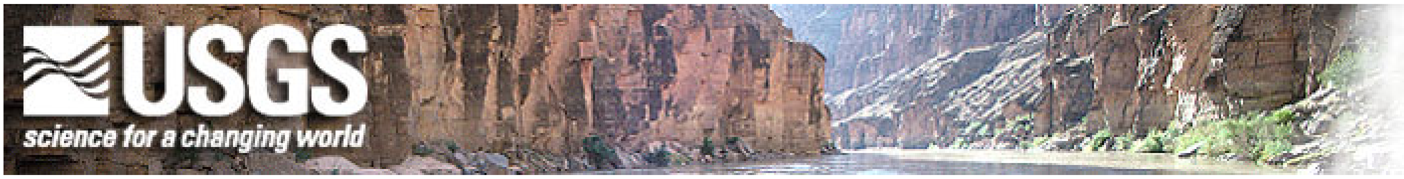

Grand Canyon Monitoring and Research Center Monitoring & Research Plan to Support the Glen Canyon Dam Adaptive Management Program: 2007-2011

Developed in cooperation with the Glen Canyon Dam Adaptive Management Program

Draft version: November 21, 2005


Southwest Biological Science Center
2255 Gemini Drive, Flagstaff AZ 86001

GCMRC INTEGRATED MONITORING AND RESEARCH PLAN
FY 2007-2011
IN COOPERATION WITH GCD AMP

CHAPTER 1. 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, desired 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.

CHAPTER 2: THE PURPOSE AND DIRECTION OF GCMRC RESEARCH AND MONITORING PROGRAMS

A. **GCMRC's Research and Monitoring Purpose: To provide credible, objective research and monitoring information to the GCD-AMP**
   1. Critical needs for increased knowledge exists in experimentation to determine the most appropriate flows, and other management actions such as selective withdrawal to maintain or improve CRE Resource; in research studies and modeling to establish better understanding of resource integration and linkages; and in studies to develop improved monitoring protocols or new monitoring procedures.
   2. The GCD AMP (including the GCMRC) are established to evaluate and recommend differing GCD operations that maintain and/or improve the resources for which Grand Canyon National Park was established to protect. This is accomplished through managed actions for protection of

these resources. Critical to taking these managed actions and understanding their impacts are ongoing research and monitoring programs.

3. The GCD future operations were fully evaluated in the EIS (DOI, 1995), and new operating procedures specified in the established ROD (DOI, 1996). As presented in the GCD-AMP strategic plan, the ROD specifies that:
   a. An adaptive management program be developed to implement the ROD and requirements of the GCPA.
   b. A science center is established to develop the required research and monitoring to best inform management decision processes in development of new ecosystem science understanding of the resources of the CRE.
4. The GCMRC develops science approaches (research and monitoring) for prioritized goals of the AMWG (GCD-AMP). Primary shifts in emphasis occur over decadal periods. Current emphasis exists with endangered fish (HBC), sand and campable beaches, cultural resources and water quality. Within general goals, i.e., endangered fish, such as HBC, several major emphasis areas may be identified for 3-5 year program periods. For example, the issue of low HBC recruitment has resulted in intense multi-year research and modeling programs to determine food base, water quality and predation impacts.
5. The overarching mission of the GCPA and GCD-AMP is to maintain or improve the condition of critical CRE resources such as native fishes, cultural resources, sand beaches, etc.

B. Conducting Structured Science for the GCD AMP

The ROD is specific in identifying science approaches to be pursued in the GCD-AMP, especially as relates to specification of goals and information needs for science; application of an adaptive management program approach; pursuing an integrated ecosystem science paradigm; and directing all science activity at improving CRE resource knowledge:

1. Adaptive management is a critical tool for managers who work with natural and cultural resources. Introduced in the 1970s by Holling (1975, 1978), it is now applied across all agencies of USDOI. Its application requires adherence to three principles.
   a. That resource management can be advanced rapidly and effectively through close working relationship of managers and scientists.
   b. That scientists respond to information needs of managers rapidly with contributions of applied experiments, research and monitoring.
   c. That managers apply new knowledge quickly as available and evaluate and monitor with science needed corrections in management actions.

2. The adaptive management process implemented in the GCD-AMP requires managers to continually inform science regarding several factors. These factors include: changes in information needs, and priorities; changes in desired future resource conditions, and level of resolution needed in data/information. A process will be developed to specify desired future conditions for CRE resources.
3. The GCMRC must provide a continual stream of integrated information to managers from research and monitoring programs. The provided science must address manager needs and issues related to the resources from an ecosystem perspective, providing both an understanding of key linkages in the system, but also the interacting requirements of processes and resources in the total system.

C. Integrated Research and Monitoring Approaches to Respond to Management Issues and Resources of Concern

1. Research and monitoring activities are the primary science drivers for GCMRC. The research program incorporates three primary thrusts; experimentation, research to improve science and management understanding, and studies to develop new monitoring protocols or improve current methods. The scope of the research program is extensive, constantly developing new science knowledge in the above three research programs, and for nine major resources, i.e., native fish, cultural, water quality, etc.
2. Monitoring includes data collection across all resources of concern for differing resource parameters and with differing time and space dependencies, and levels of resolution. Most monitoring projects are considered core to the overall science program, and will be given priority in the overall science planning and budgeting process. However, even these science efforts may be revisited in the budget planning process.
3. Goals and information needs are contributed through resource managers and stakeholders. They are also prioritized to assist science and management planning. Managers will define desired future resource conditions, key project parameters, data resolution required, etc.
4. Resources of concern are identified primarily through a merging of the goal prioritization process and the science knowledge assessment process. Over the last decade the primary resources of concern have been somewhat consistent. Native fish, cultural resources, sediment and beaches, and aquatic food and water quality, have continued as key resources to most managers and stakeholders. Following is a listing of goals developed by managers:
   - Fish and Aquatic: Native fish especially humpback chub; non-native rainbow trout in the Lees Ferry reach; and aquatic food base.
   - Cultural Resources: Register eligible historic properties, tribal concerns.
   - Sediment: substrate, beaches, sediment storage

- Threatened and endangered species: Humpback chub, Kanab ambersnail, Southwest willow flycatcher.
- Vegetation: terrestrial wildlife, exotic and invasive species.
- Water: hydrology, springs, riparian habitat, water temperature, water quality, flow dynamics, TCD.
- Hydropower: power capacity, energy generation.
- Recreation: quality of recreation experience, recreational boating, fishing, socioeconomic benefits.
- Adaptive management process, ecosystem management, integrated research.

D. A Historical Chronology of CRE Research and Monitoring Programs; 1950-2006

Observation and study of the CRE was initiated by Powell as part of his general physical (1878), biotic, and ethnic resource assessments of the southwest. This effort has been extended by intermittent studies up to 1950 and has several primary areas as follows.

1. <u>Phase 0 - 1950-1982:</u> During this period several organized investigations took place. None were continuous over the period, and were initiated for differing reasons. They included BOR, Dartmouth, NPS and AGFD, as well as others.
2. <u>Phase I - 1982-1988</u>: "GCES Phase I", was initial BOR science program to determine whether or not dam operations were affecting downstream resources. Challenge: Determine whether or not dam operations were influencing downstream resources with respect to peaking power flows. Establish methods for science programming in CRE, establish baselines.
3. <u>Phase II - 1989-1995:</u> "GCES Phase II" was advanced program to establish active science studies tied to GCD releases (1990) & implementation of interim flows (1991); morphed into the EIS. Passage of GCDA (1992) and GCD EIS (DOI, 1995). Challenge: In cooperation with senior ecologist, establish status of knowledge on critical resources and define best management practices, improve baseline information and develop a monitoring program that promoted integrated science. Completion of the EIS become the primary focus of this era.
4. <u>Phase III - 1996-2000</u>: "Transition Monitoring" era during which time GCMRC/AMWG programs of adaptive management and ecosystem science were formerly established. Evaluate designed management actions (flows) on key resources using adaptive management. Challenges: Development of a conceptual ecosystem model and determine protocols for use of effective adaptive management, developing ecosystem science procedures, assuring quality science.
5. <u>Phase IV - 2001-2006:</u> 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. Based on improved science knowledge of resource impacts of management actions,

revised management policies are incorporated as experiments, monitoring and management actions for 2007-2011. Challenges: Continued support of research & development of monitoring protocols for major resources tied to GCD AMP Goals, while also conducting focused experimental and non-experimental research. Assuring science leadership and productivity, improving ecosystem science implementation, improving adaptive management process, focus limited resources in key resource needs. FY 2006 is milestone year for assessing new level of knowledge acquired through experimental approaches and basic research. This information is incorporated into strategic science planning that charts the activities of the Center for the next 5-10 years.

6. Phase V - 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. Significant advances in science and management knowledge is necessary to develop improved management actions for stabilizing HBC population and long term sand depletion in the CRE. The next phase for ecosystem-scale conceptual modeling is proposed as a means of advancing synthesis of knowledge in a more integrated setting.

E. Research and Monitoring Strategies that 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 upgrade the Colorado River Socio-Ecosystem Model. Possible additions are:

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

   i. Cultural resource change and protection strategies
   j. Financial impact simulations coupled to operation flow sub-models

2. Explicit science project design of system data components that specifically address the overarching science questions and promote integration and linkage to other system components. (examples: recent solicitations for the food web research).
   a. Explicit design of science projects that specifies linkages across projects and integration of programs to a landscape level. Promote integration at level of solicitation and proposal development, while also maintaining focus on conceptual modeling paradigm and previous accomplishments (1998-2001).
   b. Incorporation of "looking outward" ecosystem matrix links (Holling, 1978) to fully characterize effectors and impacts of processes relating various resources and processes. Tie management actions and desired outcomes directly to conceptual modeling and strategic science activities in Research Center.

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. Focus on synthesis and integration of new and historic data.
   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 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. CRE systems model for adaptive management and decision processes designed and linked to the more objective ecosystem science process.

F. 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 (milestone) stakeholders needs, and model evaluations to link learning with planning of science activities.

2. Using Science Questions to Guide the Research and Monitoring Process
    a. The research and monitoring programs will be structured around overarching science questions and other questions that refine the inquiry.
    b. These questions capture the ongoing priority goals and information needs of managers and stakeholders.

CHAPTER 3. DESIGNING A RESEARCH PROGRAM TO RESOLVE MANAGEMENT ISSUES AND ECOSYSTEM SCIENCE QUESTIONS

The new GCMRC science program is organized around issues, goals, and information needs of managers and stakeholders. Implementation of science efforts are within an adaptive management process, and will use an ecosystem science paradigm driven by fundamental science questions. Experimental designs used, and research and monitoring projects implemented are structured to respond directly to overarching and refined questions for each goal.

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, 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 either Research Information Needs (RINS) 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 and CMIN and RIN assessments and Science Planning by GCD AMP/GCMRC in FY 2006 identified knowledge gaps in the CMINS and RINS that are satisfied by GCMRC developed overarching and refined science questions. An overall assessment of these knowledge gaps is provided in Figure 3.1.

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.

Figure 3.1. Conceptual portrayal of general 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.

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.

B. Research Program Elements

The research program is divided into three research categories:

1. Experimental program
2. Required research to ensure management and science understanding of resources and resource interaction, including advanced conceptual modeling
3. Required research to develop and/or improve monitoring protocols, procedures, effectiveness

C. Ecosystem context of Research Program Over Planning Period

1. Explicit and implicit research and monitoring outcomes needed and associated requirements on research.
2. The dependence, linkage and integration of science (research, monitoring) and contribution of research
3. Projected management actions and associated research needs.

D. Relating Status of Knowledge to Research Information Needs, Uncertainty, Knowledge Gaps and Research Questions

1. Periodic assessment and evaluation of knowledge is a requisite for identifying and focusing monitoring and research directions that address information needs of managers. Assessments are applicable to both monitoring and research approaches and included Protocol Evaluation Panels, Knowledge Assessment Workshops, and data synthesis reports. The interval between reviews is approximately 5 years, and should coincide with strategic planning and experimentation.

2. Knowledge gaps exist among many resources in the CRE with some being fundamental to our understanding of how to manage the resource (e.g., recruitment bottlenecks associated with life stages of humpback chub). System-wide treatment blocks, mini-experiments and off-site lab

experiments can be employed to resolve cause and affect relationships. Examples include

- Mechanical removal – removal efficacy and predation/competition question.
- High Test Flow following sediment input triggers – possibility of managing and conserving sediment resources.
- Translocation of HBC – evaluating possibility of expanding HBC range.

3. Assessment and review is also pertinent to monitoring programs. Review of the adequacy of monitoring information may result in reconsidering how and what data are collected for a resource. Research to improve data collection methods or to better define what data should be collected is another aspect of the research program. Project in that past that were research for the purpose of developing monitoring include:
   - Sediment transport and mass balance project
   - Lees Ferry trout monitoring
   - Terrestrial ecosystem monitoring
   - Cultural resource monitoring

E. Designing an Appropriate Experimental Program to Address Resource Effects of Management Actions and Treatments

1. Selecting appropriate experimental program design and expected analysis capabilities – embracing the concept of a "***Hybrid***" design. There is a critical need to clearly identify management goals and objectives with regard to tangible resource outcomes. Are the desired outcomes of the GCD-AMP both Measurable & Attainable? Example: Mechanical Removal - methods developed during 2003-2005 research are known to reduce the abundance and distribution of exotic, coldwater species within treatment reaches in Marble & Grand Canyons and the reduced abundance can apparently be maintained through continued implementation. Is this currently a stated Management Objective?

   There is also a need to define the level of science support required from GCMRC for environmental compliance, as well as the protocols for how the ROD is amended. For experimental treatments to become management actions, decision makers would presumably need to modify the Record-of-Decision, but only following fulfillment of compliance requirements.

<u>a.</u> <u>Pursuing an Appropriate Design</u> - following process of dialogue between managers and scientists that effectively identifies which actions are understood well enough to be treated as long-term management actions if appropriate (in pursuit of the so called ***"hybrid design"*** experimental design), AMWG forwards recommendations to the Secretary of DOI to consider as

amendments for revision of the ROD, pending legal compliance requirements.

b. Experimental design is then pursued which will effectively evaluate uncertainties about the effects of remaining experimental policies on key resources in CRE (presumably, the other management actions which were not included in recommendations for long-term implementation as revisions within the ROD).

c. Review the strategic science questions derived from ongoing knowledge assessments that would need to be addressed to reduce uncertainties related to the proposed experimental policies tied to the GCD-AMP Strategic Plan.

d. Identify additional modeling, non-experiment research & monitoring and specific flow and non-flow elements within the agreed upon experimental design (including short-term field studies, for example, related to sand bar dynamics) that are required to answer the strategic science questions to meet management needs.

e. Compare and evaluate the experimental policies with respect to the stated management goals vs. costs and benefits.

2. Specifying management actions and treatments

The key science questions drive the experimental actions and treatments (flow and non-flow) that focus the experimental policies to be tested, for example, those related to the USFWS 1994 Biological Opinion and its Reasonable and Prudent Alternatives. On that basis, issues related to both the thermal regime and the stability of shoreline rearing habitat are relevant with respect to the following questions:

- What ultimately limits native fish populations:
  - production of young fish from tributaries
  - spawning and incubation in the mainstem
  - survival of YoY and juvenile stages in the mainstem
  - growth and maturation in the adult population as influenced by mainstem conditions?
- What is the relative importance of increased water temperature, shoreline stability, food availability, and predators on the survival of early life stages of native fish?
- How important are backwaters and vegetated shoreline habitats to the overall growth and survival of YoY and juvenile native fish?
- Do the potential benefits of improved rearing habitat outweigh negative impacts owing to increases in non-native fish abundance or disease?

Policies to be experimentally evaluated would likely include, but not be limited to: 1) construction, implementation and rigorous evaluation of a Selective Withdrawal Structure (SWS) at GCD and 2) studies on the early life history of humpback chub with respect to recruitment related to fluctuating versus stable flow operations from GCD. In addition, studies focused on removal of exotic fishes could address the role of predation and competition with natives. Finally, the role of sand bar related habitats in the near-shore environment (recruitment success of YoY native fish relative to abundance and distribution of backwater) as related to early life history success of native fishes.

3. Maximizing abilities to determine effects and minimizing confounding variables

4. Options for modifying the experimental design owing to changes in natural phenomenon (climatic forced swings in basin hydrology, tributary sediment production, etc.)

F. A Proposed FY 2007-2011 Experimental Program

1. Specifying key science questions
2. Assessment of management action(s): at present, only MLFF (w/ occasional BHBF's and HMF's) constitutes the Record-of-Decision

   Continue process of ongoing dialogue between managers and scientists regarding MLFF We know that stable flows that are "low" (less than 10,000 cfs range) are most effective at conserving sand, amplifying warming downstream and stabilizing near-shore habitats. Short-duration BHBF-type releases (2-4 days at 41,000-45,000 cfs)) can mobilize sand from the lower channel and deeper eddies and deposit this material to higher elevation shorelines relatively quickly when sand supply is enriched. The MLFF has likely improved some aspects of the recreational rafting and camping experience, as well as angling, but there no data on this (SCORE). We do know that under MLFF, campable area above the 25,000 cubic feet per second flow line has decreased, while campable area below the 25,000 flow level has increased. (Kaplinski and others, 2005).

3. Design options, strengths, and limitations
   Several design options can be considered for the experimental approach, including forward and reverse titration or a factorial design (Figure 3.2.)
   a. Natural warming; surrogate for Selective Withdrawal Structure (SWS)
   b. Mechanical removal (both cold and warm fishes)

   In fact, we have 15 years of a forward titration design already behind us with pretty solid data for both sediment and fisheries (Figure 3.3). The MLFF (and its precursor, Interim Operation) was implemented from 1991 through 2001 with no Mechanical Removal or persistent thermal warming event. Then, we continued mostly MLFF operations and implemented MR along with nature's own version of the Selective Withdrawal Structure (SWS) since 2002. Hence, after an 11-year long "block" of MLFF with cold water and unconstrained RBT recruitment, we are now heading into the 4th year of a block of MR coupled with a warm main-channel "event" conditions.

Selective Withdrawal Structure decision point needs to seek resolution in 2006, while pursuing research related to monitoring and control of warm & cold fish species in downstream reaches of interest relative to native fish monitoring and research questions, as well as management goals.

<u>MLFF Under the Range of Upper Basin Hydrologic Cycle</u> If we continue monitoring the MLFF under the paired implementation of MR and warming, we have no way of ensuring that warming will continue.

Managers might choose to enhance the probability of a HBC recruitment signal by recommending stable fall flows, but that could confound ability to discern MR & temperature from habitat stability.

4. Proposed assessments

-Ongoing evaluation and refinement of Mechanical Removal (relative to influence on HBC recruitment success),
-Ongoing evaluation of BHBF concept (under enriched conditions) with respect to sustainable, long-term flow prescription (using field studies and modeling simulations),
-Full evaluation of thermal regime relative to biological responses under SWS warmer conditions (including, development and calibration of downstream thermal simulations using monitoring data).

Figure 3.2 Pros and Cons of Block and Titration Designs

BLOCK DESIGN

PROS

- Long timeframe
- Partitions variance
- Increased learning
- Cause and effect

CONS

- Long time frame
- Emphasizes learning
- Long-term commitment

TITRATION DESIGN

PROS

- Implements management actions
- Improves some knowledge

CONS

- Decreased learning
- Cause and effect not identified (specific actions
- Confounding factors
- Not a recognized design
- Analysis methods uncertain (e.g., main effects vs. interactions)

Figure 3.3 Status of Evolved Factorial Design on Basis of Historical Perspective

Status of Evolved Design on Basis of Historical Perspective

IMPLEMENT TREATMENT — TREATMENT NOT IMPLEMENTED

Water Year, w/ HBC & RBT Recruitment Success [+ or -]	Dominant Dam Operation (with Seasonal Variants Toward "Designer Flows," but All Within ROD)	Mechanical Removal of Rainbow Trout in GC (with Progressive Optimization)	Naturally Varied Temperature (Relative to August Average at GCD, RM61) [+, 0, -]	Beach/Habitat Building Flow (Paria, LCR River Sand Inputs Relative to Historic Mean) [+, 0, -]
WY1991, **[0,0]**	EXP Flows	No Exotic Control	**[0,nd]**	[-,-](No BHBF)
WY1992, **[-,+]**	Interim only	No Exotic Control	**[-,-]**	[+,-](No BHBF)
WY1993, **[-,+]**	Interim only	No Exotic Control	**[0,-]**	[+,+](No BHBF)
WY1994, **[-,+]**	Interim only	No Exotic Control	**[-,-]**	[-,-](No BHBF)
WY1995, **[-,+]**	Interim only	No Exotic Control	**[0,0]**	[0,0](No BHBF)
WY1996, **[0,+]**	Interim+BHBF	No Exotic Control	**[0,0]**	[-,-](W/ BHBF)
WY1997, **[0,+]**	MLFF only	No Exotic Control	**[0,0]**	[+,-](No BHBF)
WY1998, **[+,+]**	MLFF+HMF	No Exotic Control	**[0,0]**	[+,-](No BHBF)
WY1999, **[+,+]**	MLFF only	No Exotic Control	**[0,0]**	[+,- (No BHBF)
WY2000, **[+,+]**	MLFF+LSSF+HMF	No Exotic Control	**[0,+]**	[-,-](No BHBF)
WY2001, **[?,+]**	MLFF only	No Exotic Control	**[0,0]**	[+,-](No BHBF)
WY2002, **[?,-]**	MLFF only	No Exotic Control	**[0,0]**	[-,-](No BHBF)
WY2003, **[?,-]**	MLFF+EXP FF	Experimental Fish Removal	**[+,+]**	[-,-](No BHBF)
WY2004, **[?,0]**	MLFF+EXP FF	Experimental Fish Removal	**[+,+]**	[-,-](No BHBF)
WY2005, **[?,?]**	MLFF+EXP FF+Fall Testing	Experimental Fish Removal	**[++,++]**	[+,+](W/ BHBF)
***WY2006, decision [?,?]**	MLFF+Fall Testing	Experimental Fish Removal	**???**	**???**(No BHBF)

Figure 3.3. A Historical Portrayal of the MLFF operation, as well as selected indicators for Rainbow Trout and Humpback Chub recruitment success (shown in terms of [+, 0, or -] data from AG&F, plus GCMRC and earlier data) shown in brackets within column #1 next to Water Year, plus historical implementation of coldwater exotic fish control (column #2), history of sand production relative to the long term mean data for the Paria and Little Colorado Rivers [+, 0, or -] and the occurrence of BHBF tests since the end of the "No Action" era. This history portrays the evolution toward a Forward Titration through time, with addition of Mechanical Removal and natural warmer releases about equivalent to what would occur with the proposed Selective Withdrawal Structure. A major decision point occurs in WY 2006 with respect to construction of a Selective Withdrawal Structure at GCD.

Figure 3.4 Potential Factorial Design with Decadal Scale Time Blocks

SWS Could Allow Factorial Design w/ Decade Scale Blocks

IMPLEMENT TREATMENT — TREATMENT NOT IMPLEMENTED

Water Year, w/ HBC & RBT Recruitment Success [+ or -]	Dominant Dam Operation (with Seasonal Variants Toward "Designer Flows," but All Within ROD)	Mechanical Removal of Rainbow Trout in GC (with Progressive Optimization)	Naturally Varied Temperature (Relative to August Average at GCD, RM61) [+, 0, -]	Beach/Habitat Building Flow (Paria, LCR River Sand Inputs Relative to Historic Mean) [+, 0, -]
WY1998, [+,+]	MLFF+HMF	No Exotic Control	[0,0]	[+,-] (No BHBF)
WY1999, [+,+]	MLFF only	No Exotic Control	[0,0]	[+,-] No BHBF)
WY2000, [+,+]	MLFF+LSSF+HMF	No Exotic Control	[0,+]	[-,-] (No BHBF)
WY2001, [?,+]	MLFF only	No Exotic Control	[0,0]	[+,-] (No BHBF)
WY2002, [?,-]	MLFF only	No Exotic Control	[0,0]	[-,-] (No BHBF)
WY2003, [?,-]	MLFF+EXP FF	Experimental Fish Removal	[+,+]	[-,-] (No BHBF)
WY2004, [?,0]	MLFF+EXP FF	Experimental Fish Removal	[+,+]	[-,-] (No BHBF)
WY2005, [?,?]	MLFF+EXP FF+Fall Testing	Experimental Fish Removal	[++,++]	[+,+] (W/ BHBF)
***WY2006, decision [?,?]**	MLFF+Fall Testing	Experimental Fish Removal	[++,++]	??? (No BHBF)
WY2007, [?,?]	MLFF only **(Ramping**	Experimental Fish Removal	**SWS Built? [++,++]**	???
WY2008, [?,?]	MLFF only **Tests for**	Experimental Fish Removal	**Warm Thermal [++,++]**	???
WY2009, [?,?]	MLFF only **Sand Bars**	Experimental Fish Removal	**Regime [++,++]**	???
WY2010, [?,?]	MLFF only **Might be**	Experimental Fish Removal	**Extended [++,++]**	???
***WY2011, decision [?,?]**	MLFF ? **Added)**	Experimental Fish Removal	**Through [++,++]**	???
WY2012, [?,?]	Amended MLFF?	Experimental Fish Removal	**Management [++,++]**	???
WY2013, [?,?]	Amended MLFF?	Perhaps Stop EXP MR?	**Action [++,++]**	???

Figure 3.4. Conceptual Phase V Experimental Design Depicting How Addition of a Selective Withdrawal Structure Might Be Used to Continue A Warm Release "block" Along with Ongoing Mechanical Removal of Warm and Coldwater Exotic Fishes Below Lees Ferry, Along With Occasional Sediment Triggered BHBF's. If a strong HBC recruitment signal is detected between 2004 and 2011, then this Forward Titration design can be evolved into a full Factorial experimental design, if, either Mechanical Removal or Thermal treatments or discontinued at the end of Phase V. Continuation of the MLFF operation is the only policy so far that has been approved as a "management action." In the event that a strong HBC recruitment signal is not detected between 2004 and 2011, a decision could be made to continue managed warming and exotic fish control, along with implementation of stable flows throughout some portion of the year for several years as a continuation of the Forward Titration.

G. FY 2007-2011 Short Term Research Studies to Address Knowledge Gaps

Research that is designed to address questions that are identified through the knowledge assessment process include single projects as well as complex programs of research that involve multiple projects within a program. An example of the latter is the aquatic food base program initiative that includes

- Stable isotope research
- Instream metabolism quantification
- Secondary production, etc.

Individual research projects addressing critical knowledge gaps include native fish translocation, population genetics of HBC, Early life history of Rainbow trout in Lees Ferry, aeolian deposition and archaeology site preservation. These projects and programs as well as others are presented in Chapter 4 discussions of research.

H. FY 2007-2011 Research Studies to Develop New Monitoring Procedures

Research to improve monitoring methods is a critical component in the adaptive management program. Providing meaningful monitoring results to managers about resources is a basis for deciding if and how operations may be improving a targeted resource. The resources that are targeted for monitoring methodology review and research are in the areas of aquatic biology and cultural resources. They include:

- Predatory fish assessments – improving detection and capture methods for warm and cold water exotic species
- Water quality – downstream and reservoir modeling to evaluate sampling frequency and parameters.
- Relationship of riparian vegetation to drift – determining the contribution and importance of riparian vegetation to trophic food webs and determining effective approaches to quantify vegetation.
- Archaeological site monitoring indicators – identification and refinement of methods and variables that will be used to assess erosion of archaeological site relative to dam operations and visitor impacts.

CHAPTER 4. LINKING MONITORING AND RESEARCH PROJECTS TO MANAGEMENT GOALS AND INFORMATION NEEDS

Various reviews of the GCFS and GCMRC science programs have been conducted in the 1980s, 1990s and 2010s by NRC, PEP panels and Science Advisors. A concern over this period has existed that more comprehensive ecosystem science approaches are not being utilized. The new proposed science planning direction of GCMRC will incorporate the ecosystem science paradigm as presented by various program constraints including budget, logistics, technology, etc.

The new proposed science 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. The monitoring program is reoriented toward core monitoring information needs.

The strong concerns of managers regarding status of selected CRE resources including HC and recreation beaches has resulted in GCMRC and the GCD-AMP pursuing a hybrid science design that attempts to obtain positive effects in selected resources while obtaining as much knowledge as possible.

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

Critical research studies will support experimentation, and will evaluate example, CRE food base, humpback chub translocation within the Little Colorado River, modeling sand dynamics and loss, etc. Extensive research studies will be focused on improving knowledge related to enhanced survival and recruitment of any back chub, including aspects of predation, food base, genetics, refugia, etc. A similar intense effort will be pursued in modeling of sand loss to the system, and contributions riparian vegetation to the system.

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

The monitoring program elements presented in this chapter are 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 research and monitoring data more closely track changes in critical resources at levels of resolution required in the advisory process associated with the GCD-AMP.

Following, are examples of research 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 framework of the adaptive management competing goals."

3. There are extensive ecosystem implications of flow changes to increase or decrease power. Flow levels, ramp up and ramp down rates, flow temporal variation etc. can effect physical, biotic and socio-cultural resources positively or negatively. 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, but potentially not beneficial to other resources. The economic trade-offs to make informed decisions are knowable owing to abundant data and protocols to track resource, 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.
   b. Monitoring Program
      Monitor water and power variability and associated changes in other resources. [Include looking outward matrix diagram here (see next section for example of this)]

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

1. Issues of Concern. Current natural warming of the CRE (2004-2007?) offers potential for evaluating some aspects of a TCD. Warm water temperature could have positive effects (e.g., HBC recruitment), but also negative effects, (e.g., higher HBC predation). The net effect becomes the critical issue and therefore the risk associated with TCD implementation must be fully evaluated through use of sub model simulations. An operational grade downstream water temperature sub-model would be valuable for other resource assessments as well and development of such a model is embraced within the context of the "looking outward" matrix approach (Figure 4.1). Model development has been initiated and can be quickly developed to the needed level with some additional work.

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 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 RBT numbers or condition. The looking outward matrix demonstrates temperature (see attached figure) to be influenced primarily by flow and power resource objectives. Knowledge assessment recently identified that changing temperature has significant impact on almost all biology in the CRE and can also influence suspended-sediment transport rates and 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 Bruce (GGEMS), but needs to be more fully evaluated, verified and incorporated into the ecosystem science program (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 temperature control device affect water temperature along the Colorado River in Grand Canyon, both in the main channel (1-dimensional) and in near-shore habitats (2 & 3-dimensional elements that tie 1-D responses to temperatures within backwaters)?

b.How does water temperature affect other water quality parameters and other resources such as the aquatic food base, fish, biological pathogens, recreation, etc? Question b. is determined via actual monitoring and research of other resources such as RBT, HBC, food base etc. However **Question *a***. can be pursued under water quality, through several other sub-questions of ***a.***, including;

- What would release temperatures and downstream near-shore temperature be like under prolonged drought conditions?
- How do backwater temperatures in the vicinity of the LCR differ under differing fluctuating versus steady flow alternative?
- What temperature would the main channel achieve at a given location during a low steady flow during a typical summer with a TCD in place?

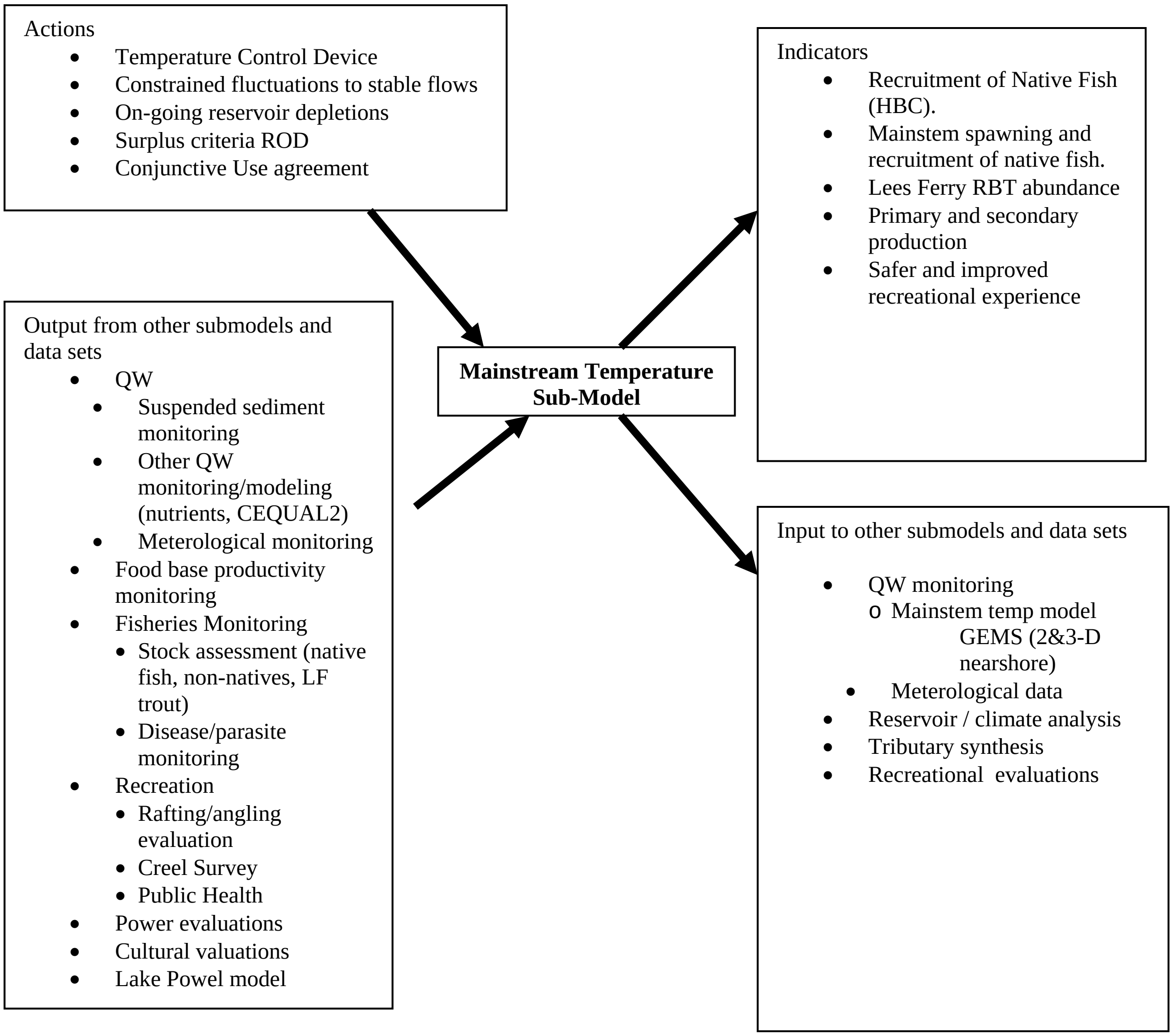

Figure 4.1. The Outward Looking Matrix for the Mainstem Temperature Sub-Model.

5. Proposed science program:

   a. Research Program

- Collaborate with BOR engineers to refine, improve development of water temperature predictive model
- Evaluate and verify model performance and link with other sub-models through advanced conceptual modeling efforts
- Synthesis of Lake Powell for the purpose of modeling and monitoring program assessment
- Synthesis of historic tributary data (e.g., LCR)

b. Monitoring Program

- Model calibration and verification, tracking changing boundary conditions (CE-QUAL2; GSTARS, UNSTEADY; GGEMS).
- Anticipate QW w/nutrients in support of aquatic resources (e.g., food base monitoring).
- Surface water and temperature measurements at discrete points (e.g., tributary inputs to Lake Powell, forebay, GCD penstocks, Lees Ferry, LCR, Grand Canyon and Diamond Creek, plus major downstream tributary inputs).

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 of 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 (DOI, 1995). Additional socio-cultural and biotic resource impacts from constraining releases (summer through fall or winter to spring) so as to retain or bank fine sediment tributary inputs until spring timing for floods. This strategy might gain increased turbidity, and influence of finer grained sediments in shoreline stored bars, but adversely influence primary productivity. 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, but the required high-stage flow depatures may only be needed for short periods. For new sand bars to persist, the deposits need to be substantially isolated from the erosional influence of daily fluctuations. The basis for on-going sediment conservation research is that the EIS paradigm has been falsified. This leads to one overarching question regarding sediment sustainability.

4. Overarching Science Question: Is there a "flow-only" (meaning, without sediment augmentation) operating strategy for Glen Canyon Dam releases that will attain and maintain necessary levels of useable sediment storage in the Colorado River ecosystem (CRE) to achieve desired CRE resource conditions and ecosystem function? Assumption: artificial floods, termed Beach/Habitat-Building Flows, are a required element of the flow-only management strategy. [Include sand mass-balance diagram here comparing EIS rating curve prediction versus measurement data]

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

   a. Research Program
      - Tied to large scale experimentation (potential replication of the 2004 sediment test, but perhaps in alternate season of spring)
      - Ongoing flow and sediment-transport model development and refinement (both for major tributaries and main channel 1-dimensional sand routing to predict fate of inputs under varied supply conditions and operations)

   b. Monitoring Program
      - Relative to concept of sustainability of sand bars and related experiments, develop event monitoring in support of experimental research and modeling associated with both tributary sand production and mainstem suspended flux.
      - Focused 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:
   Determining what is the contribution of primary and secondary productivity and critical pathways in the aquatic food web, and how operations (temperature, monthly volumes, daily range) 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. Looking outward matrix

assessments of knowledge of effectors upon and impacts to this resource in the CRE are incomplete (Figure 4.2). A knowledge assessment determined that the flux of invertebrates is expected to increase with temperature, but that the directional response in Grand Canyon is unknown. Higher temperatures and increased primary production would likely lead to increased invertebrate production and drifting rates. In Grand Canyon, relative availability of in stream production vs. terrestrial inputs is unknown. Although increased temperatures lead to increase algae production, the amount of terrestrial inputs will not increase. Thus, in Grand Canyon, basal production numbers will not increase, and it is unknown whether invertebrate production and drift rates will increase with temperature (see section B., part 4b). Dam operations (e.g., daily range, monthly volumes) also differentially affect productivity and drift.

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

    a. Basic understanding of food web linkages: What are the important pathways, and the rate of flux along them, that link lower trophic levels with fish?
    b. Relational understanding of productivity and operational affects: How is invertebrate flux affected by water quality and dam operations?
    c. Linkage between food availability (local and drifting food) and fish abundances. 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: The science program includes research to address questions in area 4a. and c. that takes a multi-part approach to identify critical pathways in the aquatic food web. The monitoring program will be developed based on research results and will be able to address 4b. through changes in operations.

    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
        - Whole river metabolism
        - Secondary producer monitoring
        - Fish diet sampling
        - Fish abundance data from fisheries program

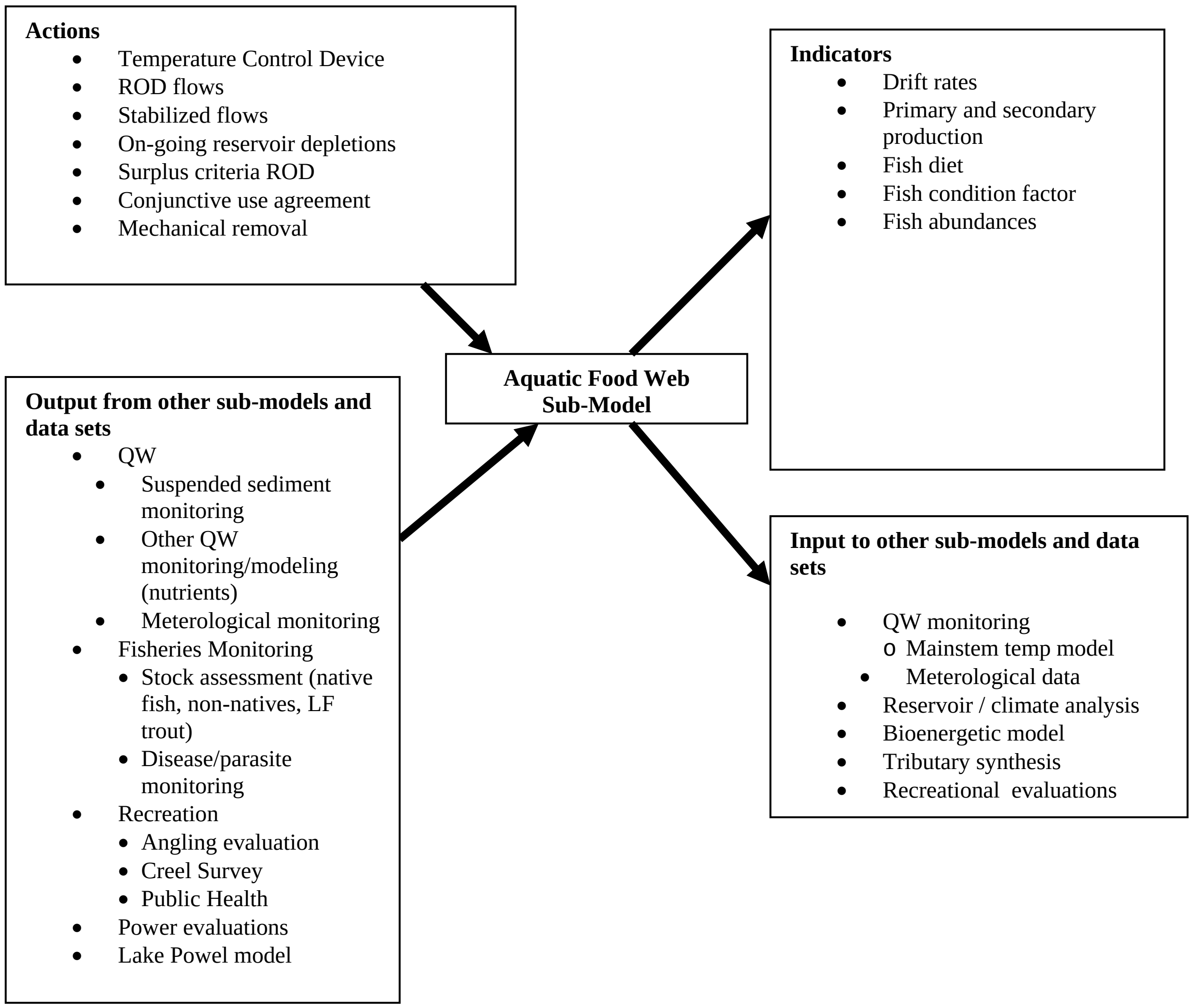

Figure 4.2 The Outward Looking Matrix for the Aquatic Food Web Sub-Model.

E. Biological Resources Goal: Maintain Lees Ferry Rainbow Trout Fishery

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 by

migrant rainbow trout. Recreational fishing interactions could increase pathogen prominence. A knowledge assessment recognized that the relationship between Lees Ferry and downstream RBT populations needs to be determined. Monthly volume changes can affect survivorship of young fish in Glen Canyon. Growth rates in YOY are affected by stability of flows and temperature.

4. Overarching Science Questions:

   a. **Operational affects on recruitment dynamics and dispersal.** What is the relationship between GCD flow regimes, and annual volumes, and population dynamics of rainbow trout in the Lees Ferry reach and downstream?
   b. **Operational affects on recruitment dynamics in Lees Ferry.** What could be the water quality effects (temperature) on RBT/Brown trout in Lees Ferry?

5. Proposed science program for study Lees Ferry rainbow trout:

   a. Research programs and strategies
      - Research plan to evaluate Lees Ferry migration downstream.
      - A research study to evaluate temperature regimes 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.
   Two factors likely responsible for the decline of native Colorado River fishes are physical-habitat modification (water quality parameters, such as thermal regime or others within main channel and tributaries, as well as shoreline habitat stability), and interaction with non-native species. However, there are fundamental uncertainties regarding how these factors, and perhaps others, influence native fishes. It has been shown that the decline of native fishes in some parts of the Colorado River basin is a result of continued recruitment failure and is suspected for humpback chub in Grand Canyon. Questions remain about how impacts at various life stages may control overall humpback chub population dynamics. It is not clear which factors (e.g., habitat modification, non-native species

interactions, or other factors) are dominant drivers of humpback chub population dynamics.

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

3. Ecosystem implications relative 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 of these resource has with flow and temperature. The looking outward matrix identifies extensive effectors on HBC and illustrates the complex interactions that HBC have with other resources as flows change. The knowledge assessment identified the uncertainty around improved growth with warm temperatures balanced against food availability as fish metabolism increased. Habitat stability relative to early life history survivorship of native fish has scant data to support enhanced growth rates, though some data exist for interactions of growth and stable habitats for YOY rainbow trout in Glen Canyon.

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

    a. **Environmental affects on recruitment dynamics.** What is the limiting life stage controlling recruitment of the HBC?
    b. **Environmental affects on recruitment dynamics.** What are the dominant factors controlling recruitment 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
        - Monitoring protocol development for disease and parasites.
        - Exotic control efficacy
        - Efficacy of developing sampling protocol/approach for estimating YOY survivorship.
        - Evaluate relative importance of temperature, fluctuations and food quality/availability on survival and growth of YOY native fish. – modeling and controlled field experiment

b. Monitoring program
- Stock assessment of LCR HBC, Flannelmouth sucker, as possible.
- Abundance and distribution of mainstem fishes.
- Stock assessment of non-natives, as possible.
- Lees Ferry Rainbow Trout monitoring.

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 (secondary production, cover), and interacts with cultural resources associated with recreation (camping sites) and indirectly with 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 and recreational components.

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, as well as other terrestrial wildlife. 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 certainty decreased as one progresses upslope. The interactions between wildlife and riparian habitat are less developed.

4. Overarching science questions are as follows:
   a. **Temporal and spatial interactions within the riparian community.** How do processes occurring at a variety of spatial scales (i.e., population level to community to landscape scales) interface to influence riparian habitat structure and composition?
   b. **Temporal and spatial interactions between ecosystem components.** What is the nature and timing of terrestrial—aquatic linkages, and what is their influence on the recipient habitat?

c. **Temporal and spatial interactions between ecosystem components.** How do terrestrial habitat and cultural resources interface?

5. Proposed science program for the riparian vegetation and springs communities involves synthetic research and monitoring:

   a. Research program
      - Vegetation synthesis
        - Quantify rates of change and assess sources of change
        - Utilizes physical science synthesis data
        - Incorporates scanning project for retrospective analysis of vegetation 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
      - Investigate the utility of remote survey of Vaseys Paradise
      - Population modeling of KAS

   b. Monitoring program
      - Annual system-wide measure of vegetation 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.

1. Issues of Concern.
   Flows are known to be important influences of recreational experience. Importance of flows relative to other physical and social attributes that define a high quality recreational experience is less certain. Flows can affect recreational experiences in multidimensional respects. Evaluation of how flows affect recreation experience requires 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 (e.g., NPS management decisions about appropriate use levels, AZGF fishing regulation, etc.). Evaluations of recreation experience are coupled with NPS management goals for river-based recreation (e.g., maintaining wilderness qualities, access, and ecosystem function) and AZGF sport fishing management goals. Existing model (Roberts and others 2002) may be useful for evaluating how different flows interact

with other variables such as numbers of trips on the water, to shape the quality of recreational experiences.

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 (food base, water quality, animal behavior, etc.). Visitor use also impacts cultural resource integrity and wilderness qualities, both of which NPS is mandated to preserve. The looking-outward matrix identifies flow as a primary affector of key recreational experience attributes (e.g., campsite size, distribution, and qualities; angling success; rafting enjoyment; crowding; human health & safety.). 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 (e.g., rafting vs. angling vs. camp site availability and flow)

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, and what is/are the optional flows for maintaining a high quality recreational experience in the CRE?

5. Proposed science program for study of recreation-related issues
   a. Research programs:
   - 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 (Roberts and others 2002) 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.

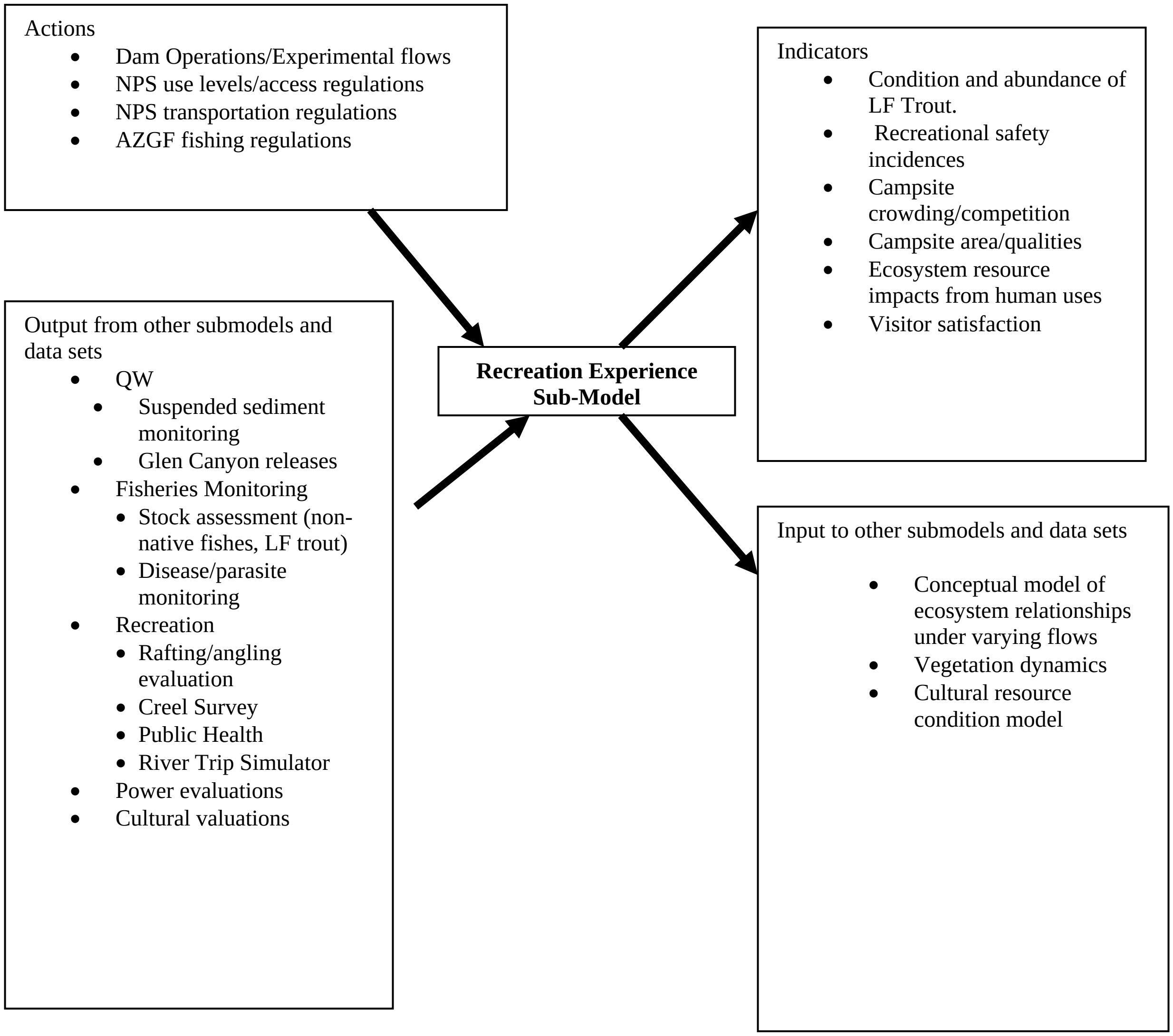

Figure 4.3. The looking outward matrix for the recreation submodel.

b. Monitoring Program

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

I. Socio-cultural Ecosystem Resource Goal: Ensure preservation of cultural resources.

1. Issues of Concern.
   1) Maintaining physical integrity of cultural resource sites; 2) balancing diverse stakeholder values in relation to cultural resources (i.e., balancing the scientific information valued by scientists and the public, the educational/interpretive qualities valued by visitors, the traditional/religious values of tribes); 3) developing/evaluating appropriate mitigation strategies to offset resource loss. NPS management preferences (e.g., desire to preserve archeological sites in situ) limit options for future science and constrains possible management directions.

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 ongoing loss of Holocene deposits results in degradation of archaeological sites and also diminishes our ability to reconstruct/understand past ecosystem processes or interpret cultural resources in their prehistoric and historic contexts. Flows also affect the culturally-valued native plants in the CRE. Proposed experimental flows and non-flow treatments for archaeological sites can potentially affect recreation and tribally-valued traditions, as well as ecosystem processes (rates of sediment erosion, vegetation cover, etc.). The looking outward matrix (Figure 4.4) identifies flow regimes as one of several key factors affecting cultural resource conditions in the CRE. Knowledge assessment workshop identified need for well-conceived geomorphic model to assess relationship between flows, sediment transport, climatic factors and archaeological site erosion and for research to inventory, evaluate, and determine effects of flows and treatment activities 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 more specifically, do flows affect (increase or decrease) rates of erosion of the higher Holocene deposits where most archaeological sites occur?

   - Subquestions (of Question a):To what extent do flows affect archaeological site stability/integrity in the CRE?
   - If dam controlled flows are contributing to (influencing rates of) archaeological site/TCP degradation, what are the optimal flows for minimizing future impacts to these historic properties?

- To what extent and in what respects can BHBFs be used to achieve systemwide mitigation of archaeological site erosion? If flows or BHBFs can not be applied to benefit cultural resources, can other sustainable treatment options be applied for preserving threatened heritage resources in the Colorado River corridor, and what are the best (most effective and least intrusive) options for in situ preservation of cultural resources?

b. How do flows positively or negatively impact the culturally-valued flora and fauna in the CRE (especially the biological communities associated with TCPs)?

c. What important historical/legacy information about the CRE ecosystem and past human use of the CRE are embedded within the higher elevation Holocene deposits and will be lost due to the ongoing erosion of these older pre-dam deposits?

5. Proposed science program for study of cultural resources:

a. Research Programs

- Develop geomorphic model to predict and quantify erosion rates at archaeological sites under varying flow regimes, taking into account effects of climate, human use, 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 and quantify rates of erosion of Holocene terraces and and track physical changes affecting integrity of archaeological sites and TCPs to build geomorphic model, verify model predictions, and track status and trends of cultural resource conditions.
- Monitor changes to specific plants/vegetation communities valued by tribes as resources of traditional concern.
- Monitor effectiveness of proposed cultural resource treatments (e.g., check dams, long-term effects of BHBFs, etc.

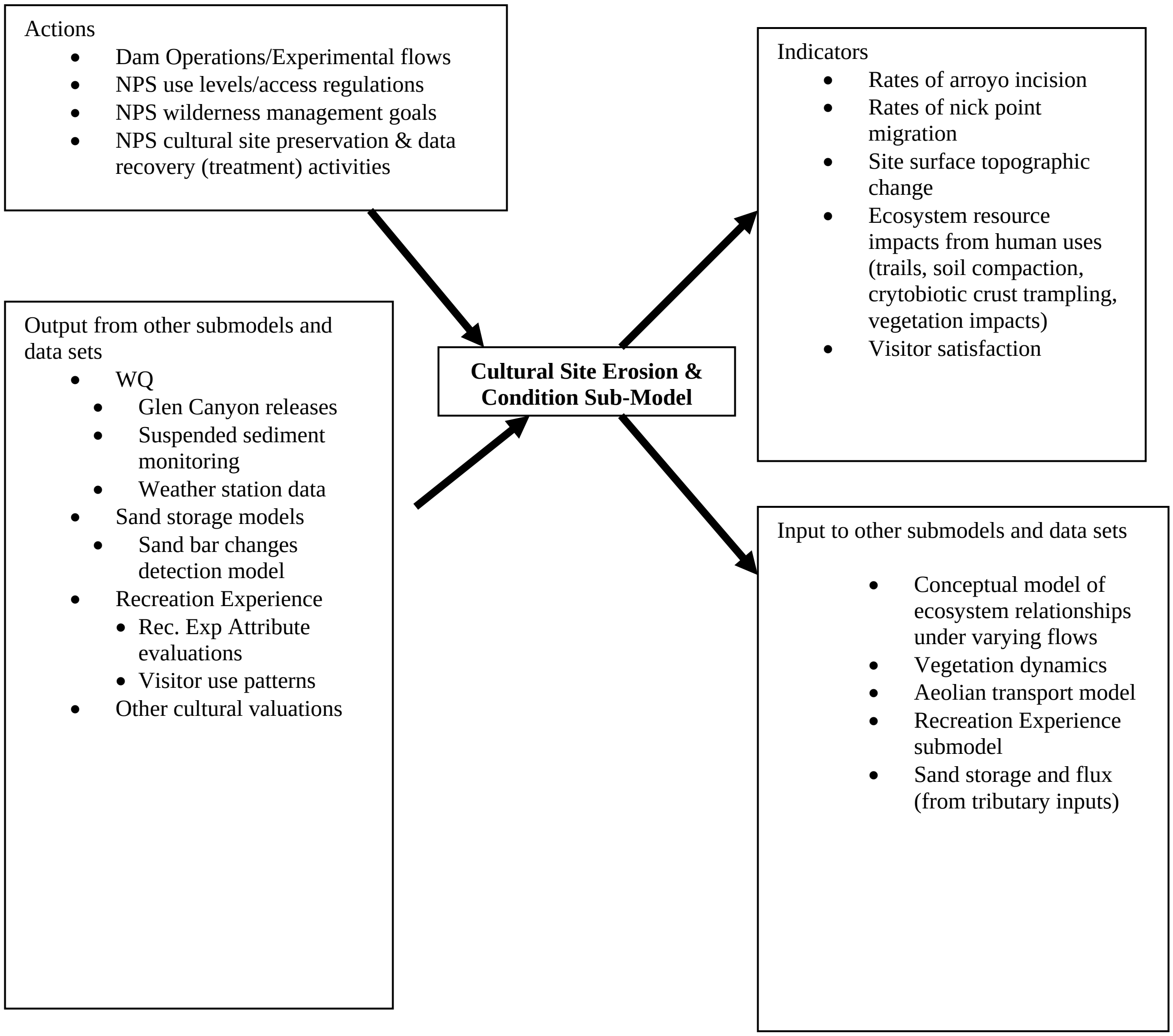

Figure 4..4. The looking outward matrix for the cultural resources submodel.

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 & 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 (such as water volume/release pattern, water temp/ qualities, sediment volume/flux, vegetation/habitats, terrestrial food resources, etc) 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.

CHAPTER 5. 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 approach 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.

CHAPTER 6. IDENTIFICATION AND DEVELOPMENT OF RESOURCE NEEDS FOR SUPPORTING SCIENCE PROCESS

A. Defining generalized 2-year and 5-year GCMRC 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 requires 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. New collaborative partnerships will be forged by the GCMRC Chief to assure success of these programs. Revisions in the budget may be necessary to 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 needed for these efforts can be obtained through GCMRC leadership. In 2007, GCMRC will 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, using new AMWG protocols. 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. 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. 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.