveniles that recruit to the adult population.

    b. Monitoring program:

        - Stock assessment of LCR HBC
        - Stock assessment of non-natives

G. **Biological Ecosystem Resource Goal. Maintain or improve riparian and spring communities including endangered species** [photo of Vaseys Paradise and kanab ambersnail here]

1. Issues of Concern. Riparian plant communities are linked to both aquatic and terrestrial resources and interacts with cultural resources associated with recreation and possibly archaeological sites. Understanding how riparian vegetation responds to flows and affects other resources of concern forms a basis for managing critical resources like native fish, archaeological properties.

2. AMWG Goals #5 & 6: "Maintain or attain viable populations of kanab ambersnail. Protect or improve the biotic riparian and spring communities including threatened and endangered species and their critical habitat."

3. Ecosystem implications of maintaining or improving riparian communities relate to aquatic and terrestrial food webs associated with native and sport fishes and riparian breeding birds including southwestern willow flycatcher. The looking outward matrix identifies flow and sediment inputs as primary effectors for riparian vegetation, but there are multiple sub-models to which the riparian community information is a contributor. The knowledge assessment recognized that there was some certainty about the relationship of marsh community development and flows, but that this uncertainty decreased as one progresses upslope. The interactions between wildlife and riparian habitat are less developed.

4. Overarching science questions are as follows:

    a. How do processes occurring at a variety of spatial scales (i.e., population level to community to landscape scales) interface to influence riparian habitat?

    b. What is the nature and timing of terrestrial—aquatic linkages, and what is their influence on the recipient habitat?

    c. How do terrestrial habitat and cultural resources interact?

5. Proposed science program for the native fish program involves extensive research and monitoring:

    a. Research program:

        - Vegetation synthesis
        - Quantify rates of change and assess sources of change
        - Estimate above ground productivity and determine contribution to energy/carbon cycles – vegetation map – field sampling - modeling
        - Quantify vegetation encroachment in tandem with camp site assessments/inventory
        - Remote survey of Vaseys Paradise
        - Population modeling of KAS

b. Monitoring program:

- Annual system-wide measure of change related to annual operations.
- Five – year overflight vegetation map to quantify community change.
- Secondary production monitoring.
- Riparian bird surveys/inventory – frequency to be determined.

H. Sociocultural Ecosystem Resource Goal. Maintain high quality recreation experience in the CRE. [photo of boaters here]

1. Issues of Concern. Flows are known to be important influences of recreational experience, but the relative importance of flows compared with other experiential attributes is uncertain. Evaluation of how flows affect recreation experience will require a trade-off analysis that considers not only the multiple and sometimes contradictory effects of flows on recreational experience, but also the effects of non-flow attributes.

2. AMWG Goal #9: "Maintain or improve the quality of recreation experiences for users of the CRE, within the framework of the adaptive management program ecosystem goals."

3. Ecosystem implications of maintaining recreation quality are not fully understood, but recreational activities can potentially affect rates of sediment erosion, terrestrial and aquatic ecosystems functions. Visitor use also impacts cultural resource integrity and wilderness qualities. The looking-outward matrix identifies flow as a primary effector of key recreational experience attributes. Faster flows result in more time at sites and more impact. Knowledge assessment identified the need to understand the importance of flows relative to other factors that may affect recreational experience. Subsequent knowledge gaps involved how the variables of flow interacted with other aspects of recreation along the river corridor.

4. Overarching science questions are as follows:

   a. What are the principle drivers of recreational experience quality in the CRE, and how important are flows relative to the other drivers?

   b. How do dam-controlled flows and other management actions affect recreational experiences?

5. Proposed science program for study of recreation-related issues:

   a. Research programs:

- Conduct study to establish importance of flow parameters relative to other experiential attributes in determining quality of recreational experience in the CRE.
- Inventory current campsites; evaluate change in campsite. size/distribution/qualities through time (1976-2006) using Weeden 1976 inventory as baseline.
- Apply NAU visitor encounter model to predict crowding/congestion under varying proposed flow regimes.
- Quantify recreational impacts from an ecosystem perspective (e.g., contributions to food base, human-induced sediment loss at beaches, vegetation impacts) focused on debris-fan complexes.
- Define indicators of recreational experience, including human health and safety under varying flow regimes for future monitoring.
- Conduct trade-off analysis of key experiential attributes under varying flow regimes.

b. Monitoring Program:

- Monitor indicators of high quality visitor experiences (e.g., campable area, campsite competition/crowding).
- Monitor visitor impacts to ecosystem processes.
- Monitor human health and safety-related parameters under varying flow regimes.

I. Socio-cultural Ecosystem Resource Goal. Insure the preservation cultural resources.

1. Issues of Concern: 1)NPS management policy and standards requires the NPS to preserve arch sites "in site" which may constrain management options; 2) resolving legal requirements and public values; 3) developing/evaluating appropriate mitigation strategies to offset resource loss; 4) resolving MNPS, BOR, and GCMRC appropriate roles in science and management.

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

3. Ecosystem implications of protecting and preserving cultural resources are not fully understood, but the ongoing loss of Holocene deposits threatens our ability to reconstruct/understand past ecosystem processes and interpret cultural resources in their prehistoric and historic contexts. Flows also affect culturally-valued native plants. Proposed treatment activities can potentially affect recreation and tribally-valued traditions, as well as effect ecosystem processes. The looking outward matrix identifies flow regimes as one of several key factors affecting cultural resource conditions in the CRE. A knowledge assessment workshop identified the need for a well-conceived geomorphic model to assess the relationship between sediment transport and arch site

erosion. The workshop also pointed out the need for research to inventory/evaluate and resolve effects to TCPs.

4. Overarching science questions are as follows:

   a. How do flows, climate, and human use interact to impact historic properties in the CRE, and what are appropriate roles for GCMRC, BOR, and NPS in science and management?

   b. How do flows positively or negatively impact the culturally-valued flora and fauna and recreation values in the CRE?

   c. What kinds of important historical/legacy information about the CRE ecosystem and past human use of the CRE are embedded within the higher elevation Holocene deposits, where they are, and how can they be conserved?

5. Proposed science program for study of cultural resources:

   a. Research Programs:
      - Develop geomorphic model to predict erosion rates at arch sites under different flow regimes, climate, and geomorphic parameters.
      - Map and evaluate ecological/cultural information embedded within CRE Holocene deposits.
      - Identify and evaluate TCPs and the flow-related processes that may be affecting them.

   b. Monitoring Programs:
      - Monitor/quantify erosion of Holocene terraces and physical changes affecting integrity of archaeological sites and TCPs.
      - Monitor changes to specific plants/vegetation communities valued by tribes as resources of traditional concern.
      - Monitor effectiveness of proposed cultural resource treatments.

J. Data Management Goal: Ensure Adequacy of Existing and Future Data

1. Issue of concern: Adequacy, accessibility and relevance of existing data (data needed for modeling ecosystem interactions as well as assessing status and trends of key resources) needs to be assessed periodically to ensure that the AMP has the data it needs to fulfill its stated goals/objectives and maintain scientific credibility.

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

3. Ecosystem implications are indirect, but this issue is important for future

monitoring and modeling of ecosystem functions.

4. Overarching Question: What is the status of existing GCMRC/AMP data related to key resources and ecosystem processes with respect to the following: 1)accuracy of existing data, 2) adequacy/precision necessary for modeling and status/trends assessments, and 3) current accessibility/utility of existing databases for analyses and future model development.

5. Proposed science program: Evaluate defined data needs relative to existing databases.

VII. A GOAL TO INTEGRATE ALL GCD AMP SCIENCE FOR IMPROVED KNOWLEDGE AND EFFECTIVE DECISIONS

A. Extensive research, monitoring and management actions are now occurring in the CRE by various management and science groups. Although most are within the GCD AMP/GCMRC programs, managed with GCD AMP protocols, some are not.

B. A Proposed SPG Aproach regarding "all non GCD AMP directed science" is to:

1. Request TWG fully document all agency and other science programs in the CRE by FY 2006/2007.

2. Evaluate potential implications of these activities to GCD AMP goals and objectives by 2007.

3. Recommend to AMWG in FY 2007 approaches for GCD AMP to benefit from these programs and/or resolve any potential conflicts to GCD AMP goals.

VIII. IDENTIFICATION AND DEVELOPMENT OF RESOURCE NEEDS FOR SUPPORTING SCIENCE PROCESS

A. Defining GCMRC generalized 2-year and 5-year budgets

1. The GCMRC will organize administratively within its own staff and in collaborative partnerships with other groups to improve its science capability to resolve GCD AMP resource issues.

a. The Center's policy, development and science leadership effectiveness in this planning period is predicated on its ability to design and implement, with diverse cooperators and leading cooperative and contract scientists, several new resource development efforts and critical systems-based biology, sediment and cultural science efforts. This will include aggressive leadership from the GCMRC Chief in new collaborative partnerships and aggressive science leadership for increased understanding of HBC population enhancement, opportunities and procedures to understand and improve CRE aquatic food base capabilities and non-native fish predation and pathogen control mechanisms. This may require positions in systems and fish ecology at the Center and development of both cooperative and contractual programs external to GCMRC for resource support and to gain expertise in modeling, food base and native and non-native fish ecology. Some cooperative science programs are in place such as RBT programs and non-native fish depredation programs. Others such as riparian vegetation contribution to drift, systems understanding of aquatic food base and predation and pathogen programs must be developed. A sediment program effort to understand fine sediment loss to the system will be pursued in both cooperative and contractual modeling programs, and new approaches to cultural resources monitoring, research and preservation will involve both cooperative and contract programs.

b. The FY 2007/2008 budget will reflect the beginning efforts in this planning period to resolve key AMWG concerns. Structured budget planning will follow the AMWG developed protocol. New collaborative partnerships will be forged by the GCMRC Chief to assure success of these programs. The proposed revisions in the biology budget is to rapidly increase aquatic food base knowledge, especially as it relates to HBC needs, including vegetation contributions to drift; critical HBC life cycle constraints; fine sediment maintenance in the mainstem; and new approaches for cultural resources protection. It is anticipated that the additional funds will be needed in these efforts in FY 2008 can be obtained through AMWG leadership.

In FY 2007, the GCMRC may need to propose opportunities for collaborative partnerships to expand external resource capability to the Center to support expanded AMWG information needs.

B. Specifying desired collaborative programs and partnerships.

The GCMRC has had to respond to many new science and administrative issues in the past 5 years; i.e., non-native fish removal, sandbar building, reductions in budget, etc. Looking forward over the next five year planning period it will be necessary to do improved budget planning with the AMWG. Support from AMWG is necessary in the area of priority setting on programs and assisting GCMRC with budget support and new collaborative programs. To respond to the expanding science needs in the CRE, GCMRC and AMWG must build additional program capability in several areas.

1. AMWG should implement a 3-5 year cycle of revisiting its priority setting exercise for AMWG goals and information needs, to assist GCMRC in program reductions and program realignment under constrained budgets.

2. AMWG should develop greater support from the Secretary/Congress to prevent budget cuts and expand budgets when AMWG feels programs should be expanded.

3. GCMRC will formally program an in depth knowledge assessment and significant program revisions at 5 year intervals to align future science activities with AMWG priority goals.

4. GCMRC, with AMWG assistance, will program expanded collaborative partnerships to increase resource capability in three areas.

   a. Develop formal cooperative partnerships with GCD AMP agencies on associated GCD AMP programs to reduce GCD AMP program cost or effort; i.e., NPS, BOR, SWSC, USF&W, etc.

   b. AMWG should develop formal collaborative partnerships with federal and state agencies not currently involved in GCD AMP, but interested in GCD AMP programs; i.e., other federal and state agencies.

   c. GCMRC should develop formal collaborative partnerships with other organizations and foundations with interest in GCD AMP programs, i.e., NRCS, NSF, museums, and foundations. Collaborative efforts will be extended to organizations interested in formal information technology partnerships with GCMRC, a program that must remain continually at the cutting edge.

C. GCMRC organizational strategy for meeting science needs through internal and external activities.

1. GCMRC has only recently (2005) replaced two key leadership positions, and still lacks significant needed help in the area of systems ecology and

systems modeling. With the placement of a new Chief and Biology Program Managers, programs staffing will be evaluated for needed revisions.