DRAFT CORE MONITORING PLAN

PREPARED BY
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SOUTHWEST BIOLOGICAL SCIENCE CENTER
GRAND CANYON MONITORING AND RESEARCH CENTER

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CHAPTER 1

Overview

A. Introduction

In the Glen Canyon Dam Adaptive Management Program (GCDAMP), monitoring and research activities are designed to enhance our understanding of ecosystem functions, processes, and patterns. Long-term monitoring is critical to understanding the status and trends of important resources, as well as the effects of the Secretary of the Interior's actions in operating the dam on those resources of special concern, such as endangered species or resources of tribal interest. Knowledge gained through research and monitoring is applied by the GCDAMP action agencies to meet regulatory compliance requirements for environmental and cultural resource laws such as the National Environmental Policy Act, Endangered Species Act, the National Historic Preservation Act, and the Grand Canyon Protection Act.

As stated in the Guidance Document from the Department of the Interior Solicitor's Office:

> Long-term monitoring and research, including test flows within the current range of authorized operations, are intended to enable finer and finer tuning of operations over time, as additional knowledge and experience are gained, to better achieve the target mix of resource benefits, as outlined in the Glen Canyon Dam Environmental Impact Statement, pages 54-65. [Loveless 2000].

Long-term monitoring also informs on the success or failure of management actions and produces data for long-term research hypotheses about the functioning of the Colorado River ecosystem. A stable monitoring program requires repetitive measurements on a consistent time scale, which allows short- and long-term comparison with previous measurements. Methods range from traditional field sampling techniques to multispectral remote sensing designed to identify stability or trends in key resources or indicator species.

B. Fundamental Mandates and Obligations

One of the primary objectives of the GCDAMP is to meet the environmental and monitoring commitments of the Glen Canyon Dam Final Environmental Impact Statement (Bureau of Reclamation 1995) and Record of Decision (Department of the Interior 1996), and to comply with the Grand Canyon Protection Act of 1992. The Grand Canyon Monitoring and Research Center was created to fulfill the mandate in the Grand Canyon Protection Act for the "establishment and implementation of a long-term monitoring and research program to ensure that Glen Canyon Dam is operated in a manner that protects the values for which the Grand Canyon National Park and the Glen Canyon National Recreation Area were created." This program includes necessary research and studies to determine the effects of dam management on the natural, recreational, and cultural downstream resources. The Grand Canyon Protection Act also identifies other management actions than dam operations to accomplish the intent of protecting the values for which Grand Canyon National Park and Glen Canyon National Recreation Area were established. Examples could include water temperature modification, stabilization of historic properties, non-native fish control, and removal of exotic vegetation. When these actions are taken, research and monitoring are necessary to assess their effects.

Glen Canyon Dam Environmental Impact Statement

The Glen Canyon Dam Environmental Impact Statement (Bureau of Reclamation 1995) (GCD EIS or EIS) was completed in March 1995. Its purpose was to "determine specific options that could be implemented to minimize—consistent with law—adverse impacts on the downstream environmental and cultural resources and Native American interests in Glen and Grand Canyons." The GCD EIS analyzed nine alternatives to allow the Secretary of the Interior to balance competing interests and to meet statutory responsibilities for protecting downstream resources and producing hydropower, and to protect affected Native American interests. The preferred alternative was the Modified Low Fluctuating Flow Alternative.

The GCD EIS also described the organization of the adaptive management program that would guide future management of the Colorado River corridor below Glen Canyon Dam. Some of the principles that explicitly underlay the design of the Adaptive Management Program include the following (FEIS 1995:35):

- Monitoring and research programs should be designed by qualified researchers in direct response to the needs of management agencies.
- A process is required to coordinate and communicate management agency needs to researchers and to develop recommendations for decision-making.
- A forum is required for the transfer of monitoring and research investigation results to the management agencies and to develop consensus on management response to information on affected resource conditions, trends, and processes.
- All monitoring and research programs in Glen and Grand Canyons should be independently peer reviewed.
- Interested parties identified in the GCPA should be provided opportunity for full and timely participation in proposals and recommendations.

Record of Decision on the Operation of Glen Canyon Dam

On October 9, 1996, the Secretary of the Interior signed the Record of Decision (ROD) that presented the rationale for choosing the Modified Low Fluctuating Flow Alternative. The ROD also identified environmental commitments and monitoring that would be accomplished under the selected alternative or any of the other restricted or steady flow alternatives described in the final EIS.

C. History of Monitoring Programs in the Colorado River Ecosystem

Management of the Colorado River requires efficient, effective monitoring of ecosystem resources and processes; however, selection of monitoring variables and resources has proven to be elusive in this system for the past 20 years. Impediments to selection of appropriate monitoring variables have been hampered by challenging logistics, poor understanding of how constrained (versus alluvial) rivers function ecologically (Schmidt et al. 1998, Stevens in press), limited data on most biological resources (Stevens 1989), limited synthesis of data, poor understanding of monitoring as a scientific process, and the lack of consistent, rigorous science administration, including information management. In this section we document the history of efforts to understand what and how to monitor the resources and physical processes of the Colorado River from lower Lake Powell through Grand Canyon.

U.S. Geological Survey Flow and Sediment Monitoring

Flow and sediment monitoring have been conducted at the Lees Ferry and Grand Canyon streamflow gauges since the 1920s. During the GCES Phase II and pre-EIS period, the U.S. Geological Survey proposed to develop an integrated particle transport analysis. This effort involved detailed LaGrangian analysis of changing geochemistry of parcels of water passing from Glen Canyon Dam to Diamond Creek, as well as increasingly sophisticated sand transport and storage monitoring and modeling. Although important advances have been made in understanding how this constrained river functions in flow and sediment transport, these efforts have traditionally underemphasized the role of silt (in bar stabilization and nutrient transport), and the linkage between sediment and aquatic habitat (but see Parnell et al. 1999). These linkages are likely to remain important topics in future decades.

National Park Service 1973-1977 Ecological Inventory

Environmental management of Grand Canyon has historically been stimulated by river running recreation concerns. Owing to dramatic increases in river running in the 1960s and poor waste management practices, the National Park Service (NPS) implemented an ecological inventory of the river corridor from 1973-1977. This was the first comprehensive inventory of the river ecosystem. This work identified numerous environmental issues recognized as problems today, and laid the groundwork for much of the subsequent river corridor science. Issues that were identified through the Carothers and Aitchison (1976) report included: (1) identification of the significance of dam effects on the riparian corridor through Turner and Karpiscak's 1980 photo-re-matching efforts; (2) human waste management (Carother's "Let's Pack It All Out" article); (3) monitoring camping beach erosion rates (Howard and Dolan 1981 and Beus's repeated sand bar surveys from 1983-1994); (4) non-native burro damage to the riparian zone; (5) the need for an on-going biological inventory program (Stevens 1976, Ruffner et al. 1978, Sutkus et al. 1978, Carothers et al. 1979, Brown et al. 1987, Phillips et al. 1987); (6) endangerment of native fish (R. Miller, personal communication); and (7) *Pogonomyrmex* ant infestation and sand discoloration of beaches in the absence of flooding.

As the final phase of the inventory project, Phillips et al. (1977) produced a riparian vegetation map of the river corridor. Calibration of that map could have established total riparian habitat area; however, further analysis of the map was not pursued. In addition, the recreational research of Shelby and his colleagues experimentally demonstrated significant impacts of boat types and crowding on visitor experience, and laid the groundwork for subsequent NPS recreational monitoring. Also, Laursen et al. (1976) identified the potential for ongoing sand bar erosion and worsening of rapids through debris flows (Silverston and Laursen 1976). Collectively, these research projects identified key river corridor management problems, presented baseline data, and helped solve several vexing environmental problems (2 and 4, above).

U.S. Bureau of Reclamation Glen Canyon Environmental Studies Program
Although the National Park Service 1976 ecological inventory provided a more refined understanding of the ecological structure of the river corridor, subsequent NPS management focused on resources and recreational issues. Issues of Glen Canyon Dam management were far beyond the scope of NPS jurisdiction. However, a 1980 Bureau of Reclamation Finding of No Significant Impact for rewinding Glen Canyon Dam's turbines and increasing flow fluctuations provoked strong public outcry. In response to that public concern, then Secretary of the Interior James Watt initiated the 1982-1997 Glen Canyon Environmental Studies (GCES) program. The first phase of GCES (1983-1987) conducted >40 research studies and Phase II resulted in nearly 100 studies. These research efforts identified virtually all of the contemporary issues related to river and dam management (Stevens and Gold 2002). The National Research Council (NRC) conducted independent reviews of the GCES program, producing several important syntheses and program critiques (NRC 1987, NAS 1991, NRC 1996). Their 1991 synthesis was particularly important for bringing together the state of knowledge on the system for the impending EIS. However, as Walters et al. (2000) recognized, the GCES studies were primarily research studies, not monitoring studies, which are critical for long-term adaptive management of the river. However, GCES Phase II and the National Academy of Sciences (NAS) recognized the need for planning a long-term monitoring program for this river ecosystem.

National Research Council 1992 Monitoring Symposium
Much of the present adaptive management monitoring program for the Colorado River is directly or indirectly derived from the 1995 EIS and ROD, but most of the monitoring guidance therein was derived from a 1992 National Academy of Sciences (NAS) symposium on long-term monitoring of the Colorado River. The NAS assisted GCES in conducting this two-day "Delphi Process" symposium in Irvine, California, bringing together leading experts on many aspects of ecosystem monitoring, river ecology, and Grand Canyon studies. The symposium was overseen by Dr. William Lewis and emphasized interactions between disciplines, as well as integration of information. The meetings were organized around four disciplines found to be important by the NAS: geohydrology, environmental chemistry and biology, sociocultural resources (power generation, nonuse values, and cultural values), and information management.
Gary E. Davis and L.H. MacDonald presented position papers on ecosystem monitoring objectives and practices from the perspectives of the National Park Service and the

Environmental Protection Agency, respectively. Both emphasized that monitoring is a scientific process, based on adequate inventory, clearly defined management goals and objectives, and with appropriate reporting and information management. Geohydrological monitoring issues focused around climate (A.J. Brazel), mainstream sediment transport (E.D. Andrews), sediment resources (J.C. Schmidt), and tributary processes (Hereford). Biological-chemical monitoring and research issues included native fish (R.A. Valdez), trout and water temperature (D.M. Kubly), the aquatic food base (D.W. Blinn), riparian and endangered terrestrial resources and linkages (L.E. Stevens), and air pollution (W.C. Malm). Sociocultural position papers were presented on cultural resource monitoring (J.R. Balsom), recreation (E. Gruntfest), and power economics (M. Roluti). Information management issues that were addressed included information management program development (D.L. Wegner), GIS applications (L. R. Dexter and M.J. Pucherelli et al.), and Lake Powell issues (R. Marzolf). The 1992 symposium also endeavored to integrate these monitoring topics with break-out groups and integration groups.

Although the 1992 symposium was regarded as a success by the participants, the results of the symposium proved difficult to incorporate into a coherent monitoring program for the 1995 EIS. Reasons for the difficulty Dr. Duncan Patten (GCES Senior Scientist) had with development of a monitoring program for the EIS are the same as those faced by the U.S. Geological Survey today, and include a lack of agreement on relationships among variables and a lack of consensus over program directions.

National Park Service 1989-1994 Monitoring Approaches
L.E. Stevens and numerous academic colleagues developed monitoring approaches for several GCES - National Park Service natural resources monitoring projects in 1989-1990, including sand bar erosion (the existing Northern Arizona University sand bar monitoring program), aquatic food base, avian studies (general and endangered species), and riparian resources. The monitoring programs were based on several premises, as described below.

1. Given that these were initial monitoring programs, it was anticipated that the initial data would serve as a baseline, and that the protocols would need reconsideration. Therefore, a synthesis and critical review were conducted early in each program. This was accomplished by publishing baseline findings in various reports and peer-reviewed journals (e.g., Beus et al. 1992; Brown and Stevens 1992, 1997, 1998; Brown et al. 1987, 1994; Stevens et al. 1995, 1997a, 1997b; Sublette et al. 1998).

2. Variation in the distribution of ecological resources and processes was strongly influenced by local and reach-based variation among the geomorphic settings with debris-fan complexes (DFC's) and reaches of the river identified by Schmidt and Graf (1990) and Stevens et al. (1995, 1997a 1997b). Sampling site selection typically involved selection through a stratified random approach from the overall population of available study sites, but including some sites (e.g., sand bars) that had an extensive history of study. Several sites were selected in each reach, and response variables (i.e., sand bar area or volume, standing mass, or riparian vegetation cover and diversity) were measured on a regular (annual, or more often) basis for the first

several years. Subsequent syntheses of monitoring data provided clarification of the timing of measurements.

3. It was considered unlikely that the assumptions of parametric statistics would be met; therefore, the early emphasis on these projects involved non-parametric analyses to distinguish major differences between stage zones, in DFC settings, and among reaches.

4. It was recognized that developing aerial mapping technologies and GIS held great promise, so analyses of aerial data (e.g., sand bar distribution, backwaters, riparian and upland vegetation) were initiated or explored to determine the value of such data, and accuracy of interpretation.

5. These studies emphasized the need for understanding dam effects in relation to reference sites. Monitoring is a scientific endeavor, one in which data from reference sites or controls is needed to distinguish ecosystem effects related to dam operations from, for example, climate effects. However, the issue of scientific controls has rarely been considered by AMP studies. Reasons for the lack of controls are attributable to the limited understanding by program participants on the importance and methods by which controls are used, and by apparent ignorance of what controls are appropriate. Seven types of controls exist for measuring the extent of change caused by dam operations on regulated rivers: (1) pre-dam versus post-dam changes, upstream unregulated versus downstream regulated differences; (3) graded downstream responses; (4) comparison with nearby, geomorphically similar, undammed rivers, (5) predictive modeling; (6) comparison with in-system tributaries; and (7) graded (e.g., stage-related) responses of resources in relation to the channel.

   The AMWG's insistence on spatially constraining the program scope precludes analyses of numerous control sites that would greatly alter program expectations. For example, Cataract Canyon in Canyonlands National Park (upstream from Lake Powell) has all the river characteristics some AMWG members wish to see in Grand Canyon, including high spring flows, enormous sediment loads, and seasonally warm water. However, the native fish populations in that reach are in dire condition. A serious examination of Cataract Canyon as a control site could significantly alter present program directions in Grand Canyon.

Around the same time that NPS scientists were developing monitoring protocols for ecological parameters in the river corridor, the NPS cultural resource management program implemented an archaeological site monitoring program. In contrast to the natural resource program, the cultural resource monitoring program strictly focused on assessing site condition relative to National Historic Preservation Act compliance mandates, and it made no attempt to establish linkages between monitoring parameters, dam operation effects, and resource conditions. Although there have been a number of minor modifications over the years, the current focus of the NPS cultural resource monitoring program remains essentially the same today (Leap et al. 2000).

GCMRC's Strategy for Development of a Long-Term Monitoring Program in the Post-GCES Era (1995-2004)

Following completion of the Operations of Glen Canyon Dam Final EIS in 1995, the Department of the Interior established the Grand Canyon Monitoring and Research Center (GCMRC) in Flagstaff, Arizona. One of the primary objectives of the GCMRC is to provide long-term monitoring data for Colorado River Ecosystem resources below the dam. These data were intended for use by managers to evaluate the effectiveness of alternative dam operations relative to resource objectives identified within compliance documents, such as the EIS.

The final EIS contained a draft monitoring plan for resources below Glen Canyon Dam as one of its many appendices (referred to here as the Patton plan). The Patton monitoring plan was developed by the GCES Senior Scientist during the EIS period in collaboration with many of BuRec's cooperators between 1990 and 1993, and was reviewed by a National Research Council review committee in 1994. On the basis of the NCR review, the plan required further development before implementation, but the revision was not completed in time for inclusion in the Final EIS.

One of the first tasks undertaken by the GCMRC staff in 1996 was to evaluate all previous science activities conducted below the dam in Glen and Grand Canyons under the GCES program, relative to perceived or documented long-term monitoring needs described in the Patton plan. The GCMRC proposed that previous or ongoing monitoring activities initiated by the GCES and carried forward in the GCMRC era, would be evaluated jointly by cooperators, staff and external peer reviewers through a process termed the Protocols Evaluation Program (PEP, see Appendix 2 below). The PEP would be conducted through a series of meetings and workshops that focused on monitoring methods specific to each of the resource areas of concern.

Initially, PEP meetings were convened with respect to remote sensing and physical resources, such as sediment and water quality. Final reports from the PEPs identified recommendations from expert review panels for resource areas where additional research and development was required to fully identify appropriate monitoring protocols for long-term implementation. Such objectives for research were then incorporated into competitive solicitations (for example, RFP's released in 2000, for research and monitoring projects aimed at sediment projects to be conducted from 2001–2005).

Following PEP meetings conducted in 1998-1999 on physical resources and remote sensing, additional meetings were conducted with focus on the aquatic ecosystem (fishes and food web), Lake Powell water quality, cultural resources, terrestrial ecosystem and survey and mapping protocols. With the exception of PEP meetings in the areas of recreation and socio-economics, all PEP reports were completed by 2003. New research in areas of monitoring development began in 2000 (remote sensing initiative) and continue as part of the GCMRC research program today. The remote-sensing initiative final report was completed in 2003. Sediment research toward monitoring began in 2001 and is scheduled for completion in 2005. Research and development in the area of native fishery monitoring in both the main channel of the Colorado River ecosystem and its tributaries began in 2000 and is currently ongoing. Research aimed at terrestrial ecosystem monitoring began in 2001 and is ongoing through 2004. Monitoring protocols in the areas of cultural and aquatic food web resources are currently the focus of research initiatives scheduled for 2005 and beyond, while PEP meetings for socio-economics and recreation are planned for FY 2005.

The PEP approach to development of a long-term monitoring design, and its resulting research and development initiatives, is admittedly a costly and time consuming strategy. However, owing to the unique characteristics of the Colorado River ecosystem and its resources below Glen Canyon Dam, the GCMRC determined this approach to be the most reliable means of identifying robust and cost effective methods for long-term monitoring below the dam. Consistent and reliable monitoring methods and resultant data were deemed a critical component of the Adaptive Management approach for evaluating the operations of Glen Canyon Dam relative to downstream resources.

While sufficient science has been completed to define some of the required long-term monitoring methods, such as fine-sediment mass balance, Lake Powell water quality, terrestrial vegetation monitoring, rainbow trout abundance, humpback chub population estimates in the Little Colorado River, several other areas of monitoring have not yet been resolved. Areas of monitoring where research and development on protocols is yet to be completed or has not yet started include: (1) aquatic food web; (2) native fishes abundance in the main channel; (3) cultural resources and archeological sites; (4) terrestrial wildlife; (5) recreation; (6) sand-storage changes; (7) downstream integrated quality of water; (8) warm-water non-native fish abundance in the main channel and tributaries; and (9) socio-economics. Owing to the fact that information is still required to reliably define the monitoring methods and strategies for the above resource areas, a description of the entire suite of activities required for the long-term monitoring program and associated costs in this draft plan is not possible at this time.

Conclusions

The historical outline provided above does not attempt to provide a comprehensive overview of all the monitoring efforts associated with each of the resources of concern in the CRE. Additional historical information on this topic is provided in Part II of this plan, in association with each of the individual resource sections.

Overall, development of a comprehensive core monitoring program has been hampered by the inability of the GCDAMP to envision its strategies and objectives for achieving its stated management goals (Schmidt et al. 1998), or grasp the magnitude and multidimensionality of the ecosystem effects of Glen Canyon Dam. It has also been hampered by imbedded biases about the relevance of some monitoring variables (Stevens, in press), and by the general failure of the AMP to endorse analysis of reference sites. Future monitoring approaches need to take on these challenges, yet maintain enough flexibility to encompass the large paradigm shifts that are likely to result if reference site analyses are conducted.

D. Core Monitoring Plan: Definitions, Assumptions and Considerations

In keeping with the first two principles of the GCD-AMP (see p. 2), a Core Monitoring Team (CMT) was convened through the AMP Technical Work Group on April 9, 2004. The CMT determined that an immediate goal of the team effort was "*Completion of a high quality, long-term core monitoring plan by 30 September, 2004 that has a high probability of acceptance by the full TWG and AMWG.*" A more proximate goal was, "*To provide a consistent, long-term (10+ years) measure of the effects of Glen Canyon Dam operations on key resources in the Colorado River Ecosystem as defined in the GCDAMP Strategic Plan*."

The CMT confirmed that this plan would follow the definition of core monitoring used in the GCDAMP Strategic Plan: "*Consistent, long-term, repeated measurements using scientifically accepted protocols to measure status and trends of key resources to answer specific management questions. Core monitoring is implemented on a fixed schedule regardless of budget or other circumstances (e.g., water year, experimental flows, temperature control, stocking strategy, non-native control, etc.) affecting target resources.*"

The CMT recognized that there is no one best way to monitor resource conditions. There is no "one size fits all" solution for monitoring resource status and trends. Therefore, it follows that monitoring programs must be customized to address specific issues or questions of concern.

Hellawell (1991:3) recognizes three basic reasons for undertaking a monitoring program:

- To assess the effectiveness of policy or legislation
- To comply with regulatory requirements (performance or audit function)
- To detect incipient change ("early warning system")

Noon (2003:30) lists similar reasons, although he uses a different set of words to describe reason #3: to "assess the value and temporal (or spatial) trend of those indicators that characterize the state of an ecological system." In the Glen Canyon Dam Adaptive Management Program, all three reasons drive the need for monitoring. We are concerned with meeting the legal mandates of the Grand Canyon Protection Act, which calls for "long term monitoring programs and activities that will ensure that Glen Canyon Dam is operated in a manner consistent with that of Section 1802". Section 1802 requires that the Dam be operated 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." These legal mandates require that the GCD-AMP monitoring program be sufficiently inclusive to track the condition of the National Parks' diverse resource values, yet the monitoring approach must at the same time be sufficiently focused so as to be able to track trends in resource conditions relative to dam operations. In addition to the mandates of GCPA, regulatory requirements of the Endangered Species Act and the National Historic Preservation Act necessitate monitoring of specific threatened resources. Ideally, we also want to be able to detect ecological changes and make adjustments in dam operating procedures before we cross undesirable ecological thresholds; however, as yet, the AMP has not resolved how to determine or define resource condition thresholds ("targets") that should trigger changes to current operating procedures outside of certain experimental activities.

The Environmental Impact Study on the Operations of Glen Canyon Dam determined that resources or issues of public concern included the following: "beaches, endangered species, ecosystem integrity, fish, power costs, power production, sediment, water conservation, rafting/boating, air quality, the Grand Canyon wilderness, and a category designated as 'other'." The Environmental Impact Study team consolidated the issues and concerns identified by the public into the following resource categories: "water, sediment, fish, vegetation, wildlife and habitat, endangered and other special status species, cultural resources, air quality, recreation, hydropower, and non-use values. These resource categories (minus air quality and non-use values) define the resources of concern that need to be tracked by a long-term core monitoring program. Specifically, the CMT decided that the following resource categories of concern would be covered in the CMP: (1) sediment; (2) wildlife/vegetation; (3) fish; (4) food base; (5) register-eligible historic properties; (6) other cultural resources of tribal concern; (7) hydrology; (8) water quality; (9) recreation; (10) threatened and endangered species; (11) power; and (12) non-native species.

The AMP Strategic Plan identifies 12 major goals and related core monitoring information needs that are related to but not precisely the same as the resource categories identified in the FEIS. The 12 goals of the AMP Strategic Plan focus on the following topics: aquatic food base; native fish; rainbow trout; Kanab ambersnails; spring and riparian habitats and associated resources; water temperature, water quality, and flow dynamics; sediment storage; quality of recreational experiences; power production capacity and energy generation; cultural resources; and the adaptive management program itself. The AMP Strategic Plan calls for "an ecosystem management approach, in lieu of an issues, species or resources approach". The Strategic Plan also emphasizes the importance of understanding cause and effect relationships, noting that "The adaptive management approach will be geared toward gaining an improved understanding of the cause and effect relationships that occur within the Colorado River ecosystem, and their connection, if any, to dam operations, while also documenting resource status and trends." These guidelines from the AMP Strategic Plan are interpreted to mean that tracking status and condition trends of individual resources without reference to the factors that contribute to the stability of their condition over time is inappropriate. Nevertheless, the core monitoring information needs identified in the AMP Strategic Plan tends to focus on individual resource status and trends, rather than on ecosystem functions, biodiversity, or ecosystem integrity in a broader sense.

The need to understand status and trends of resources in a contextual sense requires that the core monitoring plan consider and track potential interactive relationships, not just the status and trends of individual resources. For example, it would not make sense to track status and trends in sediment apart from hydrology, nor can we hope to make sense of status and trends in humpback chub without reference to their habitat conditions, such as water temperature, water quality, and so forth.

Many monitoring programs fail due to lack of clearly defined foci and objectives. In addition, certain deficiencies are common to many unsuccessful monitoring programs (Noon 2003:33). These include: a minimal foundation in ecological theory or empiricism; little or no logic justifying the selection of condition indicators; no obvious linkage to cause-effect interpretation of the monitoring signal; critical indicator values that would trigger a policy response were not identified; no connection between the results of monitoring and decision making; and inadequate or highly variable funding. With the possible exception of the last item, all of these deficiencies have plagued past monitoring efforts in the CRE.

According to Usher (1991:15), for a monitoring program to succeed, it must be carefully planned, and good planning requires asking and answering five basic questions:

1. Purpose: what is the aim of monitoring?
2. Method: how can this aim be achieved?
3. Analysis: how are the data, which will be collected periodically, to be handled?
4. Interpretation: what might the data mean?
5. Fulfillment: when will the aim have been achieved?

In a broad sense, the basic aim of the GCD-AMP monitoring program is to answer two fundamental questions: (1) How are dam operations affecting National Park values (natural, cultural, and visitor use resources) over time?; and (2) Are current dam operations resulting in protection, mitigation of adverse impacts, and/or improvements to the condition of the diverse resource values within the Colorado River corridor? These fundamental questions, which derive directly from the legal mandates of the GCPA, require that the GCD-AMP monitoring protocols establish clear linkages between potential changes in resource condition and dam operations. Although not explicitly stated, it would seem to be implicit that the specific core monitoring information needs identified in the GCD-AMP Strategic Plan must be firmly tied to these two, fundamental questions.

The CMT affirmed the importance of relating monitoring activities to the questions arising out of the AMP strategic plan. Relevant fundamental questions include the following: (1) What and why do managers need to know? (2) Where do they want to know it? (3) How frequently do they need to know? (4) What are the general methods to obtain this information? (5) What is the level of precision/accuracy needed? (6) How will the monitoring data be presented? (7) Is it answering the managers' questions? and (8) What are the metrics of success, and how is success defined?

As far as the questions concerning methods, analysis and interpretation, these must be answered relative to the resources of concern to the program. Clearly, the methods used for monitoring water quality cannot be applied to monitoring endangered bird species. However, there are some overarching concerns that seem applicable to a broad suite of resources in the CRE. For example, we are primarily concerned with understanding the effects of dam operations on various components of an ecosystem (i.e., on resources that are widely distributed throughout the river corridor.) Therefore, monitoring approaches generally need to be designed to assess changes and trends throughout the river corridor, rather than on a site-specific basis (the status and trends of Kanab ambersnails is an obvious exception to this general rule). Monitoring methods need to be appropriately designed to capture systemic trends in resource condition, not localized changes, and analysis approaches likewise must be appropriate to the scale of inquiry. For results to be meaningful for the whole system, a randomized sampling approach is generally most appropriate. However, in come cases, resources of concern are too spatially clustered or too sparsely scattered throughout the river corridor to allow the efficient application of a truly random sample approach. In these cases, the trade-offs between sample "purity", data robustness, reliability, and interpretability must be carefully weighed and considered. In Chapter 2, we discuss the various factors and considerations that played into the selection of specific monitoring designs and field methodologies for each resource of concern.

Development of this Core Monitoring Plan (CMP) was guided by the following assumptions: (1) use available technology, as appropriate; (2) adopt a minimalist framework; (3) meet the needs of stakeholders and answer their specific management questions; (4) strive for automated techniques that are less invasive and more efficient; (5) develop a budget adequate to support the plan (e.g., 40-60% of the GCMRC science budget); (6) build for consistency; (7) build for longevity; (8) incorporate flexibility to adopt new technologies; 9) the plan will be reviewed and accepted by SA's/TWG/AMWG/GCMRC staff; and (10) the results of monitoring will be regularly reported.

Where information is not yet available to guide development of a core monitoring program for specific resources, we have discussed the history and issues surrounding monitoring of these resources and inserted placeholders in the plan until these modules can be developed. This situation is exemplified by the socio-cultural program, for which Protocol Evaluation Panels are scheduled in FY05. At the completion of those PEPs, recommendations related to core monitoring activities will be incorporated into the CMP.

The CMT decided that the development process for the CMP would be driven by questions, available funds and other constraints on the AMP including the need to conduct long-term experiments and research activities in support of adaptive management. All available resources, including the AMP strategic plan and associated Goals, MOs, and INs; recommendations from the Protocol Evaluation Panels; existing components of GCMRC's monitoring efforts; and recommendations from the Science Advisors have been used in developing this plan.

E. Relationship to Other Components of the Glen Canyon Dam Adaptive Management Program

E.1. Linkages to Goals, Management Objectives and Information Needs

Research and monitoring are inextricably linked activities that collectively measure resource status and trends over time and space, and determine through experimentation the causes for change in these resources.

The primary resources of interest to the Glen Canyon Dam Adaptive Management Program (GCD AMP) are identified in the following 12 Program Goals:

1. Protect or improve the aquatic foodbase so that it will support viable populations of desired species at higher trophic levels.

2. Maintain or attain viable populations of existing native fish, remove jeopardy from humpback chub and razorback sucker, and prevent adverse modification to their critical habitat.

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

4. Maintain a naturally reproducing population of rainbow trout above the Paria River, to the extent practicable and consistent with the maintenance of viable populations of native fish.

5. Maintain or attain viable populations of Kanab ambersnail.

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

7. Establish water temperature, quality, and flow dynamics to achieve the Adaptive Management Program ecosystem goals.

8. Maintain or attain levels of sediment storage within the main channel and along shorelines to achieve the Adaptive Management Program ecosystem goals.

9. Maintain or improve the quality of recreational experiences for users of the Colorado River ecosystem, within the framework of the Adaptive Management Program ecosystem goals.

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

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

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

Under each of the above Goals, GCD AMP stakeholders have identified specific management objectives (MOs). Core monitoring information needs (CMINs) are linked to many of these MOs. The CMINs form the foundation of this Core Monitoring Plan. Discussion of the specific Core Monitoring Information Needs for each resource category of concern is included in Part II of this document, within each of the resource-specific sections.

E.2. Linkage to the SCORE Report and GCMRC Biennial Science Symposium

The State of the Colorado River Ecosystem report will be the principle reporting mechanism for the core monitoring program. This plan calls for a hard copy version of the SCORE report to be produced every five years. The report will be available on the GCMRC website and will be updated electronically on a biennial basis. Updating will occur in the years alternating with the biennial GCMRC Science Symposium, which provides another important venue for disseminating monitoring program results.

E.3. Linkage to Strategic Research Plan

Currently, there are three categories of research being programmed at the GCMRC: 1) research focused on the development of long-term monitoring protocols, 2) basic research related to critical resource management questions (e.g. Humpback chub genetics, etc.) and 3) research related to experimental flows and non-flow management strategies. In this document, the second part of Chapter 2 describes research activities related to core monitoring protocols that are still under development. Implementation of these research and development projects generally follows the path described in the previous section on GCMRC's Protocols Evaluation Program (also, see Appendix B). They are designed on the basis of management information needs, status-of-knowledge (resource syntheses, such as hydrology and geomorphology, etc.) and recommendations from PEP reviews. These projects form one component of the long-term strategic research plan that is currently (FY2005) being developed in cooperation with Technical Workgroup members.

E.4. Status of Core Monitoring Projects

To provide clarification on the current status of core monitoring projects, with respect to research and development of protocols, project titles within Chapter 2 have been color coded. Project titles that appear in GREEN highlight, have been implemented for monitoring for one to several years using methods deemed adequate for long-term monitoring. Projects in this category include: 1) Lake Powell quality of water, 2) downstream surface water (discharge and stage measurements), 3) downstream quality of water for a limited suite of parameters, such as temperature, specific conductivity, suspended sediment, etc., 4) status of Lees Ferry rainbow trout and 5) status of humpback chub in the Little Colorado River. Project titles described in Chapter 2 that have been ongoing to define monitoring protocols and are scheduled for completion and external peer review in FY 2005, are highlight in YELLOW. The remainder of the projects highlighted in RED are scheduled for implementation of research and development in FY 2005 and beyond as a means to identify monitoring protocols required to meet information needs in the long-term core monitoring program.

CHAPTER 2

Monitoring Of Ecosystem Resources

The following chapter describes the monitoring programs for ecosystem resources in the CRE, of concern to AMP stakeholders and the public, as identified in the FEIS, AMP Strategic Plan, and through the efforts of the TWG AD Hoc Core Monitoring Team. The chapter is organized into two sections. The first section (Part 2.1 Current Core Monitoring Capabilities) describes monitoring programs that are currently underway in the CRE and are considered to be fully developed. The second section (Part 2.2 Future Core Monitoring Programs Undergoing Research & Development) describes programs that are still undergoing research and development and will be implemented in the near future, after resource linkages to dam operations have been clearly established, monitoring protocols have been piloted in a test program, and the pilot study results have been peer-reviewed.

PART 2.1 Current Core Monitoring Capabilities

The following section describes monitoring programs that are currently underway in the CRE and are considered to be fully developed.

A. Lake Powell Hydrology, Quality-of-Water, Glen Canyon Dam Releases and Power

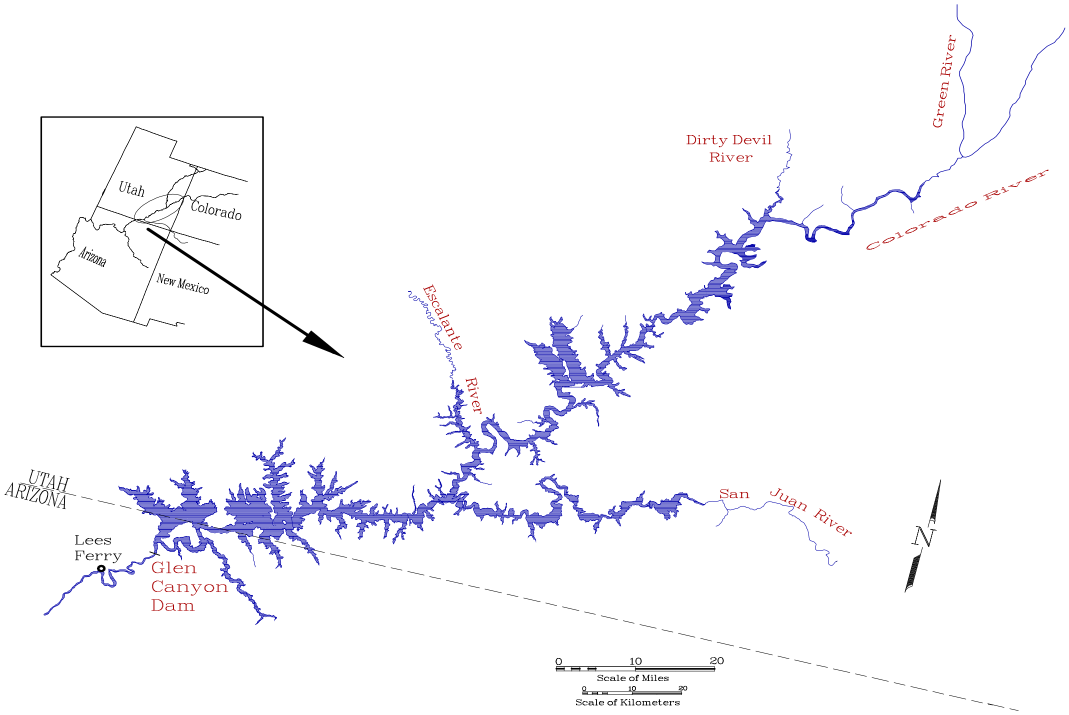
The water stored in Lake Powell and releases through Glen Canyon Dam are primary drivers of ecosystem function, hence we begin with a discussion of Lake Powell and Glen Canyon Dam.

A.1. Lake Powell

History/Rationale

Glen Canyon Dam was completed in 1963 and represents the primary regulatory feature of the Colorado River Storage Project. Glen Canyon Dam, constructed and operated by the Bureau of Reclamation, impounds the Colorado River to form Lake Powell, a 32.3 km^3 (26.2 MAF) reservoir with a surface area of 65,069 ha (160,784 ac) extending 290 km (180 miles) up the Colorado River at its full pool elevation of 1128 m (3700 ft) above mean sea level. Shoreline length has been estimated at 3,057 km (1900 mi.). The drainage area above Lake Powell is 279,000 km^2 (108,000 mi^2) (Stanford and Ward, 1991). Lake Powell is located on the border of Utah and Arizona within Glen Canyon National Recreation Area (Figure A.1). Lake Powell began filling in 1963 and reached a full pool elevation in June of 1980.

Figure 1. Lake Powell geographic setting and major tributaries



Core Monitoring Information Needs

Several CMINs exist that relate to water quality for Lake Powell and downstream resources. Some of these CMINs relate solely to downstream resources and are met by monitoring activities conducted below Glen Canyon Dam. Others relate to downstream resources but are addressed by activities conducted upstream of Glen Canyon Dam. In addition, data collected upstream of the fore bay of Lake Powell are used by the Bureau of Reclamation for their reservoir monitoring program. All monitoring work in the reservoir, excluding the fore bay is funded separately from AMP funds. For the purposes of this document, fore bay monitoring will be the focus of monitoring approaches.

Table A.1.1 CMINs for Water Quality

CMIN #	Task/Question
7.3.1	What are the status and trends of water quality releases from Glen Canyon Dam?

Data Acquisition

The Lake Powell Core Monitoring Plan consists of two components: (1) quarterly reservoir water quality surveys; and (2) monthly fore bay water quality surveys above Glen Canyon Dam. This section is focused on the fore bay monitoring as this element of monitoring is specifically included within the geographical scope of the Colorado River Ecosystem, as defined by the AMP. However, data from the associated Bureau of Reclamation sponsored reservoir surveys provide a prediction of future release water quality or potential water quality problems and form a baseline from which the long-term effects of management actions related to dam operations can be evaluated.

Fore bay Monitoring

The objective of monthly fore bay surveys will be to characterize the physical, chemical, and biological conditions of the Glen Canyon Dam fore bay and describe monthly variations in stratification patterns, mixing processes, planktonic community structure and abundance, and quality of water released downstream. Information from fore bay monitoring forms a baseline from which the immediate effects of management actions at Glen Canyon Dam can be evaluated. Sampling will focus on characterizing conditions within the major strata of the reservoir and at potential release depths. The monthly sampling frequency provides increased temporal resolution of conditions existing upstream of the dam, and though it is less frequent than downstream measurements (see below), it is informative enough to support main channel data collection efforts. Conditions in the fore bay have an immediate effect downstream and follow operational patterns at Glen Canyon Dam more closely than those monitored on a less frequent basis. A thirty-four-year period of record exists for fore bay surveys on an approximately monthly basis, with the exception of the period 1982-1990.

Monthly fore bay monitoring was recommended by the PEP reviewers and consists of a profile of physical parameters through the water column; chemical sampling for nutrients and major ions at specified depths, and biological sampling for chlorophyll, phytoplankton, and zooplankton. General field observations of existing weather conditions, water depth, and water clarity will also be made. Recent changes to the reservoir monitoring program based on PEP recommendations include the addition of several continuous thermal monitoring stations in the lake. One of four specially designated water quality buoys have been installed at the Wahweap and other sites in the reservoir. These buoys assist in collection efforts at these deep-water stations as well as act as a platform for any deployments of continuous monitors. Chlorophyll sampling protocols have been amended under recommendations of the PEP. Preservation has shifted from the in-field dry-ice freezing method to the simpler and more effective desiccation with reusable silica gel crystals. Greater efforts to keep samples darkened during and after processing have been made. Total organic carbon measurements have been added to dissolved organic carbon measurements already being taken.

Table A.1.2 Details of the Lake Powell Fore bay Core Monitoring Plan

Objective	Parameters	Methods	Location(s)	Frequency	Accuracy & Precision
Monitor the status and trends of water quality releases from Glen Canyon Dam	Physical parameters Water temperature, Specific Conductance, Dissolved Oxygen, Turbidity	Profiling with water quality sensor	Fore bay	Monthly	Temperature: ±0.15°C Conductivity: ±0.5% of reading + 0.001 mS/cm pH: ±0.2 DO: ±0.6 mg/L Turbidity: 2

					NTU.
7.3.1	Biological/chemical parameters Nutrients, major ions, chlorophyll, phytoplankton, and zooplankton	Physical water samples	Fore bay	Monthly	

Quality Control
Water quality data sondes are calibrated in the lab prior to each sampling event. Following return from the field, data is downloaded and checked for inconsistent records and data are corrected prior to analysis. Water samples are sent to a contract lab for analysis. Water samples include blanks for purposes of quality control/quality assurance.

Data Management, Analysis and Dissemination
Data are managed and analyzed using SAS data structures. These data are made available to the DASA group for incorporation into Oracle database. These data when finalized will be available via the GCMRC website. Monthly and yearly reports are posted on the web page and yearly reports are delivered in an open-file report format.

A.2. Glen Canyon Dam Releases **(**Information related to SCADA data as a source of hourly discharge from the power plant, to be completed with information provided by Bureau of Reclamation.)

A.3. Glen Canyon Dam Power and Revenue (To be completed with information provided by Bureau of Reclamation and WAPA.)

B. Aquatic Ecosystem Resources

B.1. Surface Water Measurements (stage and discharge)

History/Rationale
Surface water (SW) measurements have historically been made along the Colorado River ecosystem and its major tributaries within Grand Canyon by the Water Resources discipline of the U.S. Geological Survey. Earliest records of stage and discharge were made at the Lees Ferry gage in May of 1921, and records have been continuously collected there by USGS since that time (see Topping and others, 2003). This measurement station has provided data for monitoring flow volumes of the river related to the 1922 Colorado River compact between basin states. In addition, the Paria River at Lees Ferry station also provides water supply data related to the Compact. The Lees Ferry record on the main channel has also been determined by managers to be the logical site for monitoring releases from Glen Canyon Dam, as related to the Secretary's current Record-of-Decision. Additional continuous flow measurements below Lees Ferry are proposed here as part of long-term monitoring to determine how dam releases evolve as

they move through the ecosystem with respect to quality-of-water (QW) parameters, including but not limited to, suspended sediment concentration and grain size.

Core Monitoring Information
The SW monitoring proposed here addresses Goal 7, Management Objective (MO) 7.4, and the Core Monitoring Information Needs (CMINs) associated with this MO. The CMINs associated with SW measurements are summarized in Table B.1.1.

Table B.1.1. CMINs Related to Surface Water

CMIN #	Task/Question
7.4.1	Determine and track releases from Glen Canyon Dam under all operating conditions.
7.4.2	Determine and track flow releases from Glen Canyon Dam, particularly related to flow duration, upramp, and downramp conditions.

Data Acquisition
These CMINs will be addressed by monitoring stage and discharge at several locations along the main channel of the Colorado River. Also, in support of the Quality-of-Water core monitoring plan, surface water stage and flow monitoring will be conducted at several key tributaries known to supply sand and finer sediment. Details of the surface water core monitoring program are summarized in Table B.1.2.

Table B.1.2. Details of the Surface Water Core Monitoring Plan

Objective	Parameters	Methods	Locations	Frequency	Accuracy and Precision
Monitor stage and discharge at several locations on the mainstream Colorado River and key tributaries.	Stage and discharge	Standard USGS gaging methods.	**Colorado River** at river miles: 0, 30, 61, 87, 166 and 226. **Paria River** at Lees Ferry **Little Colorado River**: near Cameron & near Desert View **Moenkopi Wash** near HWY 89 **Kanab Creek** near mouth **Havasu Creek** near Supai	Stage measured every 15 minutes; flow measured periodically (e.g., monthly)	±0.01 feet for stage; ±5-15% , for discharge, depending on the quality of the site.

The periodic discharge measurements are used, along with the stage data, to develop stage-discharge rating curves for each site, yielding 15-minute discharge data.

Quality Control

All SW monitoring is proposed to be continued through a management agreement with the USGS Arizona District Water Resources Discipline. The USGS WRD follows standard protocols, including QA/QC procedures as documented in the series of USGS manuals entitled "Techniques of Water-Resources Investigations of the U.S. Geological Survey", available on-line at http://water.usgs.gov/pubs/twri.

Data Management, Analysis, and Dissemination

The USGS WRD makes the 15-minute stage and discharge data available real-time on the world-wide-web. These data also move directly to the USGS ADAPS database, which is accessible to GCMRC (but not the general public, as the data is provisional). These data will also be transferred to the GCMRC database and made available to the public upon final certification of the data by the WRD. Also, following the annual WRD data review, the mean daily flows are published in the annual Arizona Water-Data Report.

Data analyses performed by GCMRC staff and cooperators will be presented regularly at TWG and AMWG meetings, as warranted by the findings, as well as published in peer-reviewed USGS publications and/or professional journals.

Discharge associated with the base flow of key perennial springs are included in the above measurements made at the Paria River at Lees Ferry, Little Colorado River near Cameron and near Desert View, Kanab and Havasu Creeks. Additional monitoring of SW at other springs of concern (e.g., Vasey's Paradise or Bright Angel and Tapeats Creeks) is not currently proposed, but could be undertaken if such data needs are specifically identified by managers.

B.2. Quality-of-Water Measurements

History/Rationale

Quality-of-Water (QW) data have also been historically collected throughout the Colorado River ecosystem. These data have been collected by the U.S. Geological Survey, as well as other agencies, including the Bureau of Reclamation and the National Park Service. During the early twentieth century, interest in QW data focused mostly on suspended-sediment concentration, suspended-sediment grain size (for the calculation of sediment loads and construction of sediment rating curves) and temperature measurements, as related to water supply and sediment flux in the basin. Later, specific conductivity measurements were included as a means of monitoring salinity levels throughout the basin. With growing recreational use of the river and associated environmental studies that began following dam closure, additional QW measurements were periodically made, such as dissolved oxygen and pH. Recent emphasis on endangered, native fish, introduced exotic species and food base dynamics has increased the need for high-resolution monitoring of the above parameters, as well as new parameters related to the nutrient flux, bio pathogens, etc. While the strategy for collecting temperature, conductivity and suspended-sediment data below the dam is relatively obvious, the need for data on nutrients and bio-pathogens still needs to be addressed through ongoing research. An example of where additional information is needed to fully implement long-term QW monitoring can be found in the section describing the state of the food web monitoring program (see below).

Core Monitoring Information Needs

Core monitoring for Quality-of-Water in the CRE addresses Goals 7 and 8, MOs 7.1 – 7.3 and 8.1, and the CMINs associated with these MOs. The CMINs related to QW are summarized in Table B.2.1.

Table B.2.1. CMINs Related to Quality-of-Water

CMIN #	Task/Question
7.1.1	Determine the water temperature dynamics in the main channel, tributaries (as appropriate), backwaters, and near-shore areas throughout the Colorado River ecosystem.
7.2.1	Determine the seasonal and yearly trends in turbidity, water temperature, conductivity, DO, and pH, (decide below whether selenium is important) changes in the main channel throughout the Colorado River ecosystem.
7.3.1	What are the status and trends of water quality releases from Glen Canyon Dam?
8.1.2	What are the monthly sand and silt/clay -export volumes and grain-size characteristics, by reach, as measured at Lees Ferry, Lower Marble Canyon, Grand Canyon, and Diamond Creek Stations.
8.1.3	Track, as appropriate, the monthly sand and silt/clay -input volumes and grain-size characteristics, by reach, as measured or estimated at the Paria and Little Colorado River stations, other major tributaries like Kanab and Havasu creeks, and “lesser” tributaries.

Data Acquisition

To address the CMINs, QW data will be collected at several locations on the main channel of the Colorado River and within several tributaries. The transport of silt/clay and sand will be monitored by measuring suspended-sediment concentration (SSC) and grain-size at various locations along the main channel and at key tributaries. The main channel monitoring locations (summarized in Table B.2.2) will consist of laser-acoustic systems for continuous monitoring of SSC and grain-size that have been developed at GCMRC over the past four years. The laser-acoustic system must be calibrated and validated using physical water samples collected from existing cableways or on river trips, using standard USGS sediment sampling and laboratory analysis techniques. Tributary SSC and grain-size will be measured periodically using standard USGS techniques on an event basis and combined with modeling to provide continuous records of tributary sediment inputs. The combination of main channel fluxes and tributary sediment inputs will provide changes in the mass of silt/clay and sand over time for several reaches of the Colorado River. Other QW data (i.e., chemical and biological characteristics) will be collected using multi-parameter continuous water quality monitors, as well as from physical water sample collection and laboratory analysis. Table B.2.2 summarizes the QW data collection in support of core monitoring.

Table B.2.2. Details of the Quality-of-Water Core Monitoring Program
[1] WT = water temperature, SC = specific conductance, DO = dissolved oxygen, SSC = suspended-sediment concentration

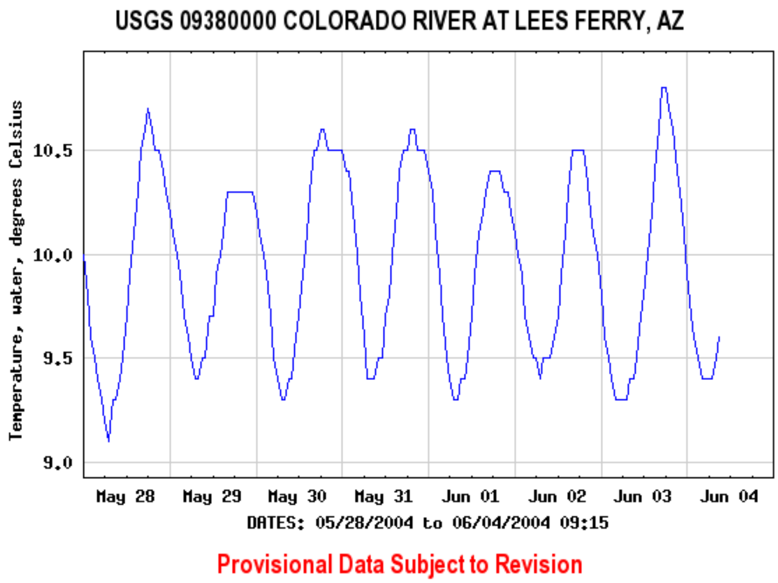
Objective	Parameter(s)[1]	Method(s)	Locations	Frequency	Accuracy and Precision
Monitor water quality conditions in the Colorado River and tributaries, and track the mass balance of fine sediment in the system.	WT, SC, DO, pH Nutrients, major ions	Water quality sensors Physical water samples	**Colorado River** at river miles: - 15 and 0	15-minutes for water quality sensors; monthly for physical water samples	Temperature: ±0.15°C Conductivity: ±0.5% of reading + 0.001 mS/cm pH: ±0.2 DO: ±0.6 mg/L ±10% for mainstream sediment loads. ±20-30 for tributary sediment loads.
	WT, SC SSC and grain-size	Water quality sensors Laser-acoustic system Physical water samples	**Colorado River** at river miles: 30, 61, 87, 166 and 226	15-minutes for water quality sensors and laser-acoustic system; monthly for physical water samples	
	WT SSC and grain-size	Tidbit water temperature loggers Physical water samples	**Paria River** at Lees Ferry, **Kanab Creek** near mouth, and **Havasu Creek** near Supai	15-minutes for water quality sensors; event-based for physical water samples	

	WT SSC and grain-size	Tidbit water temperature loggers Physical water samples	**Little Colorado River**: near Cameron & near Desert View	15-minutes for water quality sensors; even-based water samples for SSC and grain-size; quarterly water samples for nutrients	
	SSC and grain-size	Physical water samples	**Moenkopi Wash** near HWY 89	Event-based	

Quality Control
The GCMRC sediment lab participates in the USGS QA/QC program, thus ensuring the quality of the sediment data processed in the lab. Field sediment sampling will follow standard USGS protocols as laid out in the "Techniques of Water-Resources Investigations of the U.S. Geological Survey" series (http://water.usgs.gov/pubs/twri.). The multi-parameter water quality sensors will be maintained according to manufacturer specifications, including regular cleaning and maintenance of the instruments. No standard protocols exist for quality control of the laser-acoustic systems; however, GCMRC will continue routine maintenance and cleaning of the instrumentation as has been performed during the development of these systems over the past four years.

Data Management, Analysis, and Dissemination
Sediment samples will be processed for concentration and grain-size in the GCMRC sediment lab, which participates in the USGS sediment lab QA/QC program. The conventional suspended-sediment and bed material data will be published annually in a USGS report series, and all sediment data will be maintained in the GCMRC Oracle database and available through the GCMRC website (www.gcmrc.gov). The water quality sensors will have telemetry to provide data real-time over the World-Wide-Web (an example is shown in Figure 2.).

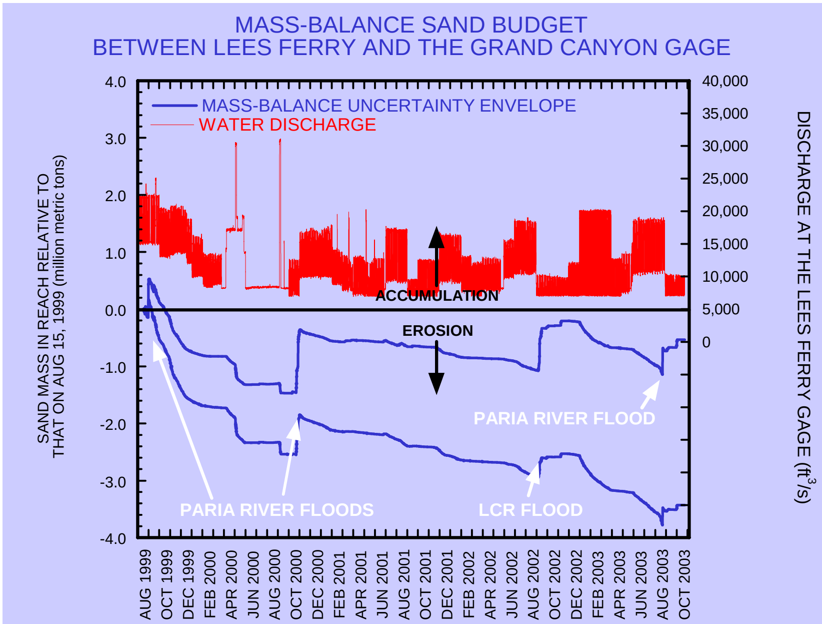
Figure 2. Example of real-time temperature data from Lees Ferry
(http://waterdata.usgs.gov/az/nwis/uv?09380000)



The 15-minute data, monthly and quarterly physical sample results, and bi-monthly backwater temperature data will also be maintained in the GCMRC Oracle database and available through the GCMRC website. A summary of the data will be published annually in a USGS report series (e.g., Open-File Report).

GCMRC staff will analyze the sediment data to determine the mass balance of silt/clay and sand for the various reaches over several time scales (e.g., monthly, annually, periods of small tributary inputs, periods of large tributary inputs, etc.). An example of the mass balance is shown in Figure 3.

Figure 3. Example of suspended-sediment mass balance



These results, as well as the results of other analyses of the status and trends in other water quality parameters, will be presented regularly at TWG and AMWG meetings, as warranted by the findings, as well as published in peer-reviewed USGS publications and/or professional journals.

Some QW data associated with the base flow and flood events that occur in larger, sand producing tributaries containing key perennial springs, are included in the above measurements made at the Paria River at Lees Ferry, Little Colorado River near Cameron and near Desert View, Kanab and Havasu Creeks (temperature and suspended-sediment and grain size). Additional monitoring of QW at other springs of concern (e.g., Vasey's Paradise or Bright Angel and Tapeats Creeks) are not currently proposed, but could be undertaken if such data needs are specifically identified by managers.

B.3. Fisheries Resources

History/Rationale

Fisheries resources in Grand Canyon are the subject of considerable interest among a diverse group of stakeholders directly involved in the GCDAMP, as well as entities outside of the program. These interests focus attention on fisheries resources due to a broad set of issues and concerns that include the conservation of unique and federally listed native species, the maintenance of an important sport fishery in the Lees Ferry reach, and various cultural interests embodied in the health of fisheries resources. As a result of this intense interest, GCMRC and its predecessor (Glen Canyon Environmental Studies) have devoted significant research and monitoring efforts over the last two decades towards gaining a better understanding of the status, trends, and linkages among these resources, and the operations of Glen Canyon Dam. GCMRC recognizes the importance of continuing these efforts in order to provide credible, science based information to the public and decision makers regarding the status of fisheries resources in Grand Canyon.

The history of fisheries monitoring arose from the original recognition by R. Miller about the endangered status of Colorado River fish, several of which were federally protected before the Endangered Species Act was passed. The work of Carothers and Minckley (1981) set the stage for monitoring humpback chub, which still continues, albeit in a more efficient and reliable fashion. Main channel sampling started in 1979 with oar-powered boats bearing electrofishing equipment, and has developed into a highly sophisticated program, following the recognition by Walters et al. (2000) that most of the prior studies had been designed for research, rather than monitoring. Valdez and Ryel (1997) summarized the intensive monitoring studies of the EIS period.

Beginning in 2000, GCMRC began developing a core monitoring program for fishes in the Colorado River Ecosystem (CRE). The initial thrust of this effort focused on four elements of the fish resources in the CRE: (1) Lees Ferry Trout Fishery; (2) Humpback Chub (HBC); (3) Downstream Native Fish; and (4) Downstream Non-Native Fish. At this time, we believe that progress sufficient to define a core monitoring program has been reached for the Lees Ferry Trout Fishery, the LCR population of HBC, and the currently abundant members of the Downstream Non-Native Fish community (i.e. rainbow trout, brown trout, and common carp). However, we believe that our efforts to define a monitoring program for: (1) HBC outside of the LCR population; (2) Downstream Native Fish; and (3) non-abundant members of the Downstream Non-Native Fish community have been largely unsuccessful. We attribute this failure largely to two factors: (1) non-abundant species; and/or (2) inefficient sampling methods. As a result of these factors, recent efforts can be grossly characterized as providing minimal information on the relative abundance and distribution of these resources. Further, these efforts have failed to achieve the specific Core Monitoring Information Needs (CMINs) specified in the AMP strategic plan.

To remedy this situation, we suggest that a major research effort be initiated to develop new techniques and technologies to meet the CMINs relative to assessing the abundance and distribution of these fish resources. This effort may be particularly important to the overall monitoring program as well as future non-native control efforts if major changes in the fish community arise as a result of increased water temperature or other unforeseen events. We envision possible research projects evaluating the use of sonar and acoustic camera technology as potential enumeration devices. These devices also have potential applications relative to evaluating the efficiency of current or proposed sampling gear. Additionally, we would like to explore modified electrofishing configurations and trot lines as sampling gear for channel catfish and other warm water non-native fishes. We suspect that with adequate support, this effort could be completed in 2-3 years and could provide the necessary information to specify a fisheries core monitoring program that addresses all the needs of the AMP.

The remaining sections of this chapter outline a core monitoring program for the fisheries resources for which we feel we have made sufficient progress to define specific procedures. Note that there are several sections that make reference to the research initiative described above.

B.3.a. Lees Ferry Trout Fishery

History/Rationale

Non-native rainbow trout (Oncorhynchus mykiss) were first introduced in 1964 (Stone 1964) into the Lees Ferry reach, a 26 km tailwater immediately below Glen Canyon Dam (GCD). Following introductions of benthic algae (*Cladophora glomerata*) and macroinvertebrates (e.g., *Gammarus lacustris*, chironomids, gastropods) into the tailwater during 1966-69 (Stone and Queenan 1967, Stone and Rathbun 1968, 1969, Maddux et al. 1987) the fishery achieved a “trophy” status by about 1977 (Reger et al. 1989). The fishery achieved national recognition as a blue-ribbon tailwater rainbow trout fishery.

Operation of GCD affects the ecology of non-native rainbow trout and the aquatic food base in the Lees Ferry reach (McKinney et al. 1999). The Lees Ferry fishery was recognized as a resource of concern in the Glen Canyon Dam Final Environmental Impact Statement (1995): “NPS, AGFD, Hualapai, and Navajo objectives for the trout fishery are to provide a recreational resource while maintaining and recovering native fish in Grand Canyon. In the Glen Canyon reach, their objective is to encourage natural reproduction, survival, and growth of trout to blue ribbon quality sizes.”

Angler use and catch rates have been monitored by NPS and AGFD since the late 1970s (McKinney and Persons 1999). Monitoring the fishery by electrofishing has been used by AGFD under both the Glen Canyon Environmental Studies program and the Adaptive Management Program (Grand Canyon Monitoring and Research Center) since 1991. Thorough reviews and data synthesis of the fishery and monitoring program were conducted by McKinney and Persons (1999), McKinney et al. (1999a), and McKinney et al. (1999b). A Protocol Evaluation Panel (PEP) evaluation of the monitoring program was conducted in May 2000 and many of the recommendations of the PEP panel have been incorporated into the sampling program.

Core Monitoring Information Needs

Goal 4 of the Adaptive Management Program Strategic Plan states, “Maintain a wild reproducing population of rainbow trout above the Paria River, to the extent practicable and consistent with the maintenance of viable populations of native fish.” Two management objectives are identified in relation to this Goal: (1) M.O 4.1 Maintain or attain RBT abundance, proportional stock density, length at age, condition, spawning habitat, natural recruitment, and prevent or control whirling disease and other parasitic infections; and (2) M.O. 4.2 Limit Lees Ferry RBT distribution below the Paria River of the Colorado River ecosystem to reduce competition or predation on downstream native fish. Only MO 4.1 is specific to the Lees Ferry area. Core monitoring information needs related to MO 4.2 are addressed in a following section of the plan (Downstream Non-Native Fish).

Table B.3.1. CMINs Related to Lees Ferry Trout Fishery

CMIN #	Task/Question
4.1.1	Determine annual population estimates for age II+ rainbow trout in the Lees Ferry reach.
4.1.2	Determine annual proportional stock density (PSD) of rainbow trout in the Lees Ferry reach.
4.1.3	Determine annual rainbow trout growth rate in the Lees Ferry reach.
4.1.4	Determine annual standard condition (Kn) and relative weight of rainbow trout in the Lees Ferry reach.
4.1.5	Determine if whirling disease is present in the Lees Ferry reach. Determine annual incidence and relative infestation of trout nematodes in rainbow trout in the Lees Ferry reach.
4.1.6	Determine quantity and quality of spawning habitat for rainbow trout in the Lees Ferry reach as measured at 5-year intervals.
4.1.7	Determine annual percentage of naturally recruited rainbow trout in the Lees Ferry reach.

Data Acquisition

The current monitoring program consists of a creel program and an electrofishing program. Data are collected between Glen Canyon Dam and Lees Ferry. The creel program estimates angler use, catch and harvest on a monthly basis. NPS collects and reports angler use on a monthly basis and AGFD interviews anglers for catch and harvest information. The creel data is likely the longest-term dataset available to GCMRC and the PEP panel recommended that the creel program needed to be maintained. Angler catch rates appear to be a useful surrogate for abundance, and our population modeling efforts rely on creel data. Present sampling design can detect a 6-10% linear change in angler CPUE over a 5-year period.

The fishery is sampled by electrofishing to estimate biological parameters to assess the status and trends of the fishery. Electrofishing provides information on size composition (PSD), relative abundance (catch per minute as a surrogate for population size), condition (length weight relationships), and samples are collected for whirling disease examination. Samples are collected at 27 stratified random and 9 fixed electrofishing transects 3 times per year in an augmented, serially alternating sampling design as recommended by the PEP panel. Present sampling design can detect a 6-10% linear change in abundance over a 5-year period. Work is currently underway to assess the statistical power of intra- and inter-annual comparisons. We are evaluating other methods to estimate abundance, including snorkel surveys (Korman et al.); mark-recapture population estimates similar to those done in 1991 and 1998; and depletion sampling to convert CPUE estimates to population estimates.

Present methods for assessing abundance using a catch rate index (CPUE) may or may not be adequate for addressing management objectives and targets. If managers need an "n" (number of fish), further work needs to be done to find the most cost effective way to generate reliable population estimates. We are working to evaluate different abundance estimators and discussing management targets with managers (Arizona Game and Fish Department) and anglers. We will likely suggest some alternative methods to assess the abundance objective rather than "annual population estimates" as stated in CMIN 4.1, or attempt to clarify the CMIN.

Statistical power to detect shifts in size structure (i.e. proportional stock density; PSD) of the rainbow trout population has not been conducted. Present sampling design allows for a detection of 4-10% linear change in relative condition over a 5-year period based on data collected since 1991. However, the statistical power to detect changes in condition is likely greater than reported given that the variability in condition of the population has increased since 2002 corresponding to an increase in mean condition. If the population stabilizes at or near this higher mean and annual variability decreases, 5-year linear changes of less than 4% of the mean may again be detected.

All RBT captured at fixed sites with clipped adipose fin are scanned for the presence of a PIT tag. At fixed sites PIT tags are implanted into fish larger than 150 mm and their adipose fins are clipped for future assessment of PIT tag loss. All brown trout and all native fish larger than 150 mm are scanned for the presence of a PIT tag. All previously unmarked native fishes receive PIT tags. Data are used to address CMIN 4.1.1 and CMIN 4.1.3 as well as CMINs associated with downstream native fish monitoring. At present PIT tagging data for rainbow trout are used only to assess growth and movement. We are investigating the use of otoliths to provide growth data, and may begin utilizing floy tags to increase the sample size and probability of recapture to better assess downstream movement.

Table B.3.2. Specific Elements of the Lees Ferry Monitoring Program

Objective	Parameters	Methods	Location(s)	Frequency	Accuracy & Precision
4.1.1	Relative abundance of rainbow Trout (Electrofishing Catch per unit Effort; CPUE)	Electrofishing	27 stratified random and 9 fixed electrofishing transects between Glen Canyon Dam and Lees Ferry	3 times per year	6-10% linear change in relative abundance over a 5-year period
4.1.1	Relative abundance of rainbow trout (Angler Catch per unit Effort; CPUE)	Creel Survey	Between Glen Canyon Dam and Lees Ferry	Monthly	6-10% linear change in relative abundance over a 5-year period
4.1.2 4.1.3	Fish length and weight to	All fish captured	27 stratified random and 9	3 times per year	4-10% linear

4.1.4	estimate Proportional Stock Density (PSD), growth rate, and Condition Factor	during electrofishing sampling are measured to the nearest mm. Fish larger than 100mm are weighed to the nearest	fixed electrofishing transects between Glen Canyon Dam and Lees Ferry		change in condition over a 5-year period.
4.1.3	PIT tag mark/recapture to assess growth and movement	All RBT captured during electrofishing sampling at fixed sites with no adipose fin are assessed for PIT Tags.	27 stratified random and 9 fixed electrofishing transects between Glen Canyon Dam and Lees Ferry	3 times per year	Evaluations to determine power of sampling to detect changes in growth ore movement rates have not been conducted
4.1.5	Presence of whirling disease and nematode infestation	Approximately 40 fish per year are assessed for whirling disease and nematode infestation	27 stratified random and 9 fixed electrofishing transects between Glen Canyon Dam and Lees Ferry	Annually	Current design appears adequate to assess disease and parasite prevalence
4.1.7	Natural Recruitment	All RBT in Lees Ferry are assumed to be naturally recruited since stocking was discontinued in 1998.	N/A	N/A	N/A

Quality Control

Quality control relative to data delivery will be assured through the use of standardized data collecting, recording, and electronic entry procedures. These include use of standardized fish handling protocols, field data collection forms, and computerized data entry routines. Additionally, various automated summary reports of submitted data are being developed to aid in identifying errors in electronic versions of submitted data.

Copies of original field data sheets are help by the GCMRC Library so that future problems encountered with fish databases may be checked against field data sheets.

Data Management, Analysis, and Dissemination
Analysis and dissemination of core monitoring activities will be primarily through annual reports prepared by principal investigators associated with this monitoring element. As needed, GCMRC will also request periodic synthesis reports be prepared to summarize longer term trends in monitoring data. Finally, data collected associated with core monitoring activities will be presented in GCMRC authored SCORE reports.

B.3.b. Humpback Chub

History/Rationale
Humpback chub are the only remaining member of the genus *Gila* inhabiting the Colorado River between Glen Canyon Dam and Grand Wash Cliffs. This species was the first fish listed as endangered by the U.S. FWS in 1967 and is protected under the Endangered Species Act of 1973. Humpback chub distribution in Grand Canyon has been characterized as occurring in discrete locations or aggregations (Valdez and Ryel 1995). Of these nine aggregations (30 Mile, RM 29.8-31.3; LCR Inflow, RM 57-65.4; Lava Canyon to Hance, RM 65.7-76.3; Bright Angel Creek Inflow, RM 83.8-92.2; Shinumo Creek Inflow, RM 108.1-108.6; Stephen Aisle, RM 114.9-120.1; Middle Granite Gorge, RM 126.1-129.0; Havasu Creek Inflow, RM 155.8-156.7; and Pumpkin Spring, RM 212.5-213.2), only the Little Colorado River (LCR) Inflow is recognized as a population in that it consistently demonstrates some level of successful recruitment (Kaeding and Zimmerman 1983, Valdez and Ryel 1995, Gorman and Stone 1999). The current paradigm is that the remaining eight aggregations exist as a result of either downstream transport of juvenile humpback chub from the LCR Inflow aggregation, or relict fish (30 Mile population) produced in years immediately following construction of Glen Canyon Dam (Valdez and Ryel 1995). However, limited movement between the LCR Inflow and both the 30 Mile and Havasu Creek Inflow aggregations has been observed (GCMRC unpublished data).

Core Monitoring Information Needs
Goal 2 of the Adaptive Management Program Strategic Plan states: “Maintain or attain viable populations of existing native fish, remove jeopardy for humpback chub and razorback sucker, and prevent adverse modification to their critical habitats.” Management Objective 2.1 is to “Maintain or attain humpback chub abundance and year-class strength in the LCR and other aggregations at appropriate target levels for viable populations and to remove jeopardy.” The Core Monitoring Information Needs (CMINs) associated with MO 2.1 are listed in the table below.

Table B.3.3. CMINs Related to Humpback Chub

CMIN #	Task/Question
2.1.1	Determine and track year class strength of HBC between 51–150 mm in the LCR and the main channel.
2.1.2	Determine and track abundance and distribution of all size classes of HBC in the LCR and the main channel.

Data Acquisition

<u>Specific Components of the Humpback Chub Monitoring Program</u>

Little Colorado River Humpback Chub Population

Due mainly to the reproductively functional status of the LCR Inflow aggregation (hereafter referred to as the LCR HBC population) and the distribution of this population in both the LCR and the Main channel of the Colorado River near the confluence of the LCR, monitoring strategies differ among the LCR HBC population and the remaining eight aggregations. The long-term monitoring strategy of the LCR HBC population is essentially a four pronged approach: (1) annual Spring and Fall HBC abundance assessments in the lower 15km of the LCR; (2) annual Spring HBC relative abundance assessment in the lower 1200m of the LCR; (3) annual Spring/Summer collection of HBC mark recapture information in the LCR Inflow (RM 57-65.4); and (4) annual assessment of the overall LCR HBC population abundance and recruitment. This strategy provides a comprehensive view of the dynamics of the LCR HBC population where each of these programs are designed to complement each other. Each element is described in greater detail below.

Annual Spring and Fall HBC Abundance Assessments in the Lower 15km of the LCR

This program has been ongoing since 2000 and annually produces assessments of the abundance of HBC > 150mm TL (Coggins and Van Haverbeke 2001, Van Haverbeke and Coggins 2003, Van Haverbeke 2003, Van Haverbeke 2004). The spring sampling is intended to coincide with the peak of HBC spawning within the LCR and likely provides our most reliable estimate of annual spawning magnitude. The fall sampling is aimed primarily at providing an estimate of the abundance of sub-adult fishes rearing in the LCR. These efforts rely on multiple event mark-recapture analysis of PIT tag data to produce abundance estimates using closed population models. Four twelve-day trips into the Little Colorado River are conducted to collect the data utilized to construct these estimates. These trips occur in the spring (April and May) and in the fall (September and October). Sampling is predominantly conducted using hoopnets evenly distributed throughout the lower 15 km of the LCR.

Recent review of the LCR HBC population monitoring program suggested the current program was adequate with some modifications (Kitchell et al. 2003). One of the proposed modifications was to increase the number of sampling trips in the spring in order to examine heterogeneity in capture probability. This modification will be conducted as a research element as soon as resources allow. However, concerns about handling stress and impacts of monitoring activities on populations will be considered.

Annual Spring Relative Abundance Assessment in the Lower 1200 m of the LCR

This program was established by the Arizona Game and Fish Department in 1987 and has operated continuously through 2004 with the exception of the years 2000-2001(Ward and Persons *In Review*). This program annually produces assessments of the relative abundance (i.e. catch per unit effort; CPUE) of all size classes of HBC, flannelmouth sucker (FMS), blue head sucker (BHS), speckled dace (SPD), and a host of non-native fishes in the lower 1200 m of the LCR. Data is collected during a 30–40 day period in spring using hoopnets set in standardized locations distributed throughout the reach. In general, this effort represents the longest and most consistent database available to infer trends in the LCR HBC population. Importantly, it provides an independent assessment of the spring population estimation trips. The statistical power of this portion of the monitoring program has not yet been assessed, but statistically significant differences in relative abundance are apparent in the most recently submitted report.

Annual Spring/Summer HBC Relative Abundance Assessment in the LCR Inflow (RM 57-65.4)

This program has been ongoing since 2002 with a primary objective of estimating the relative abundance and distribution of native fishes between Lees Ferry and Diamond Creek. Sampling is conducted according to a stratified random design that distributes effort broadly throughout the entire reach as well as focusing on index sites that correspond with HBC aggregations, including the LCR Inflow. Sampling is conducted using trammel nets and hoopnets. During 2002-2004, two annual river trips were conducted with the first concentrating on the stratified random design, and the second focusing on multiple aggregation sites (Johnstone et al. 2003, Johnstone and Lauretta *In Review*).

Based on results from monitoring during 2002-2003, relative abundance data associated with this program is imprecise, requiring at least a 30% linear change in abundance over a 5 year period in order to detect a statistically significant change. However, sampling in this reach does bolster HBC mark-recapture information used in the overall assessment of the LCR HBC population (see below). We recommend retaining one late spring/early summer sampling trip within the LCR Inflow reach to obtain HBC mark recapture information. Additionally, as described under section 2.2 Future Core Monitoring Programs Undergoing Research & Development, we recommend initiating a research effort to develop new technologies and techniques to assess native fish abundance in the main channel of the Colorado River.

Annual Assessment of the Overall LCR HBC Population Abundance and Recruitment

The historic data set and the ongoing activities described above constitute a nearly unparalleled collection of mark-recapture data beginning in 1989. Since 2001, a number of open population mark-recapture abundance estimation models have been constructed to infer LCR HBC population dynamics (GCMRC 2003). The last version of these models, called Age Structured Mark Recapture (ASMR), has recently been reviewed by an independent panel of experts in the assessment of animal abundance (Kitchell et. al. 2003). The panel found that the overall strategy for conducting stock assessment described above was sound and that ASMR was structured appropriately for the data available for this population. The panel recommended minor modifications in monitoring strategy that will be implemented and assessed as research endeavors as soon as resources allow. Additionally, the panel suggested simulations to explore model performance with respect to various fish movement assumptions. The ASMR model provides estimates of population size, recruitment, and appears to be a very effective tool for tracking status and trends of the HBC population.

Table B.3.4. Specific Elements of the LCR HBC Population Monitoring Program

Objective	Parameters	Methods	Location(s)	Frequency	Accuracy & Precision
2.1.1 2.1.2	Abundance	Closed population mark recapture abundance estimators	Lower 15 km of the LCR	Twice annually, Spring and Fall	Target level of precision is CV <15% allowing 25% linear change in abundance over a 5-year period
2.1.1 2.1.2	Relative abundance (i.e. CPUE)	Hoopnet catch per unit effort	Lower 1200 m of the LCR	Annually, Spring	Not yet determined
2.1.1 2.1.2	Mark Recapture data	Sampling with trammel and hoop nets to obtain HBC mark-recapture data for the ASMR model	LCR Inflow reach of the Main channel of the Colorado River (RM 57-65.4)	Annually, late spring/early summer	N/A
2.1.1 2.1.2	Abundance and Recruitment	Analyze all LCR HBC population mark recapture data using ASMR	Data collected in the Lower 15 km of the LCR and the LCR Inflow reach of the Main channel of the Colorado River (RM 57-65.4)	Annually	Limited Monte Carlo simulations suggest a 50% or greater increase in recruitment over last 5 year average recruitment would be detected

Quality Control

Quality control relative to data delivery will be assured through the use of standardized data collecting, recording, and electronic entry procedures. These include use of standardized fish handling protocols, field data collection forms, and computerized data entry routines. Additionally, various automated summary reports of submitted data are being developed to aid in identifying errors in electronic versions of submitted data. Copies of original field data sheets are help by the GCMRC Library so that future problems encountered with fish databases may be checked against field data sheets.

Data Management, Analysis, and Dissemination

Analysis and dissemination of core monitoring activities will be primarily through annual reports prepared by principal investigators associated with this monitoring element. As needed, GCMRC will also request periodic synthesis reports be prepared to summarize longer term trends in monitoring data. Finally, data collected associated with core monitoring activities will be presented in GCMRC authored SCORE reports.

PART 2.2 Future Core Monitoring Programs Undergoing Research & Development

The following section describes core monitoring programs that are still undergoing research and development. The plan is to implement these programs in the near future (during FY06-FY10), after resource linkages to dam operations have been established, monitoring protocols have been piloted in test programs, and the pilot study results have been fully peer-reviewed. Implementation dates for each program varies for each program, depending on the program's current development status. For example, the vegetation program has already undergone four years of research and development, and the results of the pilot program are currently (FY05) undergoing peer-review and evaluation. In contrast, the aquatic food base program will require at least one year of years of research to establish system linkages before effective monitoring protocols can be identified and field tested, then those protocols will require several years of field evaluation to determine their utility, so up to four years to research and development will be necessary before a long-term core monitoring program for the aquatic food base is fully vetted and operational.

B. AQUATIC RESOURCES (continued)

B.2 Quality–of-Water Measurements (additional R&D)

Future Quality-of-Water core monitoring programs, including nutrients, major ions, carbon budgets, dissolved oxygen, and pH will be developed in cooperation with the aquatic food web program that is currently under development. Also, near shore and backwater temperature monitoring protocols are currently under development and will be incorporated into core monitoring as this research is completed.

B.4. Fine Sediment (Sand and finer) in the Aquatic Zone (below 25,000 cfs)

History/Rationale

Despite the loss of some 93 percent of the fine-sediment supply following closure of Glen Canyon Dam, sand and finer deposits persist throughout Glen, Marble and Grand Canyons. Periodic measurements of sand bars, with respect to their area, volume and grain size during the last third of the twentieth century indicate that sand bar erosion has occurred in response to closure of Glen Canyon Dam. Strategic management of the remaining sediment inputs from major tributaries below the dam, such as the Paria River, may result in restoration of sand bars eroded since 1963. The sand deposits of the Colorado River ecosystem require periodic monitoring to determine whether or not management actions, such as the Secretary's current Record-of-Decision, are effective at achieving restoration and maintenance of these resources, as described in the Grand Canyon Protection Act of 1992.

Conservation of new sand inputs, required to achieve restoration, may occur throughout various parts of the river channel, including the deeper portions of the center channel, lateral eddies and higher-elevation shoreline areas. Because of this, monitoring changes in sand deposits must occur throughout the entire channel over periods of years to decades. These measurements need to be made at sufficiently high resolution and spatial coverage to capture both large changes resulting from high-flow events, such as Beach/Habitat-Building Flows (either erosion or deposition) and smaller erosional changes that are known to occur between events. Although research and development of sand-storage monitoring protocols have been underway since 2001, final reporting and review of these methods remains to be completed in FY 2005, before a core-monitoring plan for sand storage change can be completely defined.

Core Monitoring Information Needs

Core monitoring for fine sediment abundance in the channel and eddies below the 25,000 cfs stage addresses Goal 8, MOs 8.1 – 8.4, and the CMINs associated with these MOs. These CMINs are summarized in Table B.4.1.

Table B.4.1. CMINs Related to Fine Sediment in the Aquatic Zone

CMIN #	Task/Question
8.1.1	Determine and track the biennial fine-sediment, volume, and grain-size changes below 5,000 cfs stage, by reach.
8.2.1	Track, as appropriate, the biennial sand bar area, volume and grain-size changes outside of eddies between 5,000 and 25,000 cfs stage, by reach
8.3.1	Track, as appropriate, the biennial sand bar area, volume and grain-size changes within eddies below 5,000 cfs stage, by reach
8.4.1	Track, as appropriate, the annual sand bar area, volume and grain-size changes within eddies between 5,000 and 25,000 cfs stage, by reach

Data Acquisition

GCMRC and its cooperators are currently conducting a research and development project entitled "Long-Term Monitoring of Fine-Grained Sediment Storage throughout the Main Channel of the Colorado River Ecosystem" (FIST), which is scheduled for completion and review in 2005. This project is addressing the fundamental question of whether a reach-based approach can be taken to characterize fine sediment storage throughout the system, i.e., whether changes in the subset of reaches track changes detected by the mass balance project. An individual "site'based" approach has been used to track sand storage changes since 1990 by the NAU Sandbar Studies Group. A reach-based, sub-sampling approach is currently being tested for a larger river corridor area by the FIST project. The answer to the reach-based approach question will have a dramatic influence on the strategy for core monitoring of fine sediment storage. Until this project is completed and peer-reviewed so that this question can be answered, it is not possible to define a complete Core Monitoring Plan for fine sediment storage.

The only aspect of core monitoring for fine sediment storage that can be defined at this time is the estimate of system-wide high elevation sandbar area and volume (above 8,000 cfs), as determined from digital imagery (providing data on unvegetated sand patch area only). The system-wide digital imagery is schedule to be collected in years 2006, 2010, and 2014 (see Chapter 3, Section B, Remote Sensing), thus providing system-wide changes in high elevation sandbar area every four years.

Data Management, Analysis, and Dissemination
The digital imagery data will be stored and analyzed as described in the DASA section of this document. Results of the analyses, including changes in high elevation sandbar area and volume every four years, will be published in peer-reviewed USGS reports and presented to the TWG and AMWG as necessary.

B.5. Coarse Sediment in the Aquatic Zone (below 25,000 cfs)

History/Rationale
The U.S. Geological Survey has studied the influence of tributary, debris-flow derived coarse sediment inputs to the Colorado River ecosystem since the 1970s. Following dam closure, such inputs have occurred regularly and have been shown to be a significant source of change in the geomorphic framework of the river's channel. Experimental research has also shown that dam releases can rework new coarse-sediment deposits relatively quickly during occasional high flows. Owing to the relationship between debris-flow inputs and river bed substrates, including sand bars, debris fans and gravel bars, coarse-grained inputs are included as a key element of the long-term monitoring program in the aquatic ecosystem. Because debris flows typically alter navigation within rapids and often bury camping areas, they are related to potential hazards for recreation enthusiasts. The debris flows and locations of their resulting deposits are not predictable, but historical data suggests an increase in debris-flow frequency during the latter half of the twentieth century. Because coarse-sediment inputs are predicted to continue aggrading areas of the river channel, changes in the distribution of sand versus coarser substrates are of interest with respect to benthic organisms and potential suitability of fish spawning habitats. Changing patterns of sand deposition in and around evolving debris fans (eddy storage of sand) is also of obvious long-term interest.

Core Monitoring Information Needs
Core monitoring for coarse sediment abundance, grain-size, and distribution throughout the Colorado River Ecosystem, below the 25,000 cfs stage, addresses Goal 8, MO 8.6, and CMIN 8.6.1 as stated in Table B.5.1 below.

Table B.5.1. CMIN Related to Coarse Sediment in the Aquatic Zone

CMIN #	Task/Question
8.6.1	Determine and track the change in coarse sediment abundance and distribution.

Data Acquisition
Coarse sediment abundance and distribution below the 8,000 cfs stage in representative reaches may be monitored through the bathymetric surveying and bed classification program, as described in the previous section (pending FY 2005 review of the Fine-Sediment research and development project for sand-storage monitoring). Following a a similar coarse-grained project review in FY 2005, monitoring of debris flow activity is recommended to occur through the use of the system-wide remote-sensing data (digital

imagery) collected once every four years in combination with biennial field trips to collect additional data in areas impacted by debris flows.

Data Management, Analysis, and Dissemination

Analyses of changes in the abundance and distribution of coarse sediment in the aquatic zone will be presented at TWG and AMWG meetings as necessary, and published in peer-reviewed journals and USGS report series as dictated by the findings. Biennial USGS reports will be published documenting the findings of the field trips.

B.6. Aquatic Food Web

History/Rationale

An independent panel (Anders *et al.* 2001) used to evaluate the GCMRC monitoring protocols for the aquatic ecosystem stated, "A long term monitoring program for the food base does not presently exist." They identified that a broader understanding of the energy fluxes, sources (allochthonous and autochthonous) and contribution still remains incomplete for this ecosystem. For this reason, the previous effort and approach should not be considered as the sole component comprising the aquatic food base. Identified below summarizes the historical food base monitoring and research efforts to date.

Over the intervening years since the construction and flow regulation of the Colorado River, research efforts have been directed toward understanding the aquatic ecology of the altered Colorado River ecosystem (CRE) (i.e., as reviewed by Blinn and Cole 1991). Food base, as the term implies is the trophic foundation that energetically supports the fish community existing in the CRE. Although considerable knowledge has been acquired over the last three-decades the research and monitoring efforts have primarily focused on the phytobenthic community (algae and benthic invertebrates). This body of work is substantial and has provided ecological insight on the structure and function of this autochthonous based community; yet it remains only a partial construct of the entire aquatic food base in the CRE.

Physical characteristics of the Colorado River are not unlike other impounded rivers (i.e., stable cold and clear conditions that lack seasonal variability in temperature and flow). Presently, this river supports substantial quantities of standing algal biomass in the upper extent, yet owing to episodic inputs of suspended sediment (Shaver *et al.* 1997) a gradient of declining primary production occurs with downstream distance (Stevens *et al.* 1997a; Stevens *et al.* 1997b). The premise has been that reduced suspended-sediment loads have transformed this once low productive allochthonous system into a highly productive autochthonous system (Shaver *et al.* 1997, Walters *et al.* 2000). The aquatic macroinvertebrate diversity in the CRE is low, consisting predominately of a neoarctic dipteran assemblage. These aquatic dipterans are primarily "simulids" (at least 3-species reported, but not taxonomically confirmed) (Blinn and Cole 1991), and "chironomids" (> 30-species) (Sublette *et al.* 1998; Stevens *et al.* 1998). Other major invertebrate taxa include *Gammarus lacustris* "scuds or side-swimmers" and *Potamopyrgus antipodarum* "New Zealand Mudsnail." Currently, the food base monitoring has emphasized the importance of *G. lacustris* and "some chironomids" because this invertebrate assemblage appears strongly linked to *Cladophora glomerata*. *C. glomerata* is a green filamentous alga and functions as a biological substrate for epiphytic attachment and refugia for invertebrates. These epiphytes are almost entirely diatomaceous species (*Diatoma vulgare*, *Cocconeis placentula*, and *Rhoicosphenia curvata*) (Hardwick *et al.* 1992; Benenati *et al.* 1998), and appear to be the primary diet items grazed on by these invertebrates (Pinney 1991; Blinn and Cole 1991; Shannon *et al.* 1994; Blinn *et al.* 1995).

It has been assumed that the primary source of energy utilized by the fish community is derived from primary production and that these trophic limitations have structured the composition, distribution and abundance of fish community in the downstream reaches (Garrett *et al*. 1997; Blinn *et al.* 1992, 1993, 1994; Shannon *et al.* 1994; Stevens *et al.* 1997). Unfortunately, these past investigations have been limited in scope, focused primarily on the autotrophic paradigm without substantially determining if secondary allochthonous sources contribute to the food web supporting this fish community. Research has focused primarily on causal mechanisms of phytobenthic disturbance and the magnitude of these effects. One such metric used to measure disturbance has been drift, which is a quantitative measure of drifting invertebrates. Findings have indicated that differences in daily flow variation (Libfreid 1989; Angradi and Kubly 1994), large floods (McKinney *et al.* 1999b; Shannon et al. 1996), seasonal growth (McKinney *et al.* 1999b) influence the phytobenthic community. Additionally these studies have viewed drifting invertebrates not strictly as a response variable but also as a metric of food availability for the fish community (Valdez and Ryel 1995; McKinney et al. 1999a). Yet, for all of this research effort no conclusive pattern has been attributable to food resource limitations.

Although standing biomass for both of primary and secondary producers is substantial within the upper tail-water section of Glen Canyon (Blinn *et al.* 1998), the proportion of the channel area potentially available for primary producers remains small (total channel area represents <10% of the CRE) relative to the total channel area for the entire canyon-bound ecosystem. Production measurements based on oxygen-generation using integrated open-channel (Marzolf *et al.* 1999) and closed chamber methods (Blinn *et al.* 1998; Brock *et al.* 2000), and primary production irradiant methods (Yard 2003) are limited for this system. Results from these independent methods have demonstrated both the utility for measuring primary production levels, and the quantity of production that appears to be occurring in Glen Canyon section; however, these monitoring and modeling efforts to quantify cumulative production on a daily, seasonal or annual basis have not been implemented.

Only a few studies have assessed fish diet-use patterns across species, space, and time; and of these most have been conducted and limited to the clear tail-water sections where primary production is known to occur (McKinney 1999b; McKinney and Speas 2001). In the tail-water section diet composition indicates a proportional use of *G. lacustris* and "chironomids." Whereas, diet studies assessing multiple fish species in the more turbid downstream sections of Grand Canyon indicate that *Simulium spp*. appears to have a higher use and perhaps a greater importance across a larger component of the fish assemblage (Maddux *et al.* 1987). More recently, diet analyses for *Gila cypha* "humpback chub" near the Little Colorado River indicate "simulids" are a primary food source (Valdez and Ryel 1995). This dietary use pattern is further supported by preliminary findings from the mechanical trout removal experiment (Coggins *et al.* 2002) that indicate that "simulids" are a significant proportion of rainbow trout diet (>70%) across all seasons (Coggins and Yard 2004).

Core Monitoring Information Needs:
The aquatic protocol evaluation panel initially articulated problems associated with the aquatic food base program, they identified the lack of established linkages between food base and fishes. Also, they identified that a possible consequence of recent increases in primary and secondary production may differentially benefit non-native species (competitors or predators) over native species. Furthermore, they felt that the present program was inadequate and would require more elemental research conducted before an affective monitoring program was developed and in place.

The aquatic food base monitoring program (1997-2003) has been discontinued owing to current management needs and strategic planning, independent reviews (Anders *et al.* 2001) and recommendations made by the GCMRC Scientific Advisor Panel (Palmer *et al.* 2004). For this reason GCMRC is planning on initiating an entirely new scientific effort referred to as the GCMRC Food base Initiative. The original core monitoring objectives and information needs identified for the aquatic food base in the Colorado River ecosystem were to address Goal 1, MOs 1.1 – 1.5, and the CMINs associated with these MOs. These CMINs are summarized in Table B.6.1.

Table B.6.1. CMINs Related to AquaticFood Base

CMIN #	Task/Question
1.1.1	Determine and track the composition and biomass of primary producers between Glen Canyon Dam and the Paria River in conjunction with measurements of flow, nutrients, water temperature, and light regime.
1.2.1	Determine and track the composition and biomass of benthic invertebrates in the reach between Glen Canyon Dam and the Paria River in conjunction with measurements of flow, nutrients, water temperature, and light regime.
1.3.1	Determine and track the composition and biomass of primary producers in the Colorado River ecosystem below the Paria River.
1.4.1	Determine and track the composition and biomass of benthic invertebrates in the Colorado River ecosystem below the Paria River in conjunction with measurements of flow, nutrients, water temperature, and light regime.
1.5.1	Determine and track the composition and biomass of drift in the Colorado River ecosystem.

It remains unknown whether or not the local contribution derived from primary production in the downstream reaches contributes energetically to higher trophic levels; and whether or not the hypothesis that in-*situ* derived organics from autotrophic production drifting downstream from Glen Canyon are the primary organic source (Maddux *et al.* 1987; Valdez and Ryel 1995) across the different trophic levels. Results from previous stable isotopic analysis (Angradi 1994; Shannon *et al.* 2001; Haden *in* *review*) suggest strong linkages that support the current autotrophic paradigm. Yet, notable differences due to fractionation, alternate carbon sources (e.g., allochthonous contribution, atmospheric CO_2), and methodological problems associated with spatial and temporal variability within collection efforts (size, location and schedule) are problematic and affect some of the inferences made. Recent advancements in analytical approaches (mixing models) using multiple isotopes, stochiometric analysis, and other complimentary approaches such as diet analysis have not been combined or applied rigorously.

For this reason, further assessment of data collection methodologies were initiated and pilot studies begun in 1993-1994 to address some of the basic questions associated with food web dynamics in the Colorado River ecosystem.

Data Acquisition:
GCMRC is planning on initiating an entirely new scientific effort referred to as the GCMRC Food base Initiative. To make this scientific effort effective (cost and applicability), a future cooperative agreement will be developed and solicited for in September 2004. The cooperative approach GCMRC suggests is a strong emphasis on hypothesis testing, using a hierarchical structure that focuses research efforts over a dichotomous and sequential process. And depending on the research findings, develop a sampling program that identifies the appropriate biotic metrics and methods to be used for future monitoring of the aquatic food base in this ecosystem.

Two elemental questions need to be understood prior to developing and implementing a long-term monitoring program for the future. These questions are:

1. Is the food base limiting to the fish community in the CRE?
2. And if so, what are the primary source(s) of this energy?

As part of this Food Base Initiative that is to be developed research questions and hypotheses will be structured that track core monitoring information needs. Findings from the Food Base Initiative may require reassessing the existing MOs and CMINs identified above.

While this project has multiple objectives it is anticipated that some objectives are to be approached in a concurrent manner, particularly, with respect to sampling methodologies for monitoring. Ancillary data and collaborative approaches associated with on-going research, monitoring and management projects are encouraged to improve integration among the existing monitoring programs, to reduce duplicative data collection efforts and to improve logistic coordination associated with data collection below Lees Ferry.

As an outcome of this Food base Initiative an appropriate monitoring program will be developed that specifies the necessary methodologies, sampling frequency and trend analysis (accuracy and precision) used. We anticipate a core monitoring program for food base to be in place in 4-5 years.

B.7. Downstream Fishes in the Main Channel

Beginning in 2000, GCMRC began developing a core monitoring program for fishes in the Colorado River Ecosystem (CRE). The initial thrust of this effort focused on four elements of the fish resources in the CRE: (1) Lees Ferry Trout Fishery; (2) Humpback Chub (HBC); (3) Downstream Native Fish; and (4) Downstream Non-Native Fish. At this time, we believe that progress has been sufficient to define a core monitoring program for the Lees Ferry Trout Fishery, the LCR population of HBC, and the currently abundant members of the Downstream Non-Native Fish community (i.e. rainbow trout, brown trout, and common carp). However, we believe that our efforts to define a monitoring program for: (1) HBC outside of the LCR population; (2) Downstream Native Fish; and (3) non-abundant members of the Downstream Non-Native Fish community have been largely unsuccessful. We attribute this failure largely to two factors: (1) non-abundant species; and/or (2) inefficient sampling methods. As a result of these factors, recent efforts can be grossly characterized as providing minimal information on the relative abundance and distribution of these resources. Further, these efforts have failed to achieve the specific Core Monitoring Information Needs (CMINs) specified in the AMP strategic plan.

To remedy this situation, we suggest that a major research effort be initiated to develop new techniques and technologies to meet the CMINs relative to assessing the abundance and distribution of these fish resources. This effort may be particularly important to the overall monitoring program as well as future non-native control efforts if major changes in the fish community arise as a result of increased water temperature or other unforeseen events. We envision possible research projects evaluating the use of sonar and acoustic camera technology as potential enumeration devices. These devices also have potential applications relative to evaluating the efficiency of current or proposed sampling gear. Additionally, we would like to explore modified electrofishing configurations and trot lines as sampling gear for channel catfish and other warm water non-native fishes. We suspect that with adequate support, this effort could be completed in 2-3 years and could provide the necessary information to specify a fisheries core monitoring program that addresses all the needs of the AMP.

B.7.a "Other" Humpback Chub Aggregations

Monitoring to characterize the relative abundance of the eight HBC aggregations (see list above, not including LCR HBC population) has occurred during the same efforts used to characterize the abundance and distribution of native fishes between Lees Ferry and Diamond Creek. During 2003-2004, this effort has consisted of two annual river trips conducted in spring and early summer (Johnstone et al. 2003, Johnstone and Lauretta (*In Review*). One of these trips has been devoted to sampling the entire river between Lees Ferry and Diamond Creek (RM 0 – 225) with a stratified random design in order to characterize changes in native fish distribution and relative abundance within reaches. The other trip is devoted to estimating the relative abundance of HBC within select HBC aggregations. In general, these trips have provided information on the distribution of HBC within the Colorado River but very imprecise information on HBC relative abundance. We have to admit that despite our best efforts over the past 4 years at developing a program to estimate relative abundance of HBC at aggregations other than the LCR HBC population, we have been unable to produce results beyond distributional information. We therefore suggest that a research initiative, as described under section B.2 Fisheries Resources, be initiated to develop new technologies and techniques to assess native fish abundance in the main channel of the Colorado River.

Quality Control
Quality control relative to data delivery will be assured through the use of standardized data collecting, recording, and electronic entry procedures. These include use of standardized fish handling protocols, field data collection forms, and computerized data entry routines. Additionally, various automated summary reports of submitted data are being developed to aid in identifying errors in electronic versions of submitted data. Copies of original field data sheets are held by the GCMRC Library so that future problems encountered with fish databases may be checked against field data sheets.

Data Management, Analysis, and Dissemination
Analysis and dissemination of core monitoring activities will be primarily through annual reports prepared by principal investigators associated with this monitoring element. As needed, GCMRC will also request periodic synthesis reports be prepared to summarize longer term trends in monitoring data. Finally, data collected through core monitoring activities will be presented in GCMRC authored SCORE reports.

B.7.b. Downstream Native Fishes

History/Rationale
Though much attention is focused on the federally listed native fish species within the GCDAMP, three other species of native fish also exist within the Colorado River below Glen Canyon Dam. These species include the flannelmouth sucker, bluehead sucker and speckled dace. While significant effort has been expended to gain a better understanding of flannelmouth sucker population dynamics, little work has been accomplished relative to bluehead sucker and speckled dace. Flannelmouth sucker, bluehead sucker, and speckled dace are found throughout the reach between Lees Ferry and Diamond Creek. Significant spawning activity is found in many of the major and minor tributaries including: Paria River, Little Colorado River, Bright Angel Creek, Kanab Creek, and Havasu Creek. Flannelmouth and bluehead sucker abundance is highest near major tributaries, particularly those listed above, while speckled dace abundance is highest downstream of RM 160 (Johnstone and Lauretta *In Review*).

Core Monitoring Information Needs
Goal 2 of the Adaptive Management Program Strategic Plan states: “Maintain or attain viable populations of existing native fish, remove jeopardy for humpback chub and razorback sucker, and prevent adverse modification to their critical habitats.” Management Objective 2.6 is to “Maintain (flannelmouth sucker, bluehead sucker and speckled dace) abundance and distribution in the Colorado River ecosystem below Glen Canyon Dam for viable populations.” The Core Monitoring Information Needs (CMINs) associated with MO 2.6 are listed in the table below.

Table B.7.1. CMINs Related to Downstream Native Fishes

CMIN #	Task/Question
2.6.1	Determine and track the abundance and distribution of flannel-mouth sucker, blue-head sucker, and speckled dace populations in the Colorado River ecosystem.

Data Acquisition

As described above, monitoring to characterize the relative abundance and distribution of the downstream native fish community has occurred during the same efforts used to characterize the abundance and distribution of HBC in the main channel of the Colorado River. During 2003-2004, this effort has consisted of two annual river trips conducted in spring and early summer (Johnstone et al. 2003, Johnstone and Lauretta *In Review*). One of these trips has been devoted to sampling the entire river between Lees Ferry and Diamond Creek (RM 0 – 225) with a stratified random design in order to characterize changes in native fish distribution and relative abundance within reaches. The other trip has been devoted to estimating the relative abundance of HBC within select HBC aggregations. As with the HBC aggregations, these trips have provided information on the distribution of native fishes within the Colorado River but very imprecise information on relative abundance. We have to admit that despite our best efforts over the past 4 years at developing a program to estimate relative abundance of native fishes throughout the Colorado River, we have been unable to produce results beyond distributional information. We therefore suggest that a research initiative, as described under section B.2 Fisheries Resources, be initiated to develop new technologies and techniques to assess native fish abundance in the main channel of the Colorado River.

B.7.c. Downstream Non-Native Fishes

History/Rationale

Non-native fishes have been present in the Colorado River between Lees Ferry and Grand Wash Cliffs since before the turn of the 20th century. Currently the non-native fish community consists predominantly of cold-water salmonids in the upper part of the system with a gradual transition to a cool and warm-water community dominated by cyprinids, ictalurids, and centrarchids near the terminus of the system. There are no management objectives within the GCDAMP related to preserving or maintaining non-native fishes below the confluence with the Paria River either in tributaries or in the main channel of the Colorado River.

Core Monitoring Information Needs

Management Objective 2.4 states: Reduce native fish mortality due to non-native fish predation/competition as a percentage of overall mortality in the LCR and Main channel to increase native fish recruitment. Core monitoring information needs associated with this M.O. are listed in Table B.7.2 below.

Table B.7.2. CMINs Related to Non-Native Fishes

CMIN #	Task/Question
2.4.1	Determine and track the abundance and distribution of non-native predatory fish species in the Colorado River ecosystem and their impacts on native fish.

Data Acquisition

The current non-native fish monitoring program began in 2000 and is focused between Lee's Ferry and Diamond Creek. The program relies exclusively on electrofishing as a sampling gear, and samples are obtained exclusively in the main channel of the Colorado River. Two sampling trips are conducted in late winter to early spring. Sampling effort is distributed according to a stratified random sample design. Electrofishing samples are standardized to 300 seconds in duration within a single habitat type (Rogers et al. 2003). The program currently has the ability to detect an annual change of less than 10% for both rainbow trout and brown trout abundance over a 5-year monitoring interval. Electrofishing is particularly effective at capturing non-native salmonids (rainbow and brown trout) as well as common carp. Based on sampling using all gear types, these three species dominate the non-native community between Lees Ferry and Diamond Creek. Though CMIN 2.4.1 makes reference to evaluating the impact of non-native fishes on native fishes, we see this as a research endeavor and note that the current monitoring program does not address this impact.

With the advent of increased water temperature released from Glen Canyon Dam as a result of the current low reservoir conditions and possibly a future temperature control device, we suggest that a research effort be initiated to develop better methods for assessing the abundance of warm water fishes that may begin to invade new reaches of the Colorado River. Though we believe that electrofishing is an adequate method to capture the fish species referenced above, we believe that this method may not adequately detect major changes in distribution and abundance of warm water non-natives, particularly channel catfish.

Table B.7.3. Specific Elements of the Downstream Non-Native Fish Monitoring Program

Objective	Parameters	Methods	Location(s)	Frequency	Accuracy & Precision
2.4.1	Relative Abundance	Relative abundance (electrofishing catch rate) of rainbow trout, brown trout, and common carp.	Colorado River (RM 0-225)	Annually, Spring	The current monitoring program has the ability to detect the following river-wide linear annual changes in

					abundance over a 5 year monitoring interval. Rainbow Trout: 6% Brown Trout: 9% Common Carp: 12%
2.4.1	Distribution	Presence/absence of fish species in electrofishing sampling by reach.	Colorado River (RM 0-225)	Annually, Spring	Potentially useful in assessing large and persistent changes in non-native fish distribution (but see above)

Quality Control
Quality control relative to data delivery will be assured through the use of standardized data collecting, recording, and electronic entry procedures. These include use of standardized fish handling protocols, field data collection forms, and computerized data entry routines. Additionally, various automated summary reports of submitted data are being developed to aid in identifying errors in electronic versions of submitted data. Copies of original field data sheets are help by the GCMRC Library so that future problems encountered with fish databases may be checked against field data sheets.

Data Management, Analysis, and Dissemination
Analysis and dissemination of core monitoring activities will be primarily through annual reports prepared by principal investigators associated with this monitoring element. As needed, GCMRC will also request periodic synthesis reports be prepared to summarize longer term trends in monitoring data. Finally, data collected associated with core monitoring activities will be presented in GCMRC authored SCORE reports.

B.7.d. Fish Monitoring Program Below Diamond Creek

History/Rationale

Historically, fish sampling has occurred in the Colorado River below Diamond Creek only sporadically and for purposes associated with documenting baseline conditions and inventories (Liebfried and Zimmerman 1996).

Development of Monitoring Program

There currently is no long-term monitoring plan for fishes in the Colorado River below Diamond Creek. However, as the management objectives associated with fishes typically apply to the Colorado River between Lee's Ferry and the Grand Wash Cliffs, there is clearly a need for a long-term monitoring program between Diamond Creek and the Grand Wash Cliffs. GCMRC has commissioned and is reviewing a monitoring proposal to address this need prepared jointly by the Hualapai Department of Natural Resources, Arizona Game and Fish Department, SWCA Environmental Consultants, and the US Fish and Wildlife Service.

Data Acquisition

Though the monitoring program below Diamond Creek is still in the formative stages, this program is envisioned as an annual survey to characterize changes in the abundance and distribution of native and non-native fishes between Diamond Creek and the Grand Wash Cliffs. We anticipate that sampling methods will include: electrofishing, trammel and hoop nets, beach seines and minnow traps, and angling and will follow design and protocols similar to those used in upstream reaches.

B.7.e. Fish Disease and Parasites

History/Rationale

Concern regarding the effect of disease and parasitic infestation on fisheries resources in Grand Canyon exists associated with several species and for a variety of reasons. For instance, the Lee's Ferry trout fishery is potentially vulnerable to adverse effects associated with nematode infestations as well as whirling disease. Additionally, both the Asian Tapeworm (*Bothriocephalus acheilognath*) and the parasitic copepod (*Lernaea cyprinacea*) are implicated as a potential direct or indirect mortality source for native fishes, including humpback chub (Valdez and Ryel 1995, Clarkson et al. 1997, Cole et al. 2002). There is particular concern that these parasites may become more problematic under increased water temperatures potentially associated with a temperature control device fitted to Glen Canyon Dam. Therefore, the following management objectives and monitoring information needs have been developed by the GCDAMP.

Core Monitoring Information Needs

Management Objective 2.3 states: "Monitor HBC and other native fish condition and disease/parasite numbers in LCR and other aggregations at an appropriate target level for viable populations and to remove jeopardy." Core monitoring information needs associated with this M.O are listed in the table below.

Table B.7.4. CMINs Related to Fish Disease and Parasites

CMIN #	Task/Question
2.3.1	Determine and track the parasite loads on HBC and other native fish found in the LCR and in the Colorado River ecosystem.
2.3.2	Determine and track status and trends in the condition (Kn or Wr) of HBC and other native fish found in the LCR and in the Colorado River ecosystem.

Development of Monitoring Program

The long term monitoring program to assess these CMINS has yet to be formulated. A proposal is being developed by Arizona Game and Fish Department and USGS-BRD National Wildlife Health Center to inventory parasites and diseases and to recommend a long term monitoring program.

C. Terrestrial Ecosystem Resources

C.1. Fine Sediment in the Terrestrial Zone (above 25,000 cfs)

History/Rationale
Long-term objectives related to sand conservation are primarily focused on high elevation sand deposits associated with the terrestrial elements of the Colorado River ecosystem. Recent geomorphic synthesis research by Schmidt et al. (2004) indicates that approximately 25 percent of the sand bar area in Marble Canyon was lost to erosion between 1984 and 2001. Areas above the active fluctuating zone (25,000 cfs) are of particular interest with respect to restoration of sand bars following implementation of Beach/Habitat-Building Flows. Fine-sediment deposits above the active zone have historically been monitored using conventional, analog aerial photography and photogrammetry methods. Because the higher elevation sand deposits are known to erode more slowly than deposits of the active zone, management strategies for sand conservation are aimed at moving new sand from lower areas of the channel to areas above the active zone.

Core Monitoring Information Needs
Core monitoring for fine sediment abundance, grain-size, and distribution in the terrestrial zone addresses Goal 8, MO 8.5, and CMIN 8.5.1, as stated in Table C.1.1 below.

Table C.1.1 CMINs Related to Fine Sediment in the Terrestrial Zone

CMIN #	Task/Question
8.5.1	Track, as appropriate, the biennial sand bar area, volume and grain-size changes above 25,000 cfs stage, by reach

Data Acquisition
This information need will be accomplished through the fine sediment storage core monitoring activities described in Section B.3.2. As for the lower elevation areas, the digital imagery with automated photogrammetry will provide ~~a~~ system-wide estimates of sand bar area and volume above 25,000 cfs every four years.

Data Management, Analysis, and Dissemination
Results of change detection analyses will be published in tandem with the fine sediment in the aquatic zone results.

C.2. Coarse Sediment in the Terrestrial Zone (above 25,000 cfs)

History/Rationale
Coarse sediments deposited by tributary debris flows structure terrestrial habitats associated with hundreds of debris fans throughout the ecosystem. Terrestrial camping areas tend to occur as sand bars above the 25,000 cfs stage elevation located on the margins of these debris fans. Because of the unique association between debris flows, debris fans and sand deposits, coarse-sediment impacts from debris flows are of interest

long term with respect to high-elevation sand storage, biological habitat, archeological site preservation and recreational camping.

Core Monitoring Information Needs

Core monitoring for coarse sediment abundance, grain-size, and distribution, above 25,000 cfs, addresses Goal 8, MO 8.6, and CMIN 8.6.1, as listed in Table C.2.1 below.

Table C.2.1. CMINs Related to Coarse Sediment in the Terrestrial Zone

CMIN #	Task/Question
8.5.1	Determine and track the change in coarse sediment abundance and distribution.

Data Acquisition

As with fine sediment in the terrestrial zone, core monitoring for coarse sediment in this zone will be aided by the remote-sensing overflights. Change-detection monitoring for debris-flow impacts above the 25,000 cfs stage elevation is proposed to be tied to system-wide digital image inventories of river resources conducted once every four years, in combination with collection of terrestrial LiDAR data at selected sites of concern and interest.

Data Management, Analysis, and Dissemination

Analyses of changes in the abundance and distribution of coarse sediment in the terrestrial zone will be combined with the results of coarse sediment in the aquatic zone, and presented at TWG and AMWG meetings as necessary, as well as published in peer-reviewed journals and USGS report series as dictated by the findings. The biennial USGS reports documenting changes in the aquatic zone will also contain the results from the terrestrial zone.

C.3 Terrestrial Vegetation

The environmental impact statement for Glen Canyon Dam (1996) and current AMP strategic plan identify vegetation as a resource of concern that merits monitoring in association with operations of the dam. Vegetation is viewed from many perspectives as a cultural resource and as habitat for animals. The adaptive management program has identified that riparian vegetation should be monitoring for native and exotic species, for the increase or loss of area associated with specific communities, and for the quality of the vegetative communities to support wildlife. Riparian communities in the CRE encompass pre-and post-dam vegetation, marshes, river's edge and springs.

History/Rationale

Vegetation studies have occurred along the Colorado River for more than 65 years. Studies varied from floristic inventories (Patraw 1936; Clover and Jotter 1944) to mapping habitats (Phillips et al 1977, Pucherelli 1986, Waring 1996), to ecological studies either associated with a specific community like mesquite (Anderson and Ruffner 1987) and tamarisk and coyote willow (Stevens and Waring 1986; Stevens 1989), or to address questions about the effects of Glen Canyon Dam releases on the riparian habitats, in general, along the Colorado River (Stevens and Ayers 1993; Stevens et al 1995; Kearsley and Ayers 1996). Pre- and post-dam inventories indicate that many constituents that currently exist along the CRE existed prior to Glen Canyon Dam, though they were less consistently present along the corridor and less abundant (Dodge 1936; Clover and Jotter 1944; Green 1982) as a result of flooding frequency. Mapping habitats has determined that vegetation since 1965 has increased along the corridor, and the most dynamic area is that between the 5,000 – 45,000 cfs stage, the zone most affected by operations. Ecological studies confirmed that hydrology is the primary variable that affects riparian plant assemblages. The effects of hydrology on the riparian community were most noticeable in the mid 1980's in association with high flows that resulted in a lost of up to 85% of the vegetation in low lying areas, and in the 1990s under interim flows which resulted in the loss in marsh or wetland plants at higher stage elevations associated with a reduction in maximum discharges.

In the 1990s, Stevens along with several NAU colleagues, initiated a riparian vegetation effort primarily focused on analysis of a stratified random array of 5 x 10 m study plots. The use of plots versus general aerial mapping was chosen because vegetation mapping is generally difficult to truly replicate, and because cover does not provide much information on the ecological performance of individual plant species. A large number of plots were established to ensure adequate degrees of freedom for multivariate analyses. The plots were randomly located in 7 geomorphic settings associated with the configuration of large debris fan complexes: marsh, bar platform, debris fan, channel margin deposit, middle riparian zone terrace, upper riparian zone terrace, and adjacent uplands. It was recognized early on that annual monitoring of sensitive Upper Riparian Zone and Xeric sites was not necessary, and those sites were recommended for monitoring on a 5-10 yr basis, coupled with aerial photographic analyses (below). Debris fan complexes were randomly selected on 20 sand bars among the Schmidt and Graf (1990) reaches. Control sites were selected in tributaries well upslope from dam operations, and plots were placed on lower and upper riparian zone terraces and in the adjacent uplands in 10 randomly selected perennial and 10 ephemeral tributaries (1-2 in each reach). All stems were identified and measured on each plot, along with measurements of slope, aspect, particle size distribution, % ground cover, shrub, and canopy cover. Several of the dominant perennial plant species were tagged on each plot to develop data on individual plant performance. This monitoring program also recognized that vegetation data on whole debris fan complexes was needed for habitat analysis for terrestrial fauna. Therefore, the DFCs with study plots and sand bar erosion data were also used to initiate a vegetation mapping project using true color aerial photographs.

In addition to plot analyses, this program involved random stops to evaluate non-native plant invasions, which led to NPS invasive management efforts that have virtually completely removed several invasive species (Stevens et al. 2001). Some dendrochronological analysis of riparian trees was also accomplished, and such studies may provide insight into long-term dam effects (Salzer et al. 1996, Mast and Waring 1997). The vegetation study sites were also selected for sand bar erosion studies that focused on the area and volume of sand stored in an eddy, sand bar history through analysis of aerial photographs, the mechanisms of erosion (seepage erosion, hydraulic aggradation and degradation, wave action, wind action, and trampling), and responses of sand bars to experimental flows from 1990-1991.

A protocol review panel convened in 2000 (Urqhuart et al. 2000) recommended that sampling of vegetation be expanded and measurements be tied to discharge to adequately characterize changes in riparian vegetation as related to dam operations. In addition, the panel recommended that sampling be randomized and incorporate other trophic levels (birds, invertebrate food base, mammals, reptiles) to address ecosystem change monitoring. Incorporating these recommendations into the development of a monitoring program that meets the AMP objectives and goals requires a multi-scale approach involving ground-based data collection to provide information about species change, and vegetation mapping using remotely sensed imagery to address riparian zone level (e.g., marsh, new high water, sand beach communities) change. The latter approach also provides a base map for randomizing ground-based sampling points. The approach implemented and currently under evaluation for terrestrial monitoring, consists of: (1) ground-based integrated monitoring (addressed under wildlife this document); (2) ground-based species cover and diversity for vegetation tied to discharge, and lastly; (3) remotely-sensed riparian zone monitoring which feeds back to ground-based sampling and addresses change detection questions related to vegetated area.

Ground-based vegetation monitoring

A new sampling design developed through the RFP process in FY2001 was implemented, involving a rotated panel design for vegetation transects that are coupled to the GUI model, and integrated sampling sites for vegetated habitat and wildlife. The approach for vegetation itself is patterned to some extent from the Environmental Protection Agency's approach for water quality monitoring and by the Forest Service in the Northwest Forest Plan. While determination of the ecological responses of individual species has been reduced, measurements of species cover and diversity relative to operations has become a focus. Measuring change in vegetation in this manner is in its fourth year. The current approach has the ability to detect trend after four years when year 1 panels are revisited (Kearsley et al 2003). As with all monitoring approaches, time is a critical element to determine if this approach meets AMP goals.

Core Monitoring Information Needs

The Management Goal for vegetation states: *Protect or improve the biotic riparian and spring communities within the Colorado River ecosystem, including threatened and endangered species and their critical habitat.* The specific management objectives and core monitoring information needs associated with Goal 6 are listed in tables C.3.1 and C.3.2 below:

Table C.3.1. Management Objectives Related to Vegetation

MO #	Objective
6.1	Maintain marsh community abundance, composition and area in the CRE in such a manner that native species are not lost.
6.2	Maintain NHWZ community patch number and distribution, composition and area to be no lower than values estimated for 1984.
6.3	Maintain OHWZ community abundance, composition and distribution in the CRE.
6.4	Maintain sand beach community abundance, composition, and distribution in the Colorado River ecosystem at the target level.
6.5	Reduce invasive non-native species abundance and distribution.
6.6	Maintain seep and spring habitat in the Colorado River ecosystem.
6.7	Maintain riparian habitat in the CRE capable of supporting Southwestern Willow Flycatcher.

Table C.3.2. CMINs Related to Goal 6 and Management Objectives 6.1 - 6.7

CMIN	Objective
6.1.1	Determine and track the abundance, composition, distribution, and area of the marsh community as measured at 5-year or other appropriate intervals based on life cycles of the species and rates of change for the community.
6.2.1	Determine and track the patch number, patch distribution, composition and area of the NHWZ community as measured at 5-year or other appropriate intervals based on life cycles of the species and rates of change for the community.
6.3.1	Determine and track the abundance, composition and distribution of the OHWZ community as measured at 5-year or other appropriate intervals based on life cycles of the species and rates of change for the community.
6.4.1	Determine and track composition, abundance, and distribution of the sand beach community as measured at 5-year or other appropriate intervals based on life cycles of the species and rates of change for the community.
6.5.1	Determine and track the distribution and abundance of non-native species in the Colorado River ecosystem as measured at 5-year or other appropriate intervals based on life cycles of the species and rates of change for the community.

6.6.1	Determine and track the composition, abundance, and distribution of seep and spring communities as measured at 5-year or other appropriate intervals based on life cycles of the species and rates of change for the community.
6.7.1	Determine and track the abundance, distribution, and reproductive success of southwestern willow flycatcher in the Colorado River ecosystem

Management Objectives and Core Monitoring Information Needs (CMINs) for vegetation have been developed for each identified community type with similar objectives for each. As a result, similar monitoring methodologies may address multiple objectives, though rates of change between communities will differ depending on the extent of herbaceous vs. woody vegetation that characterizes the community, and the heterogeneous nature of the community.

Data Acquisition

Methods

Proposed vegetation monitoring will consist of a ground-based and remote sensing component. The ground-based component addresses management objectives associated with exotic and native species abundance, distribution, diversity, and wildlife habitat as related to vegetative structure (Kearsley et al 2003). Methods to assess compositional changes relative to operations will be tied to stage/discharge and the hydrograph. The sampling approach is currently being considered as a pilot for monitoring pending review. The intent of the approach is to characterize the vegetation along the river corridor using line transect methodologies and grid pilots measured at specific discharge levels. When data are collected across the hydrologic gradient then operational vs. climatic effects can be separated.

The remote sensing component addresses management objectives associated with area, distribution, and to a lesser extent, community composition. Vegetation mapping has the capability of tracking large-scale change and is inherently less specific than ground-based data collections. Data acquisition would be digitally based, orthorectified, and ideally include more than four spectral bands. The current vegetation mapping project determined that four-bands are insufficient to discriminate between some vegetation alliances as their spectral signature is too similar. These similarities reduce the confidence associated with assigning vegetation classes to polygons. Alliance determination would follow standard methods developed by USGS/NPS vegetation mapping program.

Where

Ground-based monitoring: Yearly or biennial data would be collected in a stratified random approach using a rotated plot design to characterize species cover and diversity for the river corridor. As is currently done, 20 sites are fixed and 40 sites are rotated each year. The rotated sites are revisited every four years.

Remote-sensing: Data would be acquired for the entire river corridor through an overflight.

Frequency: The ability to detect trends is dependent on the frequency of revisiting the plots. If plots are visited yearly, then trends can begin to be observed in four years. However skipping years will result in delay in trend detection and essentially double the time to detect changes in resources. The frequency of measurement and scales differ between ground-based and remote sensing components, but these efforts would compliment each other rather than as replicated effort. Ground-based monitoring would occur at a higher frequency (e.g., yearly or biennially vs. semi-decadally for remote sensing), and addresses change at a finer scale (species within a community vs. total community/alliance change for a particular polygon).

Rate of change is an important variable to consider when developing a monitoring plan. Kearsley and Ayers (2001) conducted a review of data and literature of riparian studies completed in the CRE. They concluded that change detection of vegetation attributes varied by vegetation type and parameter measured (e.g., species richness, density). For example, changes in cover can be detected within a year's time for mixed scrub, but changes in diversity for the same community type may take over 20 years. In most cases, change was detectable within five years of measurement. Areas of high density, single species composition were more likely to show little change compared to mixed communities and would require longer time periods for change detection. Because a few management objectives target exotic species, identification of exotic colonizers should be a criterion used in determining data collection intervals. Many species that are considered potential invasive species are often herbaceous annuals or herbaceous perennial species. The introduction and potential spread of these species should be monitored from year to year, particularly in light of long-term operational experimentation that is underway.

Kearsley and Ayers' (2001) analysis also indicated that the minimum number of sites needed to detect change is between 30 and 70, depending on the type of vegetation (Kearsley and Ayers, 2001). The report also indicated that previous sites over-represented some types of vegetation (e.g., tamarisk) and under-represented others (e.g., seep willow).

Table C.3.3 identifies communities and describes the relative amount of diversity encountered, rates of change associated with each, and methodology proposed for trend detection.

Table C.3.3. Vegetation Community, Diversity, Rates of Change, and Methodology Proposed for Trend Detection.

Vegetation community	Species diversity (high, medium, low)	Rate of change	Value used in trend detection	Measurement interval
Marsh community Stage elevation (15k – 35k cfs)	High Mix of annual and perennial herbaceous species. Susceptible to invasive species.	Yearly	Species diversity, wetland scale, Percent cover	Yearly to detect native/non-native ratios and composition shifts, and cover 5-year interval for patch number, community composition inventory.
Sand Beach Community Stage elevation (25 – 45 k cfs)	Medium Perennial shrubs, sparse vegetation. Susceptible to colonization by exotics, like camelthorn	Yearly to biennially	Species diversity, wetland scale, Percent cover	Yearly for cover, native/non-native ratios.
New High Water Zone	Medium	Yearly for cover, 2-5 years for composition	Species diversity, wetland scale, Percent cover	Yearly for cover, some species diversity. 5-year interval for patch number, area, community composition inventories.
Old High Water Zone	Medium to Low	5-10 years for cover and composition	Species diversity, Percent cover, wetland score	5-year interval for patch number, area, community composition inventories.
Seeps & Springs	High	Yearly, dependent on groundwater hydrology	Species diversity, Percent cover,	Yearly for cover, native/non-native ratios

Table C.3.4. Parameters/attributes Measured

Objective	Parameters	Methods	Location	Frequency	Accuracy & Precision
CMIN 6.1-6.5	**Cover, composition, diversity, Distribution** for plants up to 60k cfs. Targets herbaceous annual and perennial species and understory species, invasive exotic species.	**Vegetation transects with meter square quadrants.** Four 1 m square quadrants sampled at 15k, 25k, 35k, 45k, and 60k cfs stage. Species occurrence and cover are recorded to determine diversity, richness, cover and wetland indicator scale. Shannon's Index, Richness, % cover, wetland indicator scale.	Probabilistic sampling throughout CRE, augmented rotated panel design tied to stage/discharge. Measured at 15k, 25k, 35k, 45k, and 60k cfs stages.	Annual or biennially dependent on rate of trend detection desired.	Inter-annual change is 0.05. Power to detect trends at 0.05 is over 4 years if collected annually. Biennial surveys would result in lower accuracy and longer time to determine trends – 8 years. CMIN 6.5 will be difficult to track individual non-native species and introductions that occur in low densities and possibly unevenly disbursed from year to year.
6.1-6.5	**Area** Targets overstory species, dominant cover species like tamarisk and mesquite	**Mapping of vegetation alliances.** Orthorectified digital 4 or more band combined with ground-truthing and supervised classification mapping/image processing methodologies. Using change detection within GIS platform.	Throughout the river corridor	Every 5 years	Vegetation mapping is proposed to occur on a 5-year repeated survey which is within the time frame for CMINS. **Power:** Change detection is every 5 years for all alliances mapped at 500 m^2.

		The mapping effort should address parameter of cover, patch number, patch area. The methodology should provide an associated species list to track compositional shift within alliances that could be compared with yearly surveys.			Significant change is relative to the question such as increase bird habitat vs, increase vegetation encroachment in camping area vs. increased in exotic species patches. Accuracy of 80% for most alliances. Change detection is every 5 years for all alliances.

6.1-6.5	**Composition Distribution**	Vegetation map of alliances. Orthorectified digital CIR combined with ground-truthing and supervised classification mapping/image processing methodologies. Alliance constituents will be delineated using Twinspan/decorana. The mapping effort should address parameters of dominant alliance class and distribution of these classes for the river corridor. The methodology should provide an associated species list to track compositional shift within alliances that could be compared with yearly surveys.	Throughout the river corridor	Tie period is every 5 years.	Vegetation mapping is proposed to occur on a 5- year repeated survey which is within the time frame for CMINS. Accuracy of 80% for most alliances. Change detection is every 5 years for all alliances. The locational precision is to within .50 m

6.7	**Structure**	Total vegetation volume, LiDAR Measurement of vegetation height and canopy structure for bird habitat. Combined with LiDAR data capture that is in support of physical resource monitoring (sand bars).	Randomized sites within the CRE. 64 sites surveyed including 10 repeated sites.	Ground surveys done every 2 years in conjunction with bird surveys. LiDAR data capture associated w/ sediment. monitoring schedule.	Provides a means of measuring habitat for SWWF and other riparian breeding birds.

Quality Control
Data collection will be out sourced through a competitive RFP process to encourage new involvement. Data will be reviewed internally and reports will be subject to internal and external review. Field collection will follow developed protocols.

Data Management, Analysis and Dissemination
Storage: Data will be stored and served through the Oracle database following delivery of data from the cooperator.

Analysis: Data will be analyzed by the cooperator and reporting will include interpretation.

Dissemination: Data will be delivered in yearly reports both of which will be available through the GCMRC website. These data will be used in the SCORE report. The GIS map will be available through the IMS map server on the GCMRC website.

C.4 Wildlife

History/Rationale
Wildlife within the river corridor includes invertebrates, reptiles, amphibians, mammals and birds. Studies associated with wildlife have primarily consisted of inventories (Warren and Schwalbe, 1988, Carothers and Aitchison 1976) although a longer term data set associated with riparian birds, raptors and waterfowl does exist (Brown and Trosset 1989, Sogge et al 1998, Kearsley et al 2003, Yard et al 2004). Bird surveys have been emphasized in the CRE since 1991.

A PEP report (Urqhuart et al 2000) recommended that monitoring needed to include other organisms besides birds to be ecosystem based and that bird surveys needed to become more randomized with emphasis placed on determining habitat quality parameters. Monitoring all faunal elements can be prohibitive due to sample size requirements and time. With respect to some fauna like invertebrates, little background information exists to determine how best to sample and detect trends. To this end, an RFP released in FY2001 requested the development and implementation of an inventory and monitoring approach for terrestrial resources that included wildlife. The funded work has resulted in inventory results associated with invertebrates, bird surveys at new as well as established bird sites, and some survey data associated with small mammals and reptiles. These results are currently under review and will provide direction for establishing a monitoring approach for wildlife.

Wildlife monitoring however may at best become an occasional survey of relative abundance for small mammals and reptiles as surveys for these organisms are time intensive requiring multiple days at a site and densities can be low for any sites. Invertebrate monitoring may focus on particular arthropod guilds and be more amenable to multi-site surveys that are coincident with bird sites. The results of the sampling approach and data synthesis are currently under review and comments will be used to provide focus for the development of a monitoring or survey approach for wildlife in the longer term. In addition, bird survey monitoring has also been reviewed separately and the report and its review will be used to develop protocols for bird monitoring. Bird monitoring will be incorporated with willow flycatcher surveys in the future.

C.5 Threatened and Endangered Species: Kanab ambersnail and Southwestern Willow Flycatcher

C.5.a Kanab ambersnail

History/Rationale

Kanab ambersnail is an endangered land snail that exists in one natural location at Vasey's Paradise and one translocated site near Elves Chasm. The snail was found in 1991 and placed on emergency listing status by the U.S. Fish and Wildlife Service (FWS) in 1994.

Monitoring the status of the habitat at Vasey's Paradise is required by the U.S. FWS. L.E. Stevens, V.J. Meretsky, and others developed small-plot monitoring protocols for Kanab ambersnail (*Oxyloma haydeni kanabensi*s) from 1994-1997 (Meretsky and Stevens 2000, Meretsky et al. 2000), and those techniques have been used by the Arizona Game and Fish Department to monitor snails at Vasey's Paradise and at a successful second population establishment site. A review panel for Kanab ambersnail (Noss et al 1999) and a PEP review for terrestrial resources suggested that sampling be designed to be less intrusive in the habitat and that modeling be incorporated into the monitoring approach. Approaches that need to be evaluated include oblique camera photography and GIS based area change detection that is combined with color infrared bands to characterize dominant vegetation type changes that comprise the snail habitat like monkey flower and watercress.

The reviewers also suggest that a grid system or alternative sampling scheme for snails be considered. Currently data collection employs methods utilized since 1994 and an adaptive sampling approach. Adaptive sampling is being tested because these methods are proving useful for organisms that occur in clumps rather than being evenly distributed. The habitat at Vasey's Paradise while appearing uniformly lush, does have somewhat spotty distribution of preferred vegetation and associated moist soils/substrates that influence snail distribution. The longer-term sampling method approach may overestimate snail abundances if snails are encountered in a small area of a large polygon, while adaptive sampling may underestimate snail abundances if initial random sampling areas are "poor" habitats for snails.

Goals, Management Objectives and CMINs.

Goal 5 of the AMP Strategic Panel is to "Maintain or attain viable populations of Kanab ambersnail." The maintenance of the snails' habitat and tracking population numbers are specific management objectives of the adaptive management program. These are also associated CMINs (see table C.5.1 below).

Table C.5.1. Management Objectives related to Kanab ambersnail

MO	Objective/Task
MO 5.1	Attain and maintain Kanab ambersnail population at Vasey's Paradise from the current level to the target level.
MO 5.2	Maintain Kanab ambersnail habitat at Vasey's Paradise from the current level to the target level.

Table C.5.2. CMINs for Kanab ambersnail.

CMIN #	Objective/Task
CMIN 5.1.1	Determine and track the abundance and distribution of Kanab ambersnail at Vasey's Paradise in the lower zone (below 100,000 cfs) and the upper zone (above 100,000 cfs).
CMIN 5.2.1	Determine and track the size and composition of the habitat used by Kanab ambersnail at Vasey's Paradise.

Table C.5.3. Parameters/attributes measured for Kanab ambersnail.

Objective	Parameters	Methods	Location	Frequency	Accuracy & Precision
CMIN 5.1.1	Snail abundances at Vasey's Paradise	Adaptive sampling of snails in patches. Abundance estimates using standard methods for estimating numbers assuming a closed population.	Vasey's Paradise	Spring and Fall	Snail distribution is spotty and can result in overestimati on of numbers.
CMIN 5.2.1	Habitat area Composition	Land survey of habitat/polygons. Dominant and associated species list within plots sampled for snails.	Vasey's Paradise	Spring and Fall	Survey accuracy within .2cm horizontal positioning. Precision is dependent on rodman interpreting habitat.

Quality Control

Data review follow the data protocol and data standards of GCMRC. Review of reports and methodology also follows GCMRC's review policy.

Data Management, Analysis, and Dissemination
Data are entered after field work into a spreadsheet and database that AGFD has developed. These data allow calculation of snail abundances and to track changes in abundances over time. These data are incorporated into the SCORE report.

C.5.b. Southwestern Willow Flycatcher

History/Rationale
The Southwestern willow flycatcher (SWWF), which is an endangered species, reaches its northern distribution along the Colorado River. Several breeding pairs have been recorded in the Lake Mead area, while the CRE has historically supported fewer pairs, as few as 1 pair for several years (2000-2002). B.T. Brown and M. Sogge and colleagues developed and tested monitoring protocols for southwestern willow flycatchers (*Empidonax trailii extimus*; summarized in Sogge et al. 1997).

Goals, Management Objectives and Core Monitoring Information Needs
Knowing the distribution, abundance and reproductive success of SWWF in the CRE has been identified as a CMIN by the GCD AMP, within Goal 6. MO 6.7 specifically addresses SWWF needs: "Maintain riparian habitat in the CRE capable of supporting Southwest Willow Flycatcher." The CMIN associated with this MO is listed in the table below.

Table C.5.4. CMINs for Southwestern willow flycatcher

CMIN #	Objective/Task
6.7.1	Determine and track the abundance, distribution, and reproductive success of southwestern willow flycatcher in the Colorado River ecosystem.

Components of Monitoring Program

- 3 spring/summer trips—this is a minimum number according to survey protocols. Purpose: to survey for abundance, distribution of SWWF at historic survey sites. Repeated surveys during early to mid-nesting season maximizes detection.
    - 15-31 May; 1-21 June; 22 June – 10 July
- 2 Summer trips to assess reproductive success—these surveys would be dependent on nesting behavior from previous 3 surveys.
- Standard protocols (walking and point count survey methods) developed by USFWS/USGS (www.usgs.nau.edu/swwf/protocol.pdf) will be followed.
- Survey conducted every year in combination with riparian breeding bird surveys,

Because there are so few individual SWWFs along the river corridor, and the management objective pertains to riparian habitat, besides surveying for SWWF, it would be prudent to survey for other riparian breeding birds in their habitats on a yearly basis, as these habitats can be considered surrogates for SWWF. While SWWF protocols are standardized for the southwestern U.S. (Sogge et al 1997), monitoring approaches for riparian breeding birds in the river corridor are currently under review. We anticipate a riparian bird monitoring program to be implemented by 2006 in conjunction with SWWF monitoring.

Table C.5.5. Parameters/attributes Measured for Southwestern willow flycatcher

Objective	Parameter	Methods	Location	Frequency	Accuracy & Precision
6.7	SWWF abundance, distribution, reproductive success	Bird surveys for SWWF and riparian breeding birds Randomized and repeat sites along the CRE. Area surveys and point counts (Ralph et al 1993 (standard methodology for bird surveys)). For SWWF surveys, U.S. FWS protocols will be followed with respect to timing, frequency and observation/tape playing (Sogge et al 1997).	CRE	Requires at least 64 sites/year, resurveyed three times. Annual surveys Historic SWWF sites checked every year.	Visual surveys at historic sites provide accuracy. Timing of nesting and new nest site require multiple trips to established sites and randomization to incorporate new sites.

Quality Control
Data for SWWF surveys require training by USFWS and protocols follow those established by USFWS (Sogge et al 1997). Crews work in pairs to verify sightings.

Data Management, Analysis and Dissemination
Data are entered after field work into a spreadsheet. Data associated with SWWF are required to be submitted to the state game and fish department and the US FWS. These data are also incorporated into yearly reports and the SCORE report. Because these data are essentially presence/absence data, analysis is a very minor component of this work. Locations visited will be recorded in a GIS database as well as point or polygon data.

C.6 Cultural Resources (CR)

Cultural resources in Grand Canyon are of considerable interest to a diverse group of stakeholders directly involved in the GCDAMP, as well as to American and international members of the public. Interests in cultural resources derive from a broad set of issues and motivations that include the following:

(1) a desire to conserve unique and significant archeological sites and other historic properties that serve as tangible representations of our National heritage, as sources of information about the past, and as educational/interpretive opportunities for Park visitors;
(2) a desire to conserve and maintain culturally valued resources such as native plants and mineral sources;
(3) a broad concern for protecting and preserving the multi-cultural values embodied in the Grand Canyon landscape and in the perceived health of the Colorado River ecosystem as a whole.

In response to these diverse interests, Glen Canyon Dam Adaptive Management Program and its predecessor, the Glen Canyon Environmental Studies, have devoted considerable effort and funding over the last two decades towards gaining a better understanding of the condition and linkages among various classes of cultural resources and the effects of Glen Canyon Dam operations on their long-term integrity. In the recent past, GCMRC has sponsored several studies relevant to geomorphic processes and social factors affecting the physical and historic integrity of archaeological sites and other culturally valued resources. GCMRC recognizes the importance of continuing and building on these efforts in order to provide credible science-based information to the public and decision makers regarding the status of cultural resources in Grand Canyon.

The June 2003 version of the AMP Strategic Plan identifies one over-arching goal for cultural resources: **"Preserve, protect, manage and treat cultural resources for the inspiration and benefit of past, present and future generations."** Several Management Objectives fall under this goal:

Table C.6.1. Management Objectives Associated with Cultural Resources

MO #	Objective
11.1	Preserve historic properties in the area of potential effect via protection, management, and/or treatment (e.g. data recovery) for the purpose of federal agency compliance with NHPA and AMP compliance with GCPA.
11.2	Preserve resource integrity and cultural values of traditionally important resources within the Colorado River Ecosystem.
11. 3	Protect and maintain physical access to traditional cultural resources through meaningful consultation on AMP activities that might restrict or block physical access by Native American religious and traditional practitioners.

C.6.1 National Register-eligible historic properties

History/Rationale

Regulations implementing the National Historic Preservation Act specify that cultural resources may qualify for inclusion on the National Register of Historic Places if they are associated with important historic events or people, if they reflect the work of a master, or if they contain important information about the past. Further, the implementing regulations specify that in order to be eligible for inclusion on the National Register, historic properties must contain sufficient integrity to allow their historic significance to be conveyed. Property types that may be eligible for inclusion on the National Register include archaeological sites, historic objects, historic structures, historic districts, cultural landscapes, and traditional cultural properties (TCPs).

There is no specific requirement to monitor cultural resources under NHPA. However, Section 110 of the NHPA requires federal agencies to establish a preservation program for the "identification, evaluation, and nomination" of Register eligible properties, and it specifies that "such properties under the jurisdiction or control of the agency . . . be managed and maintained in a way that considers the preservation of their historic, archeological, architectural and cultural values." Therefore, regardless of the legal requirements of the Grand Canyon Protection Act or the Record of Decision for the Glen Canyon Dam EIS, the National Park Service is obligated to monitor its Register-eligible historic properties to ensure that NPS management actions and other activities do not adversely affect the integrity of those resources.

The National Park Service began monitoring archaeological sites in the river corridor in the 1970s. Monitoring and assessment of archeological and historical cultural sites by the NPS forms the foundation of the present archeological site monitoring program. Tribal oversight of this effort increased dramatically as a result of the GCES and subsequent emphasis on Native American involvement Recognition of the importance of traditional cultural properties and ethnobiology precipitated a flurry of cultural research for the EIS, and an on-going tribal participation process that continues to the present day.

Beginning in the late 1970s and continuing through the 1980s, National Park Service archaeologists monitored a judgmental sample of archaeological sites in the river corridor on an annual basis. These early monitoring efforts focused primarily on documenting visitor impacts. In 1992, following completion of the river corridor archaeological inventory survey (Fairley et al. 1994) and in conjunction with development of the Programmatic Agreement for Cultural Resources (PA), the emphasis switched to monitoring erosional activity, although visitor impacts continued to be tracked.

In 1991, the NPS recommended to the AZ State Historic Preservation Office that the entire river corridor be treated as a single historic property (a historic district) with numerous contributing elements (archaeological sites). Although the AZ SHPO supported this recommendation and determined that such a district was potentially eligible for listing on the National Register, the NPS and other signatories to the PA currently monitor and treat historic properties as individual entities (i.e., on a site-by-site basis) rather than as contributing elements of a historic district.

In addition to archaeological sites, there is another type of National Register historic property recognized in the river corridor: the traditional cultural property (TCP). TCPs are places of traditional cultural or religious importance to Native American tribes or other identified communities (e.g., Grand Canyon river guide community). A TCP may be eligible for listing on the National Register if it is "associated with cultural practices or beliefs of a community that (1) are rooted in that community's history, and (2) are important in maintaining the continuing cultural identity of the community." Several of the Native American tribes engaged in the AMP have identified the whole Grand Canyon, from rim to rim, as a TCP.   Many of the tribes also consider individual archaeological sites to be TCPs, a perspective that contrasts with that of archaeologists, who tend to view these places as sources of scientific information about the past. An inventory of Register-eligible TCPs has not yet been completed for the river corridor.

The current Programmatic Agreement, implemented in 1994 prior to completion of the Glen Canyon Dam EIS, specifically defines a process whereby the Bureau of Reclamation can meet its Section 106 responsibilities for evaluating and mitigating effects of dam operations on National Register eligible properties.   While there are no explicit requirements to monitor Register-eligible historic properties under Section 106 of NHPA, the PA specified that under the interim guidance of a Monitoring and Remedial Action Plan, monitoring would be conducted to "generate data regarding the effects of dam operations on historic properties, identify ongoing impacts to historic properties within the APE [area of potential effect], and develop and implement remedial measures for treating historic properties subject to damage." The ultimate intent of the PA was to "incorporate the results of the identification, evaluation, and monitoring and remedial action efforts into a Historic Preservation Plan (HPP) for the long term management of the Grand Canyon River Corridor District and any other historic properties within the APE". This latter goal – completion of the Historic Preservation Plan- remains an unfulfilled objective of the PA.

Core Monitoring Information Needs

The June 2003 version of the AMP Strategic Plan identifies several Core Monitoring Information Needs (CMINs) associated with MO 11.1, which states "Preserve historic properties in the area of potential effect via protection, management, and/or treatment (e.g. data recovery) for the purpose of federal agency compliance with NHPA and AMP compliance with GCPA." The CMINs associated with MO 11.1 are listed in Table C.6.2.

Table C.6.2.   CMINs Related to Register Eligible Historic Properties

CMIN #	Task/Question
11.1.1	Determine the status of historic properties under Record of Decision operations. (11.1.1a Determine periodically whether the essential physical features are visible enough to convey their integrity or retain their information potential)
11.1.2	Determine the efficacy of treatments for mitigation of adverse effects to

	historic properties.
11.1.3	What are the thresholds for impacts that threaten the integrity and eligibility of historic properties? (11.1.3a Are the current monitoring programs collecting the necessary information to assess resource integrity?)
11.1.4	How effective is monitoring, and what are the appropriate strategies to capture change at an archaeological site – qualitative, quantitative?

CMIN 11.1.1 is being addressed in part through the current PA monitoring program, which tracks the presence/absence of geomorphic activity and visitor impacts at a judgmentally selected sample of approximately 180 archaeological sites. CMIN 11.1.2 is also being addressed in part by the current NPS monitoring program, through revisiting and assessing the integrity of check dams that have been installed at various sites and through periodic assessments of trail closures, vegetation mats, and other stabilization measures that have been undertaken in various locations throughout the CRE. These assessments do not attempt to compare the efficacy of various treatments, however; rather, they determine whether erosion-control features and physical trail closures are intact, still functioning as intended, and whether repairs are warranted
.

The Current Historic Property Monitoring Program

The current historic property monitoring program focuses primarily on one type of historic property: archaeological sites. Archaeological sites have been evaluated as significant primarily under Criteria D of Section 106 implementing regulations, i.e., as sources of information about the past. Their value as traditional cultural properties has been recognized but not yet formally addressed or evaluated through the PA program.

Although NPS has been monitoring cultural resources in the river corridor since the 1970s, the current BOR-funded monitoring program evolved in response to a stipulation of the Programmatic Agreement for Cultural Resources, calling for the development of a Monitoring and Remedial Action Plan. The MRAP was intended to serve as an interim plan while the long-term historic preservation plan (HPP) was being developed. The PA specified that the purpose of the MRAP was "to generate data regarding the effects of Dam operations on historic properties, identify ongoing impacts to historic properties within the APE, and develop and implement remedial measures for treating historic properties subject to damage." The PA further specified (section 3.a) that the information derived from the MRAP would provide the foundation for development of a long-term historic preservation plan, which would define 'the long-term management of the Grand Canyon Historic District and any other properties within the APE." Although the PA called for the HPP to be completed by December, 1994, this document remains unfinished; therefore, the interim MRAP continues to serve as *defacto* program guidance.

The current PA program addresses approximately 318 archaeological sites in the river corridor: 54 in the Glen Canyon National Recreation Area and 264 in Grand Canyon National Park (Leap et al. 2000:I-8). The actual number of sites monitored is less than 180: monitoring has been discontinued at 87 sites in Grand Canyon (Leap et al. 2000:xiii), and at most of the sites in lower Glen Canyon (Chris Kincaid, personal comm.. 2004). All currently monitored sites fall within the Affected Environment as defined by the Final Environmental Impact Statement for the Operation of Glen Canyon Dam (1995). The monitoring is carried out by staff from the National Park Service, working with cooperators from Northern Arizona University.

In the current program, evidence of site deterioration and the effectiveness of on-site erosion control measures are documented on forms and through repeat photography. (A repeat mapping effort was initiated in the mid 1990s but subsequently discontinued due to lack of support from BOR.) The main goals of the current monitoring program are to document changes in site condition and evaluate the need for site protection measures such as check dams (around 300 have been installed to date.) Changes in site condition are documented in yearly reports prepared by the National Park Service and NAU cooperators (see Leap et al. 2000 for a listing of annual reports through 1999; see also: Leap and Kunde 2000; Dierker and Leap 2001; Dierker et al. 2002; Leap et al. 2003.) These reports discuss the results of the site-specific evaluations, identify changes in site condition, and make recommendations about future protection measures, including data recovery.

Table C.6.3. Details of the Current Archaeological Site Monitoring Program

CMIN	Parameter	Frequency	What, where, how and statistical power	Adequacy of design for meeting objective
11.1.1	Evidence of geomorphic change (e.g. erosion, deposition)	Varies by site from 1x/yr to 1x/5y depending on judgment of monitors as to frequency of change and "sensitivity" of resource	**What:** presence/absence of evidence for change in erosion/deposition and visitor impacts in relation to various site features. **Where:** ~180 archaeological sites throughout the CRE. **How:** Empirical observation of evidence for sheet washing or other recently active geomorphic processes. Current condition is also compared with condition documented in photographs during previous site visit. **Power:** Not statistical.	Inadequate due to the lack of integrity definitions, defined thresholds, or clearly established linkages between dam ops and erosional activities and visitor use patterns.
11.1.1	Rate of geomorphic change	No standard interval.	**What:** change in arroyo cross-section. **Where:** **??** judgmentally selected sites. **How:** repeat measurements at	

			specified locations **Power:** Not statistical.	
11.1.2	Efficacy of stabilization measures	Monitoring frequency varies and is tied to site monitoring schedule, rather than to needs for periodic treatment evaluation.	**What:** erosion control check dams; obliterated social trails. **Where:** 27 sites with a total of 260 erosion control features; ?? sites with rehabilitated trails **How**: repeat photographs and verbal documentation on forms **Power:** Not statistical.	

Recommended Monitoring Approaches for the Future

At the time the current monitoring program was being developed in the early 1990's, limited information was available concerning the interrelationship between dam operations and geomorphic changes occurring on adjoining river terraces and river-derived sand deposits. In the past ten years, several studies have been completed that attempt to model the complex relationships between geomorphology, hydrology, human activities, and climatic variables. These include the work of Hereford et al. (1993), Thompson and Potochnik (2000), Pederson et al. (2003), and ongoing studies by Rubin and Draut (2003). A new monitoring program is needed that can specifically test the implications of these models and track and quantify trends in resource condition in relation to dam operations.

Several stakeholders have expressed dissatisfaction with the current monitoring approach for years. Specifically, there is concern that the current monitoring program is not designed to track or quantify trends in resource condition in relation to dam operations. The sites currently being monitored are not representative of the whole system and the frequency of monitoring is biased towards those that are most actively eroding or experiencing the most visitor use, so the monitoring results cannot be generalized to the system as a whole. Also, there is concern over the lack of clear criteria for establishing loss of integrity or specific definitions of thresholds of loss that trigger management intervention. Furthermore, the attributes currently being monitored (evidence of sheet wash erosion, evidence of gullying, evidence of bank slump, evidence of aeolian activity, evidence of various kinds of visitor impacts, etc.) do not necessarily relate to effects of dam operations, and the specific linkages between erosion, other forms of geomorphic change (such as aeolian deflation), visitor impacts, and dam operations have yet to be empirically established.

In terms of treatment monitoring, there is concern that current monitoring approaches do not attempt to evaluate the efficacy of various treatments—rather they determine whether erosion-control features and other treatment measures are intact and still functioning as intended. When these features are damaged, they are generally repaired or reinforced.

Recent work by Pederson et al. (2003) suggests that erosion control measures may be inappropriate in certain geomorphic situations, and that no amount of repair or rehabilitation will change their efficacy in these settings. Pederson recommended a modeling approach for assessing optimal settings for check dam emplacement and as a means of discriminating where check dams are most likely to be effective in the future. A reassessment of the existing check dam program and establishment of guidelines for installing future erosion control devices would seem to be warranted.

An independent PEP review of the entire cultural program in FY2000 identified several issues of concern with the current monitoring program, and produced several broad recommendations for redirecting and refining the monitoring program in the future (Doelle 2000). Specifically, the PEP recommended that the monitoring program be redirected to focus on two primary purposes: "(1) permit NPS to assess the effectiveness of their management strategies (e.g., check dams and other forms of treatment) and (2) [allow] BOR to evaluate the effects of different flow regimes on archaeological sites, native plants, and other resources directly affected by changing water levels and gain and loss of sediment." The PEP report specified that in the future "monitoring should be designed and organized to serve as the basis for periodic quantitative evaluations of effect of dam operations, effectiveness of erosion control measures, and development of treatment plans."

The FY00 Cultural Program PEP made general recommendations about refocusing the monitoring program, but it did not provide many specific recommendations. The Adaptive Management Work Group and Technical Work Group have supported a GCMRC recommendation to convene another PEP to focus specifically on developing a set of core monitoring protocols for cultural resources. The PEP will conduct an overall review of current monitoring protocols in relation to program objectives and recommend new monitoring protocols as appropriate to detect trends in condition relative to dam operations and other environmental parameters.

Proposed Elements of a Future Archeological Site Monitoring Program

Several recommendations are offered below as a means of realigning the current monitoring effort with the stated goals of the AMP strategic plan. The proposed monitoring approaches will be evaluated by the upcoming PEP, along with the current monitoring program.

Recommendation 1): Complete and finalize National Register eligibility determinations. CMIN 11.1.1 and 11.1.1a assume that the essential qualities that make the archaeological sites in the CRE significant (and therefore eligible for inclusion on the National Register) have been fully determined and evaluated. As noted above, several Native American tribes view the archaeological sites in the CRE as significant for reasons other than their information potential. They consider many archaeological sites to be places with symbolic, religious, and/or historical value, rather than merely as sources of interesting information about the past. In other words, the significance of many archaeological resources to the Tribes is tied to past events—and in some cases, particular individuals—that continue to be important in perpetuating the Tribes' unique cultural histories.

Without a formal evaluation of the sites' significance from the Tribes' perspectives, there is no way to weigh the "information potential" values ascribed by archaeologists and other members of the dominant society in relation to the traditional cultural values ascribed by the tribes. Furthermore, without a formal evaluation of the TCPs in the river corridor, the loss of integrity issue cannot be resolved in a meaningful way, because right now, integrity is only being considered from an archaeological (information value) perspective. This is why a complete evaluation of historic property significance, one that fully incorporates tribal perspectives, must be a high priority for future accomplishment under the PA program. Until this is done, the appropriate methods for ascertaining whether or not resources are losing the essential elements that embody their significance cannot be ascertained or implemented.

Until significance evaluations are completed, it is not possible to monitor historic properties for loss of integrity, because significance—as defined by NHPA implementing regulations—is closely tied to the concept of integrity (National Register Bulletin 15). For example, if a historic structure is determined to be significant because it provides an example of a famous architect's unique creative spirit, then that structure needs to retain elements of workmanship, design, materials, and setting in order to convey that architect's special talent. On the other hand, if a property is considered significant primarily for its information potential, then retention of architectural integrity per se may not be so important, but the property must nevertheless contain enough physical integrity to convey the important information it embodies about the past. What constitutes "enough physical integrity" will depend on the particular types of information encompassed by the site. This is why the PEP panel considered completion of a research design so essential to furthering the aims of the PA program, for without one, there is no mechanism for determining whether significant information is being lost.

Recommendation 2): Refocus the archaeological site monitoring program to more effectively detect and quantity effects of dam operations. In the absence of explicit significance evaluations, the cultural program is forced to fall back on physical integrity alone as the means of determining whether and to what extent National Register qualities are being adversely affected by dam operations. Rather than simply monitoring presence/absence of geomorphic activity, however (which may or may not translate into loss of physical integrity), the monitoring program needs to quantify geomorphic change over time in order to establish trends in condition relative to changing dam operations and other environmental parameters (e.g., climatic patterns, visitor use patterns, etc.).

In the past, NPS has attempted to quantify change through repeat topographic mapping of judgmentally selected archaeological sites. More recently, NPS archaeologists have initiated a program of repeat measurements of arroyo cross-sections at selected sites. In neither case has an explicit rationale or justification for undertaking these activities at those particular sites been provided, nor is there a logical plan in place for managing, using, or interpreting the resulting data. Selected monitoring approaches need to be supported by an explicit long-term monitoring strategy that defines the rationale and purpose for collecting certain kinds of information. Furthermore, this strategy needs to be clearly linked to the CMINs and long-term goals of the AMP.

To meet the needs of GCPA for monitoring resource conditions in relation to dam effects, it is recommended that a stratified random sample of archaeological sites be selected for future long-term monitoring. A randomized sample is recommended so that results can be used to characterize archaeological resource conditions for the corridor as a whole and to avoid biasing the conclusions. Stratification of the sample is recommended in order to ensure that a representative sample of sites from a variety of geomorphic settings is included.

Proposed archaeological site monitoring will include both a ground-based and remote sensing component. The frequency of measurement and scales differ between ground-based and remote sensing components and can serve to compliment to each other. Ground-based monitoring would occur at a higher frequency (e.g., yearly, biennially or triennially vs. semi-decadally for remote sensing) and would address geomorphic change at a finer scale (arroyos or features within sites vs. total site areas), however, the sample of sites monitored through ground-based methods would be more restricted than the sample covered by remote sensing. The ground-based component of the proposed program will address management objectives associated with loss of physical integrity, as reflected in a relatively restricted sample of sites. The remote sensing component will track volumetric changes at a larger sample of sites, and relate the observe changes to sand bar dynamics at lower elevations.

The future monitoring program needs to focus on parameters that are relevant to assessing the stability or instability of current archaeological site conditions and tracking trends in those parameters through time. Previous studies by Hereford et al. (1993), Thompson and Potochnik (2000), Pederson et al. (2003), and ongoing studies by Draut and others (2003) confirm that the ongoing erosion and/or stability of archaeological sites in the river corridor is linked to a variety of geomorphic factors, including but not limited to direct and indirect physical effects from dam operations, climatic regimes (primarily precipitation seasonality/volume/intensity and wind direction/intensity), plus human agency (social trailing, trampling, vegetation removal, etc.) Below is a list of some of the relevant parameters that need to be monitored in a systematic fashion, and some possible approaches to monitoring them in the future:

Rates of Erosion and their relation to dam operations: Thompson and Potochnik (2000) developed a mathematical model to predict the vulnerability of archaeological sites to future erosion. Their study identified a suite of attributes that contribute to site stability and/or erosion. Mathematical modeling of these attributes allowed characterization of site vulnerability. The study predicted that some sites were likely to undergo rapid deterioration in the foreseeable future, while others were less likely to do so. The predicted rate of deterioration depended on whether terrace gullies were fully integrated with the main channel or were still in the process of becoming integrated, which in turn related to a suite of physical variables such as catchment size, soil permeability, vegetation cover, etc. The study also identified where further erosion control efforts would be pointless, due to the extent of current channel integration and state of erosion.

The Thompson and Potochnik study was criticized by members of the FY2000 PEP for not giving sufficient weight to the role of hillslope processes (gradient) in driving terrace erosion (Doelle et al. 2000). However, given that the Thompson and Potochnik model has predictive capability that was never field tested, stratifying a sample of sites in terms of the vulnerability categories established in this study would be a logical way to validate (or refute) the Thompson-Potochnik model before investing additional funds in developing additional models. Randomized arroyo cross-section measurements, in combination with thalweg surveys, could be used to quantify rates of erosional activity at sites situated in a variety of geomorphic settings (e.g., terrace sites with river-based channels, terrace sites with terrace-based channels, dune sites with side canyon-based drainages, etc.) over time. Ground based LiDAR offers another potential tool for efficiently tracking changes in topography due to erosion at a selected sample of archaeological sites, while at the same time limiting ground disturbance due to excessive monitoring traffic.

It is important that changes observed at archaeological sites be correlated with the potential geomorphic "drivers" in the system, in order to ascertain the role of dam operations in affecting site stability and/or erosion. Apparent drivers (principle agents) of erosion include river flows and flow fluctuations, precipitation, wind, and human activities. Flow parameters are monitored daily at the dam and at various established sites throughout the river corridor. Currently, weather parameters are routinely monitored at only one station within the CRE: Phantom Ranch.

Given the spotty nature of Grand Canyon's weather, it will be necessary to establish weather stations at several additional locations throughout the river corridor, concentrating in those reaches where most of the archaeological sites occur. These remote weather stations will collect information on rainfall and wind patterns. Data will need to be downloaded at regular intervals (every four to six weeks), perhaps via satellite uplinks. This weather information will be useful not only for the cultural monitoring program, but for several other resources of concern as well (e.g., vegetation, coarse sediment). An estimated 8-10 stations will be established in low-use and visually obscure locations throughout the CRE. Wherever feasible, they will be co-located with existing monitoring instruments to reduce the field time and costs associated with maintaining and down loading the weather monitoring equipment.

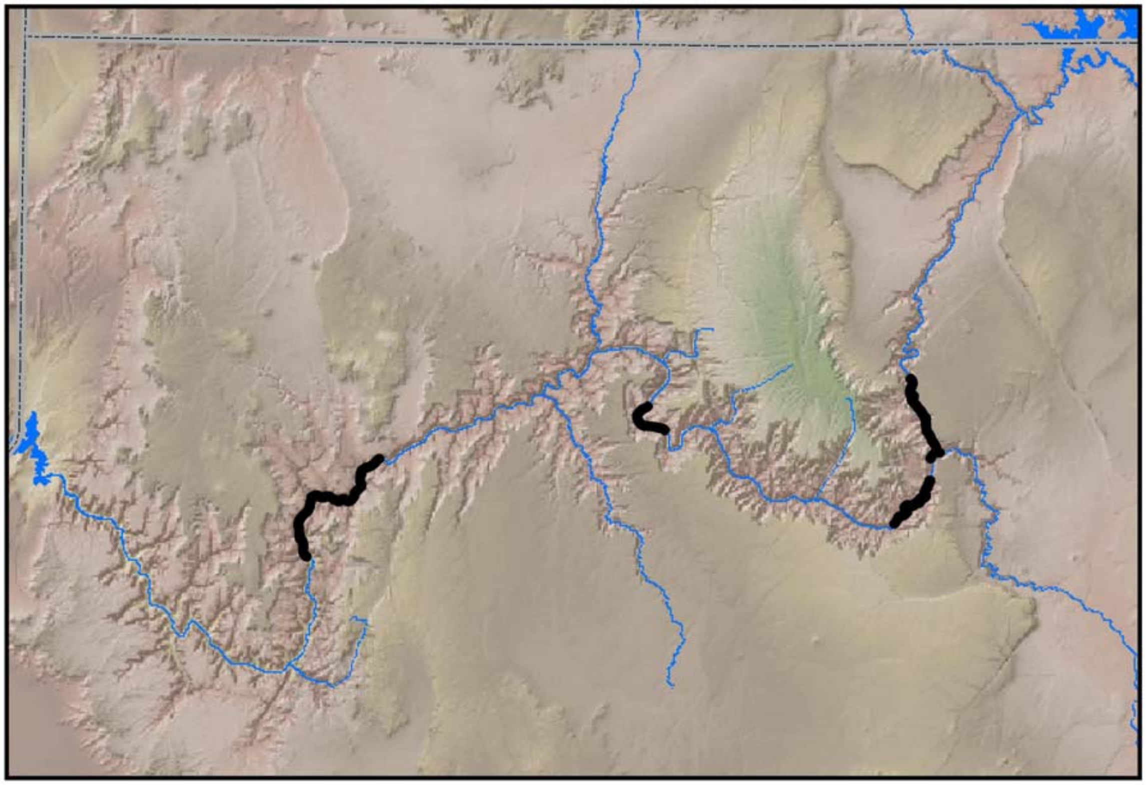
Factors influencing site stability and contributing to preservation: A recently initiated study by Rubin and others focuses on the role of aeolian processes in preserving archaeological sites and mitigating effects of terrace channel cutting (Rubin et al. 2003; Draut et al. 2003, 2004). Several previous researchers (Hereford et al. 1993, Luchitta 199-; Potochnik and Thompson 2000; Pederson 2003) have previously commented on the apparent importance of aeolian processes in stabilizing sites and their potential role in mitigating impacts from gully erosion. In the future, we propose monitoring a judgmentally selected sample of sites that are situated where low elevation sand bars currently provide a source of transportable sediment. At these locations, we will track changes in aeolian sediment deposited on archeological sites relative to bar changes under varying dam operation scenarios. Changes in sand deposition would be quantified through surveys of gully thalwegs, as discussed above, supplemented where possible with topographic data derived from very high resolution LiDAR (either ground based or airborne systems).

Wind blown sand is not the only stabilizing agent on archaeological site surfaces. Several studies outside of the Grand Canyon have shown that cryptobiotic crusts play an important role in stabilizing desert soils (Belnap 2001; Eldridge 1994; Warren 2001). Trampling by livestock or humans can severely damage these crusts, leading to accelerated erosion and surface deflation (Belnap and Eldridge 2001). Despite the fact that visitors have a noticeable impact on the river corridor's terrestrial ecosystem, and the NPS invests considerable time and funding attempting to mitigate impacts from visitor use, the role of visitor use in accelerating erosion within the river corridor generally-- and on archaeological sites specifically -- has not been systematically evaluated or monitored. Area measurements of crytobiotic cover and social trails, using digital imagery, in combination with field measurements of trail depth and surface damage, offer a potential means of tracking the impacts of human beings and their role in accelerating the loss of archaeological site integrity.

Volumetric change detection: The current FIST program defines a series of reaches that serve as proxies for measuring changing sand storage conditions in the river corridor as a whole. Since 1990, changes in sand storage above 8,000 cfs have been monitored through the use of conventional ground surveys. While highly accurate, the conventional survey approach involves a substantial commitment of personnel, field time, and data processing time, and it requires repeated, intensive pedestrian impact over the areas being surveyed. Intensive foot traffic is not a problem in areas with active, low-elevation sand bars; however, it can cause serious long-term detrimental impacts to terrestrial resources in or above the Old High Water Zone. In the future, GCMRC proposes to use airborne LiDAR as a means of tracking topographic change at archaeological sites within specific reaches.

To effectively use LiDAR for accurately tracking topographic changes at archaeological sites requires very high resolution LiDAR. This technology provides accuracies in the range of 7 cm or less, but requires the use of low elevation helicopter flights (approximately 300 m ags), which can negatively impact Park visitors' experience. We propose to monitor selected reaches of the river corridor containing expanses of sandy terrain and high site concentrations with VHR LiDAR. The low altitude remote sensing missions are proposed to be flown once every four years, during the lowest visitor use season, to maximize accuracy (less vegetation cover) and minimize impacts to Park visitors.

Figure 4. Proposed Reaches for Monitoring Archeological Sites with VHR LiDAR



Effectiveness of Treatments: The 2000 Cultural PEP recommended that in the future, the efficacy of treatments be evaluated through a systematic monitoring program. Currently, the NPS monitors check dams through periodically revisiting sites that have received this form of treatment and comparing photographs of the features as they appeared immediately after construction with their current appearance. Checks that have sustained damage are usually repaired.

The study by Pederson et al. (2003) concluded that check dams can be effective in slowing erosion. However they also noted that check dams are not effective in certain geomorphic settings. Pederson proposed developing a mathematical model that would have predictive capability for determining the most and least optimal settings for these features. GCMRC recommends funding a four-year program to develop the model, using a sample of sites that have been treated and are proposed for future treatment with check dams. In lieu of such a model, the next best alternative would be to use the predictive capabilities of the Thompson-Potochnik model for assessing the effective and longevity of check dams under varying geomorphic settings and climatic regimes. Once again, for the results to be interpretable, it is important that changes observed in check dam condition be correlated with the potential geomorphic "drivers" in the system, in order to ascertain the role of climatic variables in affecting check dam stability and/or erosion.

Quality Control
Quality control relative to data delivery will be assured through the use of standardized data collecting, recording, and electronic entry procedures. These include use of standardized field measurement protocols, field data collection forms, and computerized data entry routines. Additionally, various automated summary reports of submitted data that are being developed for other monitoring data sets to aid in identifying errors in electronic versions of submitted data will be applied to the cultural data sets. Copies of original field data sheets will be archived in the GCMRC Library so that future problems encountered with cultural monitoring databases may be checked against field data sheets.

Data Management, Analysis, and Dissemination
One of GCMRC's main responsibilities within the Adaptive Management Program is to serve as the repository for information resulting from research and monitoring activities related to the program. To date (2004), no cultural monitoring information has been turned over to GCMRC by the NPS. In the past, the reasons given by NPS for not sharing data had to do with the lack of a fully functioning data management program at GCMRC and concerns over confidentiality of site location information. The technical aspects of these issues have been resolved in recent years through the development of GCMRC's Oracle Database and implementation of the DASAA program and by the availability of encrypting devices that prevent dissemination of sensitive electronic information to unauthorized users. In the future, cultural monitoring data will be housed at GCMRC, stored in secured systems, and made available to PA signatories and other authorized users on a need-to-know basis. Specific protocols for accessing and disseminating data will be developed by GCMRC in consultation with the NPS, BOR and other PA signatories.

Analysis and dissemination of core monitoring results will be primarily through annual reports prepared by principal investigators associated with this monitoring program. These reports will incorporate and build on trend data from previous years. As needed, GCMRC will also request periodic synthetic reports to summarize and evaluate the long term trends in monitoring data. Finally, data associated with these core monitoring activities will be presented in GCMRC authored SCORE reports.

Proposed Monitoring of Traditional Cultural Properties
Systematic monitoring of TCPs is currently hampered by the lack of a complete inventory and formal evaluation of tribal TCPs within the CRE. Because TCPs are highly variable in nature, ranging from unmodified natural landmarks to humanly crafted structures and from very small areas to extensive expanses of terrain, it is necessary to identify the TCPs and their values in order to devise appropriate monitoring strategies.

Initial identification and evaluation of TCPs must be carried out by the community that values these resources, as the values are in most cases culturally specific. Many Native American communities are reluctant to identify TCPs for fear that these places will be co-opted or desecrated by culturally insensitive people. It is nevertheless necessary to identify the values associated with TCPs, at least in a general sense, in order to ensure that monitoring and management approaches are relevant and sensitive to the particular resource of concern.

Regardless of the final inventory and evaluation results, future monitoring of TCPs needs to be explicitly linked to the goals of GCPA and the needs of the AMP for current information on the status of resources relative to dam operations. Currently, three of five tribal entities engaged in the AMP are conducting monitoring programs of one kind or another in the CRE. Most of these programs monitor one or more tribally-identified (although not yet formally evaluated) TCPs. In no instances are any of the current tribal monitoring programs explicit about the rationale, purpose, or goals of TCP monitoring relative to the needs of the AMP. The upcoming PEP will be reviewing these programs in the near future. GCMRC will work with the tribes to provide guidance on implementing the PEP recommendations and modifying current protocols as necessary to meet the specific needs of the GCDAMP.

C.6.2 Cultural Resources not eligible for listing on the National Register

History/Rationale

Cultural resources not eligible for listing on the National Register include a broad suite of plants, animals, and minerals that Native Americans traditionally or currently use in ceremonies, as medicines, and in daily living. Numerous native plant and animal species in the CRE have been identified by the Southern Paiute, Navajo, Hualapai and Hopi people as having significant cultural value (Jackson 1993; Lomaomvaya 1999; Southern Paiute Consortium and Bureau of Applied Research 1997).

Since the mid 1990s, three of the five tribal entities participating in the AMP (Southern Paiute Consortium, Hualapai, and Hopi) have monitored some of their traditionally-valued resources at selected locations in the river corridor in conjunction with the annual tribal river trips sponsored by the AMP. Like the current historic property monitoring program, current tribal monitoring of non-eligible cultural resources is not explicit in terms of the purpose, rationale, or long-term goals. The methods being used are highly variable, and the data being gathered and reported is not always clearly tied to the needs of the AMP for information on the effects of dam operations.

In 2001, GCMRC attempted to engage the Tribes in the development of a long-term terrestrial ecosystem monitoring program (TEM) that would incorporate tribal needs for information about non-eligible plant and animal resources of cultural importance. This attempt has met with only limited success. Although representatives from Southern Paiute, Hualapai, and Hopi have attended most of the TEM meetings, and representatives from Hopi and the Kaibab Band have participated on at least one TEM river trip, only the Hopi Tribe has provided specific input to GCMRC about the program and offered suggestions on how current data collection strategies could be modified or supplemented to meet their specific needs. Hualapai and Kaibab representatives have indicated that their needs are not being met through the current TEM program, and they have orally expressed the opinion that their needs can never be met through the program as currently designed, because the resources of interest to them are tied to specific locations in the river corridor, while the TEM program relies on a randomly selected sample of study sites, none of which overlap with their specific locations of interest.

Table C.6.4. Management Objective and Core Monitoring Information Needs Related to Non-Register Eligible Cultural Resources

MO/CMIN #	Task/Question
MO 11.2	Preserve resource integrity and cultural values of traditionally important resources within the Colorado River.
11.2.1	Are the traditionally important resources and locations for each tribe and other groups being affected?

Proposed Program

Current tribal monitoring of traditionally valued resources will be reviewed as part of the upcoming cultural monitoring PEP. Both the tribes and reviewers will be asked to assess the current programs in terms of their relevance to GCPA and the AMP goals and to the management objectives identified in the AMP strategic plan. Tribes will be asked to articulate their rationales for using specific approaches and methodologies, as well as the values of interest to them that they consider important to monitor and preserve. For example, if a tribe's primary interest is with preserving the full suite of native plants associated with certain culturally important locations in the river corridor, a monitoring strategy that is specifically designed to measure and track the proportion of native vs. non-native plants at those locations needs to be developed. On the other hand, if a tribe is particularly concerned with tracking the abundance of a specific plant or animal species, a different monitoring approach will be required. The first step, however, is for the tribes to define the values of interest to them and articulate the parameters they need to track in order to determine whether those values are being retained, degraded, or enhanced under current dam operations.

C.7 Recreational Resources

Recreational resources, also known as visitor use values, encompass several diverse elements. Tangible resources include the trout fishery at Lees Ferry, the challenging whitewater rapids in the Colorado River, and camping beaches along the shore of the river. Recreational resources also encompass experiential attributes, such as opportunities to experience solitude, visual and auditory aesthetics of the natural environment, and the physical and mental challenges that come with living in a wilderness-like setting.

Recreational issues of specific concern to the GCDAMP include changes in the range of recreational opportunities and/or quality of recreational experiences within the CRE (including trout sport fishing, recreational river trips, and wilderness-dependent recreational opportunities) due to effects of dam operations, affects on visitor safety due to dam operations, and changes in the size and availability of camping beaches due to dam-controlled flows. The economic impacts to the recreation industry from varying flow regimes has also been identified as a concern of the program.

The AMP have defined five management objectives under Goal 9: "Maintain or improve the quality of recreational experiences for users of the Colorado River ecosystem, within the framework of the GCDAMP ecosystems goals." The management objectives are listed below in Table C.7.1. Core Monitoring Information Needs (CMINs) associated with each of the MOs are discussed separately under the relevant sections that follow.

Table C.7.1. Management Objectives Related to Recreation

MO #	Objective
9.1	Maintain or improve the quality and range of recreational opportunities in Glen and Grand Canyons within the capacity of the Colorado River ecosystem to absorb visitor impacts consistent with the NPS and tribal river corridor management plans.
9.2	Maintain or improve the quality and range of opportunities in Glen and Grand Canyons in consideration of visitor safety, and the inherent risk of river-related recreational activities.
9.3	Increase the size, quality and distribution of camping beaches in critical and non-critical reaches in the main channel within the capacity of the Colorado River ecosystem to absorb visitor impacts consistent with NPS and tribal river corridor Management Plans.
9.4	Maintain or enhance the wilderness experience in the Colorado River ecosystem in consideration of existing management plans.
9.5	Maintain or enhance visitor experiences as a result of GCDAMP research and monitoring activities.

C.7.1. Quality of Recreational Experiences

History/Rationale

Maintaining a high quality experience for Park visitors is a core objective of the National Park Service nationwide. As a nationally designated Recreation Area, the Glen Canyon NRA has a specific mandate to maintain diverse and high quality recreational opportunities for visitors. Providing recreational opportunities *per se* is not a core objective of Grand Canyon National Park, but providing for the enjoyment of "scenery and the natural and historic objects and the wildlife . . . in such manner and by such means as will leave them unimpaired for the enjoyment of future generations" is central to its stated mission. The importance of maintaining, protecting and improving visitor use values through dam operations was identified as a key goal of the future GCDAMP in the Grand Canyon Protection Act of 1992.

Evaluating and monitoring experiential attributes is a complicated undertaking for a variety of reasons. For one thing, visitors to the Parks come from all over the world and bring with them a diverse set of expectations and values, many of which are culturally determined. Many visitors come only once in a lifetime, precluding the possibility of making any comparison of change in the perceived quality of their experience over time. Furthermore, the expectations and values of the public tend to change in conjunction with changing circumstances in the world at large, making it difficult for managers to compare qualities from one time period to the next. For example, with the planet's population doubling every 30-35 years, people the world over are becoming accustomed to increasingly crowded conditions. Therefore, what seemed crowded to visitors in the 1970s may no longer seem crowded to most visitors in the 21st century, even though the actual number of people using the Parks has increased significantly since the 1970s.

In addition to crowding, some of the elements that affect the experiential aspects of recreational quality include perceived levels of safety or risk (e.g., likelihood of getting hurt or killed) and perceived levels of personal reward (e.g., numbers and size of fish caught, opportunities to socialize, opportunities to experience natural quiet in a wilderness setting). Again, the quality of experience will vary and depend in large measure on the expectations that visitors bring with them. If a visitor comes to Lees Ferry with expectations of catching lots of large trout and they don't succeed in doing so, the quality of their experience is likely to be rated less than satisfactory. On the other hand, if they come expecting to spend the day fishing in a beautiful, quiet setting away from crowds and man-made noises and are successful in finding a location where these expectations are met, they may perceive the experience as better than satisfactory, despite never catching a single large fish.

Recreation monitoring was initiated by Shelby and his colleagues in the 1970s and continued by Brown and Hahn-O'Neill (1988). Visitor use monitoring has been largely focused on white water boating in Grand Canyon and campsite use, and it encompasses data on visitation rates and trip types. River running safety data have been synthesized for the period of record up to Year 2000 by Myers et al. (1999). Jalbert (2003) evaluated the effect of FY2000 low, steady flows on visitor use patterns, including safety issues.

A fairly recent study by Stewart and others (2000) provides some baseline data on visitor preferences relative to dam-controlled flows and quality of camping opportunities. This study may provide a useful starting point for tracking changing perceptions in the future. The study concluded that users of the Colorado River were relatively unconcerned about impacts of fluctuating flows, had strong concerns (generally positive) about impacts of spike flows, and strongly preferred sandy beaches with shade (especially from trees) for camping.

Because the visiting public enters to the National Parks with diverse expectations and objectives, not all of which are compatible with the NPS mission, the Park Service must establish specific objectives for the types of recreational opportunities it plans to provide, consistent with its dual mandate to "protect and conserve" resources and "provide for their enjoyment". Borden (1976) made a similar observation in his pioneering study on carrying capacity in the Grand Canyon river corridor, when he stated that, "policy is the basic definer of visitor capacity." For this reason, future monitoring of recreational quality cannot be undertaken without reference to the Park Service's specific goals and objectives for providing certain types and qualities of recreational opportunities within the CRE. Grand Canyon National Park is currently (2004) redefining its visitor use objectives for the Colorado River corridor through development of a Colorado River Recreational Management Plan. The status of visitor use planning for the lower Glen Canyon reach is unknown at this time.

Core Monitoring Information Needs
Four of the five recreational management objectives are directly concerned with maintaining or improving the range and quality of recreational opportunities in the CRE: MO 9.1, 9.2, 9.4, and 9.5. The CMINs that specifically track recreation experience qualities are listed below in Table C.7.2. CMINs that do not specifically relate to recreational experience qualities (e.g., CMIN 9.1.4) are discussed elsewhere.

Table C.7.2. CMINs Related to Various Experiential Aspects of Recreation

CMIN #	Task/Question
9.1.1	Determine and track the change in recreational quality, opportunities and use, impacts, and perceptions of users in the Colorado River ecosystem.
9.1.2	Determine and track the frequency and scheduling of river-related use patterns.
9.1.3	Determine and track the level of satisfaction for river-related recreational opportunities in the Colorado River ecosystem.
9.2.1	Determine and track the change in quality and range of opportunities in consideration of visitor safety and the inherent risk of river-related recreational activities.
9.2.2	Determine and track accident rates for visitors participating in river-related activities including causes and location (i.e., on-river or off-river), equipment type, operator experience, and other factors of these accidents in the Colorado River ecosystem.
9.4.1	Determine and track the effects of Record of Decision operations on elements of wilderness experience specific to the Colorado River ecosystem.
9.5.1	Determine and track the frequency and scheduling of research and monitoring activity in Glen and Grand Canyons.

Current Monitoring Approach
A well-defined monitoring approach that captures changes in visitor perceptions about their experience in the CRE relative to the effects of dam operations is not currently in place. This deficiency has been acknowledged by the AMWG. The AMWG approved funding for a recreation PEP in FY04. With concurrence from the TWG and AMWG, this review has been postponed until spring, 2005. Monitoring protocols suitable for tracking trends in recreational opportunities and experiential qualities will be two of several recreational resource concerns considered by this PEP.

Proposed Monitoring Program

The future monitoring program is likely to involve the use of several survey instruments that are distributed randomly once every four or five years. These surveys will need to be tailored to the specific recreational experiences of interest, e.g., white water rafting; trout fishing. Hiker use the river corridor may also be targeted. These surveys will be designed to measure how satisfied visitors are by their experience, with reference to the experiential goals established by NPS and the effects of flows on the targeted experience.

A random sample of river and fishing guides will be queried in addition to a sample of visitors, because guides are more consistently and directly affected by the changes in dam controlled flows than visitors who don't routinely operate boats on the river. Also, commercial guides are much more in tune with safety issues associated with flow changes than first-time visitors.

As noted above, it is essential that the NPS articulate its experiential goals before the monitoring program is implemented, so that the degree to which dam operations (or other factors) impinge on the successful achievement of those goals can be assessed. For example, if the Park Service decides to continue managing the river corridor below Lees Ferry as a wilderness, but trips routinely become congested in the Upper Granite Gorge on Saturdays, because boaters anticipate that flows will become dangerously low on Sundays and therefore converge above Hance and Horn Creek before the flows drop below 8,000 cfs, then the desired wilderness experience would be adversely affected. This is just one example of how changes in flows can improve or degrade the perceived qualities of a managed recreational experience.

The future recreational monitoring program will also track boating incidents (on-river injuries and costly equipment damage) relative to flows and the changing conditions of rapids over time. The latter aspect will require coordination with the coarse sediment monitoring program, which will remotely track changes in rapids due to debris flow and main channel flood events. A simple survey instrument will be developed that can be completed by commercial outfitters and private trip leaders to document boating incidents relative to specific flow regimes.

Quality Control

Quality control will be assured through the use of standardized data collecting formats, recording protocols, and electronic entry procedures. These include use of standardized survey instruments and computerized data entry routines. Additionally, various automated summary reports of submitted data that are being developed for other monitoring data sets to aid in identifying errors in electronic versions of submitted data will be applied to the recreation survey data. Copies of original field data sheets will be archived in the GCMRC Library so that future problems encountered with recreation monitoring data may be checked against field data sheets.

Data Management, Analysis, and Dissemination

Data resulting from periodic surveys of the recreational community will be stored on the Oracle data base in tabular formats. Analysis and dissemination of monitoring results will be primarily through reports prepared by principal investigators associated with this monitoring program. These reports will incorporate and build on trend data from previous surveys. As needed, GCMRC will also request periodic synthetic reports to summarize and evaluate the long-term trends in the monitoring data. Finally, data associated with these core monitoring activities will be presented in GCMRC authored SCORE reports.

C.7.2. Campsite Monitoring

History/Rationale

Sand bars serve as campsites for rafting groups and are highly valued based on amount of sandy area, boat mooring quality, wind protection, access to side canyon hikes, scenery, and shade. Historically, camping beaches were replenished annually by sand and silt transported by the river during spring runoff. Today, beaches downstream of Glen Canyon Dam are diminishing in size due to the erosive power of the river's clear, sediment-free flows (Kearsley et al., 1994) and the absence of scouring floods that prevent vegetation encroachment on open sand areas. Camping beaches are also being degraded through gullying induced by monsoon rainstorm runoff and by debris flows that cover beaches with boulders and cobbles. The absence of flows sufficient to rebuild the bars further contributes to the loss of campable areas.

The first attempt to assess recreational carrying capacity in the Grand Canyon river corridor was undertaken by Borden (1976), in conjunction with the first (and so far only) effort to establish a visitor carrying capacity for the river corridor. Campsite size and availability in critical (narrow) reaches of the river corridor were found to be the principle limiting parameters of visitor capacity. Size and availability of camping beaches was also found to be tied to visitor experience parameters in that the decreasing size, abundance, and distribution of campsites can lead to crowding and reduction in visitor access to recreational opportunities (e.g., attraction sites, side hikes), thereby creating adverse impacts to visitor use values. Kearsley et al. (1993 and subsequent work) followed up on monitoring the fate of individual sand bars to erosion and overgrowth.

In 1994, change in campable area from previous studies was analyzed using aerial photographs (Kearsley et al., 1994). This analysis revealed that loss of campsites was an ongoing process. They noted that not all sand bars responded in the same manner to flows and vegetation encroachment, and that campsite availability in critical reaches (Marble Canyon, the Inner Gorge, and the Muav Gorge) had decreased the most. Effects of the 1996 controlled flood at selected campsites were also evaluated, and it was found that the increase in the number and size of campsites was of short duration (Kearsley et al., 1999). The post-BHBF data indicated that while floods temporarily increased campsite number and size, the beneficial effects to campsites were temporary, and that campsite size rapidly degenerated to pre-BHBF levels and then continued to erode more slowly. Although the effects of the 1996 artificial flood were temporary, periodic “floods” above power plant capacity appear to be the only feasible means of depositing sediment and rejuvenating camping beaches above normal fluctuations (Kearsley et al., 1999).

Core Monitoring Information Needs
The AMWG strategic plan identifies two CMINs under Management Objective 9.3 related to camping beaches. These CMINs are listed in Table C.7.3 below.

C.7.3 Core Monitoring Information Needs for Camping Beaches

CMIN #	Task/Question
9.3.1	Determine and track the size, quality, and distribution of camping beaches by reach and stage level in Glen and Grand Canyons.
9.3.2	Determine and track the effects of Record of Decision Operations on the size, quality, and distribution of camping beaches in the Colorado River ecosystem.

Current Monitoring Program
Annual monitoring of a judgmentally selected sample of campsite areas has been ongoing as part of the FIST program. These campsites were originally selected for monitoring in the early 1990s and have been monitored more or less continuously, using area survey techniques, for the past decade. Results from this monitoring indicate that camping areas are continuing to erode (Kaplinski et al. 2004).

In addition to the quantitative evaluation of beach area, camping beaches are also being monitored in a less rigorous, more qualitative fashion through the Adopt-A-Beach (AAB) program. Initiated in 1996, the low cost Adopt-A-Beach program relies largely on the volunteer efforts of commercial river guides to provide repeat photographic snapshots and anecdotal information on changing beach conditions. The program relies on repeat photography taken from established photo points, supplemented by guides' empirical observations. The results of the AAB monitoring effort supplements the quantitatively derived information derived from the campsite surveys.

Proposed Monitoring Program
Recently, at the request of the NPS, GCMRC has explored the feasibility of using remotely sensed imagery to track changes in campable sand area throughout the CRE. The approach uses GIS tools in combination with the reflectivity of sandy areas in 2002 ISTAR digital imagery to detect and measure campable sand areas. Initial results show this approach has great promise, both in terms of amount of field time required for monitoring, accuracy, and overall efficiency (M. Breedlove, personal comm.). Some level of ground truthing will still be required, however, to ensure accuracy of results.

Kaplinski and others (2003) recently completed a comprehensive synthesis and assessment of past and current campsite monitoring efforts. In this assessment, they evaluated the various protocols used to qualitatively and quantitatively assess changes in beaches (sand bars) and detect area and volume changes. One of their concluding recommendations was that GCMRC should convene a panel of recreational experts to assess the effectiveness of current approaches for monitoring campsite attributes over the long-term. This recommendation has been supported by the AMWG, who approved funding for a recreation PEP in the FY04 budget.   As noted above, this PEP has been delayed (with AMP support) to FY 05.

Kaplinksi and others (2003) also recommended that a comprehensive, ground-truthed inventory of currently used camping areas within the CRE be completed. A baseline inventory of current campsites will be a fundamental tool for any future system-wide campsite monitoring efforts in the CRE. We propose to conduct this inventory in FY06-07. The inventory will build on the pilot study of Breedlove and others (n.d.), using digital imagery coupled with field assessments, to define the location and extent of currently used campable areas in the CRE.

Quality Control

Quality control will be assured through the use of standardized data collecting formats, recording protocols, and electronic entry procedures. Additionally, various automated summary reports of submitted data that are being developed for other monitoring data sets to aid in identifying errors in electronic versions of submitted data will be applied to the campsite monitoring data. Copies of original field data sheets will be archived in the GCMRC Library so that future problems encountered with campsite monitoring data can be checked against field data sheets.

Data Management, Analysis, and Dissemination:

Data and digital imagery resulting from campsite monitoring activities will be stored on the Oracle data base in tabular, vector and raster formats.   Analysis and dissemination of monitoring results will be primarily through computerized comparisons of digital imagery and reports prepared by principal investigators associated with this monitoring program. These reports will incorporate and build on trend data from previous years of monitoring. As needed, GCMRC will also request periodic synthetic reports to summarize and evaluate the long-term trends in the campsite monitoring data. Finally, data associated with these core monitoring activities will be presented in GCMRC authored SCORE reports.

C.7.3. Recreational Economics

History/Rationale

Recreation economics data were summarized as part of the EIS process, but little follow-up or synthesis has been accomplished, except in relation to individual flow experiments (e.g., Harpman 1999, Hjerpe and Kim 2001). Non-use value monitoring has not been pursued since the EIS, following the controversial nature of a report on that topic late in the GCES process.

No specific management objectives related to recreational economics were identified in the AMP Strategic Plan, but one core monitoring need was identified under Management Objective 9.1 (CMIN 9.1.4): "Determine and track the economic benefits of river related recreational opportunities."

Current Program

There is currently no program in place for systematically monitoring recreational economics, beneficial or otherwise, within the CRE.

Proposed Program

AMWG approved funding for a socioeconomic PEP review in FY04. With concurrence from the TWG and AMWG, this review has been postponed until Spring 2005. The monitoring of recreation-related economic factors will be one of the program areas addressed through the review process.

CHAPTER 3

Implementation

A. Roles and Responsibilities

As a preliminary step in developing this long-term Core Monitoring Plan (CMP), a TWG Ad Hoc committee was convened at the March 30-31 TWG Meeting. The first formal meeting of the TWG Core Monitoring Ad Hoc Committee was held in Flagstaff, Arizona on April 9, 2004. Participants included most members of the Ad Hoc Committee (listed on the cover page of this plan) and staff of the USGS, Grand Canyon Monitoring and Research Center (GCMRC). This group subsequently referred to itself as the Core Monitoring Team (CMT). Jeff Lovich, Chief of the GCMRC, served as Chair of the CMT.

The CMT determined that the role of GCMRC in developing the plan was to provide the science foundation for the document. The role of the TWG was to provide technical assistance related to the needs of their constituencies relative to core monitoring, and to maintain a strong linkage to the needs of their AMWG member during the process. The role of the Science Advisors was to provide independent review of the draft plan and final documents. The CMT agreed that if additional expertise were required, the group would solicit outside assistance on an as needed basis.

Roles and responsibilities during implementation of the plan are similar. GCMRC is responsible for implementing the plan, maintaining oversight of the monitoring results, and ensuring that monitoring data is returned to the GCDAMP in a useful and timely manner. The TWG has responsibility for reviewing the results of the monitoring, providing constructive feedback to the GCMRC on the quality and utility of monitoring data, and ensuring that AMWG members are fully apprised of the information resulting from the monitoring program, as well as its implications for future policy decisions. The AMWG member is responsible for keeping himself or herself apprised of monitoring results and using the monitoring information to make sound, science based decisions that will benefit the resources of concern to the GCDAMP as a whole.

DOI agencies and Native American tribes who have land managing responsibilities within the CRE have an obligation to ensure that their permitting processes and any internal reviews related to implementation of the plan are conducted in a transparent, timely fashion. The Bureau of Reclamation, as the operator of Glen Canyon Dam and the lead agency for compliance in the GCDAMP, retains primary responsibility for any compliance documentation required to implement the CMP.

B. Remote Sensing

Resource monitoring in the CRE is inherently difficult and expensive owing to the remote nature of the canyon environment. Airborne and ground-based remote sensing represents the least intrusive and most cost-effective set of techniques for gathering the large quantities of data required for many core monitoring activities. Current technologies can effectively measure reflective properties of terrestrial and sub-aqueous surfaces at spatial resolutions of 20 cm or less and elevations at a density of 1 to 14 points per square meter within accepted horizontal and vertical control accuracies of 30 and 25 cm that were established for historical sand bar surveys. Existing remote sensing technologies that have been successfully tested by the GCMRC during the Remote Sensing Initiative include: multi-spectral digital imagery, high-resolution terrestrial LiDAR and multi-beam sonar. These conform to the recommendations of the June 1998 Protocols Review Panel and GCMRC's Remote Sensing Initiative 2000-2003 report.

Where core resource monitoring entails the classification and measurement of surfaces for change detection, current remote sensing technologies have been shown to be highly effective as sources of core monitoring data. These data sets can be utilized for monitoring multiple resources and provide spatial integration of multiple resource parameters. We estimate that remote sensing can provide as much as 80 percent of core-monitoring source data. Ortho-rectified digital imagery has been used to support canyon-wide, two-dimensional mapping and monitoring of terrestrial vegetation types; fine and coarse-grained sediment storage; movement and changes; size and quality of camping beaches; and shoreline habitat classification.

System-wide, core-monitoring remote sensing missions will be conducted every 4 years beginning in FY 2006. Products acquired will include: canyon-wide, multi-spectral digital imagery and automated photogrammetry (DSM) at a minimum spatial resolution of 22 cm and 1 meter respectively. Additionally, research and development of newer technologies such as very high resolution terrestrial LiDAR and hydrographic LiDAR will be utilized during remote sensing mission years to support research and monitoring activities that fall outside of the current core monitoring realm. Very high resolution terrestrial LiDAR can capture from 7 to 14 data points per square meter, and we are currently planning to acquire data for approximately 70 km of archeological site areas in 2006. We are also planning to explore the potential of sub-aqueous airborne remote sensing using water-penetrating hydrographic LiDAR with an initial test tentatively scheduled for November 2004 along the San Juan arm of Lake Powell and the Paria reach of the Colorado River.

Specific products in support of core monitoring and research efforts will be produced during the year following the remote-sensing overflights and include system-wide fine-grained sediment; vegetation and campground (open sand) inventories with changes from the previous monitoring period, and other specific classifications or analyses as requested. The appropriate data will be integrated into the physical, biological and cultural core-monitoring efforts within the Integrated Science Program. Results of these analyses will be provided to the science advisers for review and comment as well as being placed on the GCMRC's developing web sites for public access.

Table 3.a. Ten-year Projection of Current Core Monitoring Remote Sensing Costs

Year	Remote Sensing Component	Cost per km	Kilometers	Total Cost
2006	System-Wide Overflight • Digital Imagery and DSM (1-meter) • Mission Overhead	$835	480	$439,300 $400,800 $38,500
2010	System-Wide Overflight (same as 2006)	Same as 2006	Same as 2006	$439,300
2014	System-Wide Overflight (same as 2006)	Same as 2006	Same as 2006	$439,300

Table 3.b. Ten-year Projection of additional Core Monitoring Remote Sensing Costs

Year	Remote Sensing Component	Cost per km	Kilometers	Total Cost
2006	Mission Total Very High Resolution LiDAR Hydrographic Sonar / LiDAR	 $3000 $1000	 70 100	$310,000 $210,000 $100,000
2010	Research Mission Total (same as 2006)	Same as 2006	Same as 2006	$310,000
2014	Research Mission Total (same as 2006)	Same as 2006	Same as 2006	$310,000

C. Logistics and Permitting

Implementation of the GCMRC core monitoring plan requires effective coordination of technical and logistical support needs. The Research Coordination and Support Program (a.k.a. "Logistics Program or RCS) encompasses the integration of 5 elements:

- Permitting
- Library Operations Coordination
- Survey Support Coordination
- Technical Support Coordination
- Logistics Operations

RCS program staff address each of these elements in assessment of support requests from internal GCMRC staff and co-operators to determine which tools and processes will best facilitate the most effective collection and delivery of information from monitoring and research projects. The process is initiated in the proposal review and permitting stage, continued through the support coordination stage, and completed with information delivery. The process acts as an accountability checkpoint. Failure to meet agreed data collection and delivery standards is addressed immediately and corrective solutions are sought to avoid any delay in project completion.

C.1. Permitting

All monitoring and research projects supported by the GCMRC must hold the required permits in compliance with Federal, State, Tribal and local agencies in which project activities are conducted and accessed. Monitoring and research activities conducted within Grand Canyon National Park and Glen Canyon National Recreation Area require National Park Service **Research and Collecting Permits** and **Access Permits** for all river launches, back country use, over flights, and media (filming) production. All permits acquired for GCMRC-supported projects are processed and submitted through the Logistics Program. Copies of all approved permits are kept on file in the GCMRC Research Coordinator's Office.

All investigators, permitees, and project cooperators are responsible for compliance with the regulations and restrictions of their Research and Collection Permit. All trip participants are expected to comply with all GCNP Commercial Operating Requirements while participating on GCMRC-sponsored trips. All PI's and their designated permitee are required to sign a Research Use Affidavit/Notice of Adverse Actions and Penalties Form which specifies potential penalties for violations of permit conditions. **Failure on the part of investigators or their representatives to adhere to Park and Permit Regulations may result in withdrawal of their permit and other penalties.**

- **Research and Collecting Permits**-Reseachers submit project proposals and all other required information (guidelines available on NPS web site) to the GCMRC Research Coordinator **at least 150 days** (5 months) prior to the proposed project start date. Proposals are distributed externally for review in accordance with the GCMRC Peer Review Guidelines and Protocols. Internal review is completed by program managers, support coordinators, and are submitted to the GCMRC Chief for final approval. Finalized permit information is then submitted to the NPS for final review and approval. **NPS Research and Collecting Permit applications require a minimum of 90 days for processing.**

- **Access Permits**-Researchers holding approved R & C Permits submit a Trip Request Form to the Research Coordinator 60 days in advance of their planned research activity. This form includes request for logistical and support services and all information required for an NPS access permit application. **NPS Access Permit applications require 45 days for processing.**

C. 2. Survey Operations

The long term monitoring objectives of GCMRC require positions and elevations for past, present, and future spatial datasets. The GCMRC Survey Department's mission is to provide survey support for: (1) collection of these spatial measurements, and (2) referencing the spatial data collected in the Colorado River ecosystem to the primary control network. The survey department is also responsible for establishing and maintaining the geodetic control network in Grand Canyon. The geodetic control network serves as the foundation for all spatial measurements necessary for long term monitoring.

This control network also serves as the spatial framework for the Geographic Information System (GIS). The referencing of spatial data must be consistent in order to perform accurate change detection. All measurements collected for studies approved by the Adaptive Management Program are archived for quality assurance, quality control, network adjustment, and database integration.

The survey department provides network control point coordinates and error estimates, QA/QC for remote sensing, topographic and hydrographic maps, and the additional manpower necessary to collect these data. The survey department staff also incorporates historical datasets that had been previously referenced to superseded or local control coordinates into the CRE database. This integration requires translation and rotation of the instrument and reference azimuth stations to match the most current coordinates, which reference the primary geodetic control network.

The survey department is familiar with data collection and processing of topographic, hydrographic, and geodetic data. Specific equipment available to researchers includes static, kinematic, and Real Time Kinematic (RTK) Global Positioning Systems, single-beam and multi-beam hydrography, acoustic Doppler sensors, laser scanners and conventional survey equipment. The Survey coordinator assesses the level of survey support required to efficiently implement individual studies and evaluates and schedules equipment and personnel requests.

C.3. Technical Support Coordination

Integration of support capabilities in the areas of GIS and Remote Sensing is critical to the success of scientific data collection and integration of GCMRC's research and monitoring projects. Technical Support Coordination requires effective communication with researchers, program managers and GIS and DASA personnel to facilitate collection and delivery of information that complies with GCMRC Data Standards. Coordination entails evaluation of requests and scheduling of the appropriate equipment, materials, services and personnel required to implement monitoring and research activities. Examples of Technical Support requests for monitoring work include:

- Copies of existing map products and aerial photo sets.
- Processing requests to GIS for new map products.
- Scheduling of Field Equipment (i.e., Computers, handheld GPS units, digital cameras, etc.).
- Scheduling of personnel required to assist with field work.
- Consultation with GIS personnel for recommendations on data collection methods to achieve effective integration with the GIS.
- Consultation with Data Base personnel for advice on data collection formatting to achieve effective integration with the GCMRC Data Base.

Additionally, future dissemination of essential information to researchers related to permitting procedures, trip planning and survey and technical support requests will necessitate utilization of the GCMRC web page. Development of a Research

Coordination and Support Program web page is underway and will include information pages and access to on-line forms to submit requests for scheduling river trips, and survey and technical support. The web pages will be developed in cooperation with the Information Management Program staff.

C.4. Library Operations Coordination

The RCS program manager coordinates researcher library requests with the GCMRC librarian. Interaction with Library Operations is a vital component in the successful support of GCMRC's monitoring and research projects. Coordination with Library Operations facilitates support of research and monitoring activities in two key aspects:

1. The Library provides a centralized repository for hard copy information such as books, reports, maps, photography, and videos. A fundamental function of the library is to provide funded researchers access and use of these library's materials unique to the GCMRC collection.

2. The Library has also implemented a consistent peer review process to help ensure the quality of scientific projects conducted by the GCMRC. The Peer Review Protocols developed and administered by the library are utilized in the NPS permitting process for external review of project proposals prior to submittal to the NPS Research Office for review and approval.

C.5. Logistics Operations

The GCMRC provides complete logistical support for 35-50 research, monitoring and administrative river trips through the Grand Canyon annually. These trips range in length from 7 to 21 days and from 4 to 36 people in size. Trips are comprised of a variety of motor and oar powered boats operated by contracted boat operators. Monitoring projects operating in the Glen Canyon reach of the Colorado River (Glen Canyon Dam to Lee's Ferry) are supported by a variety of motor powered boats operated by GCMRC researchers and contracted boat operators. Additionally, monitoring activities on the Little Colorado River are supported by helicopter services contracted with the Bureau of Reclamation.

The GCMRC uses a method of supporting trips in which government owned boats and river logistical equipment are used in conjunction with a contracted vendor who supplies Technical and Logistical Boat Operators. A concerted effort is made to match PI's with the best possible Boat Operators for their particular study. Food packs, trip supplies, and equipment are organized, packed and maintained at the GCMRC warehouse. Put-in and take-out transportation is provided with the use of GSA leased vehicles and contracted shuttle drivers.

This logistical approach has evolved since the GCES phase to allow a detailed overview of trip particulars that most influence cost and efficiency, ultimately giving the GCMRC control over trip costs and productivity. Effective communication with PI's and sensitivity to and awareness of the challenges they face in implementing their studies enable the GCMRC to offer more customized (and therefore more cost-effective and productive) logistical support than other support strategies utilized previously. Retaining control over the process of supporting trips also facilitates compliance with NPS regulations and allows greater control over issues sensitive to the general public and the "recreational river community."

The trip planning and scheduling process begins in the fall when the Logistics Coordinator, in cooperation with contracted PI's, program managers and the RCS staff work together to generate a draft schedule of trips for the fiscal year. The schedule includes; launch and take-out dates, numbers of personnel and specific boat and boat operator requests for each trip. Researchers must submit a Trip Request Form a minimum of 60 days prior to the scheduled launch date. This form provides information for two purposes: (1) determine and schedule logistical and support services, and (2) complete a GCNP River Trip Application in order to meet the GCNP 45-day deadline for submitting access permit applications.

The current core monitoring plan identifies the need for approximately **XX** river trips per year. This number assumes that each monitoring project requires trips specifically dedicated to each individual project. However, the NPS prefers to see trips combined whenever feasible to reduce the amount of administrative river trips launching each year.

The Logistics Budget is distributed across GCMRC monitoring projects based on a formula proportional to use of services. The formula takes into account contractor costs, trip size and length, and a percentage of operating expenses, salaries and permitting costs.

D. CORE MONITORING DATA ACQUISITION AND MANAGEMENT

The Database Acquisition, Storage, Analysis and Access (DASAA) group, a newly formed entity that emerged through the GCMRC reorganization process, was created to improve communication and data flow between the technical aspects of database management and the science staff and managers who utilize the data. As the name suggests, this group incorporates all aspects of database management including the acquisition of remotely sensed and field based data; data storage in an Oracle database; archival activities of stored data; analysis of spatial and tabular data using GIS and other analytical tools; and accommodating appropriate access to data.

Data Management

Data management is an integral element of the GCMRC core monitoring program, providing a logical framework for the acquisition, storage, and retrieval of scientific data for analysis. GCMRC monitoring and research activities generate vast quantities of data on a wide range of parameters, from water discharge rates at Lees Ferry to levels of dissolved oxygen in Lake Powell. Currently, GCMRC manages approximately 3 terabytes of data, including tabular, spatial, and image data types. In addition to the management of existing data, new data are collected on an almost daily basis and must be integrated into the data management framework in a logical and efficient manner.

Projected growth of the database is anticipated to be approximately 1.5 terabytes per year, with expected surges during the years of combined remote sensing missions. This section of the report outlines data management practices as they pertain to the core monitoring program currently being developed.

Data Types

As indicated above, core monitoring data consist of three primary data types: (1) tabular, (2) image, and (3) spatial data. Tabular data capture specific measurements or inventories of a relevant resource at a specific location and time in the ecosystem. Examples of such data would be water quality measurements take at Glen Canyon Dam or species sampling data along the CRE. These data are ultimately stored in a relational database as rows and columns, or fields in tables belonging to a logical scheme. The database allows tables to be linked or related based on the unique values in these fields.

Most image data are visual representations of physical properties of an object or landscape surface, and consist primarily of photographs, including aerial and oblique photography, and videography. Image data are capable of capturing physical properties both within the spectrum of visible light and beyond the normal perception of the human eye. For the CRE, data within the visible to near-infrared spectrum are periodically collected in order to obtain desired information pertaining to the physical properties of the resources being monitored.

The term spatial data is often used synonymously with geographic data and generally refers to information that is tied to a spatial reference system. Most tabular and image data can be processed into spatial data by assigning a spatial reference system with geographic coordinates. When different spatial datasets all use the same spatial reference system, they can be viewed simultaneously in relation to one another using a geographic information system (GIS). Using GIS, spatial data can be gathered, viewed, manipulated, analyzed, and output to a digital format such as a table displaying coordinate values, or to a more traditional hardcopy map.

Data Storage

The Grand Canyon Monitoring and Research Center utilizes two relational database components in its data management infrastructure: (1) Oracle database management system for tabular data, including raw imagery, and (2) Environmental Systems and Research Institute's ArcGIS for spatial data. The two technologies operate on separate physical servers, and are integrated using the Oracle spatial data option in conjunction with the ArcGIS spatial data engine (SDE). This infrastructure enables a relatively seamless exchange of data between the two technologies.

The Grand Canyon Monitoring and Research Center relies on the Oracle database management system for the backbone of its data management infrastructure. This technology is used to consolidate, organize, store, and deliver data using built-in and custom software tools. Oracle database design is based upon two fundamental criteria: (1) maintaining the integrity of measurements including precision and accuracy, and (2) optimized storage space and access speed. The database is organized by discipline with all data spatially and temporally registered. Database design tries to achieve a balance between access efficiency and storage utilization.

Most of the data currently stored on the Oracle database are spatial data. Spatial data can be either continuous or discontinuous. Discontinuous spatial data are usually represented by points, lines, or polygons and are often referred to as vector data. Points representing water quality monitoring site locations are examples of discontinuous or vector data. This is a very efficient and direct method for storing certain types of spatial data. Continuous, or raster, data store geographic information in the form of grid cells, or pixels, with each pixel retaining its own unique value. Raster data can be simple images or spatially referenced imagery, the latter of which often result in larger file sizes because of the need to store the additional geographic coordinate information. Raster data can be from a variety of sources and have different resolutions depending on the area represented by an individual pixel. Examples of raster spatial data include scanned aerial photography prints, aerial imagery collected using digital sensors, and surfaces derived from LiDAR or digital elevation model (DEM) data. The size of raster data is significantly larger than other spatial data due to its continuous format. The pixel resolution, spatial extent, and range of pixel cell values all contribute to the size of a raster dataset. Continuous spatial data are not contained to a set of points or polygons, but rather reach across the entire spatial extent of the dataset. The nature of raster data, combined with the scope which it is collected and stored by GCMRC, makes the management of raster data a constant challenge.

The growth rate of spatial data, and more specifically, spatially referenced digital imagery, now managed by DASAA is continual. Sources contributing to the increase of large imagery data sets to be stored electronically are two-fold: aerial photos currently in hardcopy format that will be scanned into digital format, with selected datasets being spatially referenced to match existing data, and future remote sensing missions that will provide new, and in many cases, increasingly larger datasets to be managed by the DASAA group. Improvements in remote sensing technologies such as higher pixel resolution from new airborne digital sensors are likely to enhance the amount of data collected with successive missions over the next ten years. The DASAA group is planning for increased storage capacity concurrently with its acquisition schedule provided in the Remote Sensing section of this chapter (see Tables 3.a. and 3.b.). A 10-year proposed budget for annual support of core monitoring activities is included in this document as Appendix E.

Core Monitoring Data

Core monitoring data gathered by GCMRC staff and contractors are currently being consolidated and added to the Oracle database management system. Database schema for all core monitoring activities are being developed by the DASAA group in conjunction with appropriate internal GCMRC staff, external researchers, and stakeholders. The following resource and mapping support items are currently part of the core monitoring database:

1. Lake Powell water quality data including phytoplankton, specific conductivity, and water temperature

2. Water data relating to dam discharge rates, sediment, and tributary inputs collected between Glen Canyon Dam and Lake Mead

3. Colorado River water temperature between Glen Canyon Dam and Lake Mead

4. Fisheries data collected between the Glen Canyon Dam and Lake Mead

5. Spatial data stored on the Oracle server and accessed by GIS software using the spatial database engine (SDE).

6. Survey Control Network – Coordinate locations belonging to a geodetically corrected network along the CRE that serves as a basis for all spatial reference information.

Current Data Availability and Access

Support of scientific research and management decisions can be improved through greater accessibility to the contents of the database, and in return, the database will become more robust as it is made more accessible. Over the past year, the GCMRC implemented a spatial database engine (SDE) that serves as the vehicle for accessing the vast amounts of spatial and tabular data pouring into the Oracle database. Currently, there are over 60 spatial data layers in vector format (points, lines, or polygons) with themes ranging from terrestrial ecosystem monitoring sites to fish sampling units to water quality monitoring sites. Numerous remote sensing products are also available in the form of panchromatic and color infrared imagery for partial and, more recently, canyon-wide coverage of the CRE, and as LIDAR-derived products collected over the past few years. Additionally, other surface data are available including DEM data with resolutions of 30 meters and 10 meters for the entire basin, and a 1-meter digital surface model (DSM) for the CRE. In the future new data sets will continue to be made available through this platform. Also, further developments to the SDE will allow versions of existing spatial database layers to be exclusively checked out to a researcher, updated by the researcher, and then returned to DASAA for quality control, accuracy assessment, and database inclusion. This will be extremely useful for those databases with potential for high usage by preventing confusion from multi-user conflicts.

The SDE component also has provided for the implementation of an internet map server (IMS) that offers interested parties internet access to available spatial data stored in the Oracle database. The IMS service has been used effectively over the past year with updates and custom services provided to GCMRC staff, cooperators and contractors, stakeholders, and the public alike. This is a fairly new technology with significant advances expected in the future.

Increased web-based access to tabular data sets within the Oracle database will continue to be made available. Currently, a water discharge web page is available through the

GCMRC website that allows the download of both daily discharge and unit value information for 7 locations (5 main channel, 2 tributaries) across the Colorado River basin. The available data currently range from 1921 to the present, depending on the status of the monitoring site, and are updated daily through an automated process employed by DASAA. Development has begun to produce a similar web page to access specific water quality data with an emphasis on water temperature. This would be in addition to, and compliment nicely, the current discharge temperature information being displayed through the Products page of the GCMRC website.

Both tabular and spatial data can be accessed from the Products page of the GCMRC web site: http://www.gcmrc.gov/what_we_do/products/products.htm.

Additionally, selected spatial data will be made available on the U.S. Geological Survey enterprise FTP site located at ftp://ftpext.usgs.gov/pub/wr/az/flagstaff.

Future Data Accessibility and Improvement Plans

Initial improvements to the SDE over the next year will include the ability to query Oracle tabular databases directly through the spatial indices provided within the IMS viewer. By visually selecting on a feature, a user could query the related tabular information for that particular feature, or for all the features within a specific geographic extent. An example of this type of access for both spatial and tabular data will be implemented for water temperature data collected for the DIQWP monitoring sites. Newly collected data will be incorporated in the Oracle database and linked to a spatial index layer representing the location of a particular monitoring instrument. With the tabular data linked to its associated spatial index, the water temperature readings collected at that location can then be queried and displayed.

Over the next few years, improvements will be made in the accessibility of not only data, but also the processes and analytical techniques used to create many of the datasets. Tools developed by the DASAA group will be made available to others utilizing existing platforms such as SDE and IMS. A pilot project will demonstrate this concept by taking an existing GCMRC model used to measure solar radiation for a given segment of time along the center of the Colorado River and modifying it to provide localized solar radiation for any area throughout the CRE. The degree of resolution for data output will be scalable and dependent on the spatial extent for which it is run. This tool will have a variety of uses for both terrestrial and aquatic ecological research including, but not limited to, terrestrial vegetation productivity, herpetological habitat modeling, and aquatic algal responses. Since the user decides the spatial extent to be analyzed, the new model will be much more applicable to a wide array of uses. This model serves as an example of how the DASAA group plans to expand upon the level of services now available.

The DASAA group is also developing a new two-way telemetry system that will allow daily retrieval of field instrument readings, and the ability to control field instruments remotely from anywhere with internet access. This has great implications for monitoring events that might otherwise be missed due to instrument failure or limits in field data storage capacity. It will also allow for greater control in the data collection process. GCMRC staff will be able to troubleshoot instruments for potential problems, reset internal parameters, or even re-program collection intervals to more effectively monitor natural events. Previous attempts at using advanced instruments to monitor phenomena within the CRE have occasionally resulted in some downtime where no data were collected. The purpose of implementing a two-way telemetry system, in conjunction with the current instrumentation used by GCMRC, is to reduce that downtime and improve how we monitor the resource.

Data Protection
Data is protected against accidental loss, hardware failure, and disaster using Redundant Arrays of Independent Disks (RAID), tape backup, and archiving on optical media. Media storage is located both on and off the U. S. Geological Survey Flagstaff Field Center campus to protect data assets if disaster were to occur locally.

E. Reporting Process and Feedback

E.1. Reporting

Effective information delivery involves a two-way dialogue on the characterization of information that will actually create improved knowledge in the decision-maker. Simply finding improved ways to provide scientific information does not result in better decisions. For effective community-based decision-making, environmental information should be:

- Timely.
- Relevant to problems and players.
- Useable in form and for a specific context.
- Targeted, accessible and understandable to its audience.
- Integrated, and suggest a course of action.

In order to achieve these characteristics, capacity must be developed to generate, deliver and use ecological monitoring information. GCMRC has traditionally reported data and information through peer-reviewed publications and grey literature developed by individual contractors and staff, and a biennial science symposium that focus on the CRE. In addition, the GCMRC has produced an interpreted report containing summary trends of data and information collected over time that pertains to specific resources in the CRE in the State of the Colorado River Ecosystem (SCORE) report. This report was last published in 1998. More recently, GCMRC has promoted the use of electronic media and the Internet as a way to increase the distribution of data and information in a manner more convenient for the broad range of information consumer that make up its constituency. It is likely that all of these methods will remain in use for the foreseeable future with new emphasis placed upon electronic data being made available over the Internet and the publication of the SCORE report on a regular basis.

Beginning in 2005, the SCORE report will be published in hard copy every five years and contain a summary of all of the monitoring data collected as part of the core monitoring program. In addition, an electronic version of the SCORE report will be maintained on the GCMRC public website that contains real time data trends for selected resources as it becomes available. Raw (un-interpreted) data contained in the GCMRC data base management system and internet map server will also be available via the Internet no later than 60 days after its acquisition once these systems have been fully developed. In addition, data and information pertaining to core monitoring activities will be formally presented to the TWG and AMWG members biennially during the science symposium or as need dictates. Presentation of this information will be followed by formal data and interpretive reports that document monitoring results, interpret data in terms of management objectives, and suggest future management actions.

Hard copy reports and electronic media are archived and made available to scientists, stakeholders, and the public through the GCMRC library. Library content is organized and indexed using a computerized library catalog that is searchable electronically using the Internet. Reports that are available electronically can also be accessed and downloaded using the Internet and modern web browsers. A full time librarian is also available to assist patrons in finding and obtaining information that they are interested in. Data contained on electronic media is also partially available on the GCMRC website and FTP site. However, this data is often non-descript and difficult to navigate. GCMRC is currently developing data management practices that address this shortcoming.

E.2. Feedback and evaluation cycle

Monitoring is a structured, repeatable process of observing and recording (measuring) something over time, ideally for a specified purpose. Monitoring does not solve problems. It only tells you what the current condition is (status) and whether or not it is getting better or worse over time (trends) based upon a set of previously defined criteria. Monitoring is also an essential component of an iterative management cycle. The ability to assess whether or not a monitoring program is working depends upon how well the objectives of the program have been defined and articulated and how sensitive the monitoring methods are to detecting change within those objectives.

The objectives of the feedback and evaluation cycle are:

- To promote responsiveness to the needs of the AMP at all times through regular feedback and evaluation.

- To ensure that resources are monitored at regular intervals in accordance with the best scientific practices and prescribed data standards.

- To ensure that processes involve all stakeholders and are action-oriented.

- To ensure that attention is given to both qualitative and quantitative measures of monitoring performance, employing an agreed upon set of indicators.

- To promote high standards of reporting and accountability at all levels in order to maintain the integrity of the GCMRC and the science its science programs.

- To modify the program in response to changing program needs or refinement of existing needs.

Meaningful monitoring requires that the objectives of each component of the monitoring program needs to be explicitly defined. At the present time, the AMP Strategic Plan defines a broad suite of core monitoring information needs, but it does not provide an explicit strategy for linking the desired information to a management decision-making process whereby the monitoring information is used to formulate management actions to achieve the stated strategic goals of the AMP. The AMWG needs to address this key deficiency in the current strategic plan, so that monitoring objectives can be more clearly defined and prioritized relative to long-term management objectives.

The results of the monitoring efforts should subsequently be compared to the defined objectives. The monitoring program should be evaluated and modified based upon the degree to which the monitoring effort meets the identified objectives. To facilitate this exchange, the Technical Work Group and GCMRC staff will meet formally to present results of the monitoring program and receive input and direction from the resource managers as part of the biennial science symposium sponsored by GCMRC.

Final Note: There are some additional implementation topics that should be included in the final version of this plan. They include:

- Integration of Monitoring Activities
- Future Staffing Needs
- Future Flexibility and Consistency (PEPs)
- Endpoints: How We Determine Success

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APPENDIX A. Annual Core Monitoring Budget

Core Monitoring Project Descriptions	Data Acquisition	Approx. Annual Cost	BUDGET NOTES
U.S. Geological Survey (GCMRC)	**Measurement Frequency and Related Notes**	**Starting in FY 2006**	
Integrated Ecosystem Science Program (ISP)			
Integrated Quality-of-Water Program (IQWP)			
Lake Powell Quality of Water	Quarterly to Monthly Water Sampling	210,000	Current Annual Cost (Non-AMP funding)
Downstream Integrated Quality-of-Water	Continuous Mainstem/Tributary + Quarterly Sampling in LCR	200,000	Current Annual Cost also Equal to AZD est.
Streamflow & Suspended-Sediment Transport	Continuous stage/discharge & Weekly suspended sediment	860,000	This is AZ District WRD Estimate for FY 2006
	IQWP Subtotal	**1,060,000**	Not including Lake Powell
Sediment Storage, Geomorphology & Biological Elements			
Impacts of Coarse-Grained Inputs	Biennial Field Visits & 4-YR Overflights (change detection)	50,000	Cost Based on Current Annual Efforts
Fine-Sediment Storage	Biennial Field Visits & 4-YR Overflights (change detection)	175,000	Cost Based on Current Annual Efforts
Terrestrial Ecosystem	Biennial Field Visits & 4-YR Overflights (change detection)	250,000	Cost Based on Current Annual Efforts
T&E Wildlife - Kanab Ambersnail	Annual to Seasonal	25,000	Cost Based on Current Annual Efforts
T&E Wildlife - Southwest Willow Flycatcher	Annual to Seasonal	115,000	Cost Based on Current Annual Efforts
Food Web (Research Toward Development of a Monitoring Plan)	Probably Annual to Seasonal	300,000	Research Effort Initiated in FY 2005-07
Rainbow Trout in the Lees Ferry Reach	Seasonally - Related to Life History	160,000	Cost Based on Current Annual Efforts
Humpback Chub in the Little Colorado River	Seasonally - Related to Life History	315,000	Cost Based on Current Annual Efforts
Downstream Fishes in the Main Channel	Seasonally - Related to Life History	825,000	Estimated for Research & Development

	Integrated Science Program (w/o DASA component) Subtotal	**3,275,000**	Of this total, $1,535,000 funds the five "core monitoring" projects in FY 2006
Data Acquisition, Storage and Analysis (DASA) - Support			
Airborne Remote Sensing (Digital, Orthorectified Imagery & High Resolution LiDAR & Very High Resolution LIDAR for arch sites)	System-wide Digital Imagery Every 4-Years [w/High Res. LiDAR in FIST sub-reaches, and Very High Res. LIDAR in Archeological reaches]	202,000	Mission Cost Estimated at $808,500 (w/ overhead). About 50% of cost is for LIDAR
DBMS - Storing New Core-Monitoring Data (See Appendix E for a detailed breakdown on this component)	Annual added Storage Costs for Monitoring Data	225,000	Current Oracle License Costs & Ongoing Storage Needs
Geographic Information System - Support Fieldwork & Overflights	Annual Support of Core Monitoring Activities	5,000	This is Ongoing Annual Equipment, Storage & Supplies Costs
	DASA Subtotal	**432,000**	$330,000 of this toward "CM" in FY 2006
Core Monitoring Share of Annual ISP Personnel Costs	Approx 50% of the Total Annual Salary Cost projected for FY 2006 is devoted to core monitoring and R&D of monitoring protocols	650,000	Salaries Projected for 2006 on Basis of 2004
SUBTOTAL INTEGRATED SCIENCE PROGRAM (Core-Monitoring)	**ISP + DASA Core-Monitoring Support**	**4,357,000**	
Sociocultural Program			
Cultural Resources Monitoring - Archaeological Sites (TBD)	Probably annual field visits and 4-YR Overflights	400,000	Research Initiated in FY 2005
Tribal Monitoring of TCPs and culturally important resources (TBD)	Probably annual field visits by each tribe	250,000	Research Initiated in FY 2005
Recreational Monitoring - visitor use & experiential attributes TBD)	Surveys, probably every 4 or 5 years per user group/topic	75,000	Research initiated in FY 2005
Recreational Monitoring - campsites (TBD)	Probably biennial field visits and 4-YR Overflights	150,000	Review in FY 2005
Core Monitoring Share of Annual Cultural Program Personnel Costs	Approx 50% of the Total Annual Salary Cost projected for FY 2006 is devoted to core monitoring and R&D of monitoring protocols	75,000	
SUBTOTAL SOCIOCULTURAL PROGRAM		**950,000**	
Logistics & Survey (Trip costs in projects above)	Logistic Subtotals Embedded in Projects		
Control Network	Annual Support of Core Monitoring	100,000	Continued as Need Dictates
Survey Operations	Annual Support of Core Monitoring	100,000	Continued as Need Dictates
SUBTOTAL LOGISTICS CORE MONITORING SUPPORT		**200,000**	

SUBTOTAL INFORMATION OFFICE	**Annual - Serving Core Monitoring Data**	**233,000**	
TOTAL CORE MONITORING BUDGET		**5,740,000**	Includes "CM" plus R&D for future CM

Note: Highlighted color of project title in column 1, indicates the status of the activity with respect to its implementation as a "core monitoring" activity (although the scope of the effort may still be adjusted to meet managers' needs). Green highlighted projects are deemed as completed with respect to research & development of the core monitoring protocol, while Yellow highlighted projects are still undergoing research & development and review in FY 2005. Red highlighted projects are those for which research & development of core-monitoring protocols is scheduled to begin in FY 2005 and beyond. Project titles that are not highlighted indicate that these activities generally support core monitoring efforts whether they are completed or still under development.

Appendix B
Grand Canyon Monitoring and Research Center
Protocol Evaluation Program

As a result of several meetings of the GCMRC staff, science cooperators and stakeholders in 1997 and 1998, a prospectus for the GCMRC protocols evaluation program (PEP), was drafted. Following is an excerpt from that document intended to provide additional background information on the approach taken by the GCMRC to develop and refine a long-term monitoring program for the resources of the Colorado River ecosystem below Glen Canyon Dam.

Excerpt from the GCMRC's Protocol Evaluation Program Prospectus

The proposed strategy for implementation of the PEP is a staggered, multi-stage effort that investigates new technologies, as well as existing and past protocols used to monitor Colorado River Ecosystem (CRE). The geographical scope of the CRE covers a distance of 291 river miles (-15 to 276) between the forebay of Lake Powell and the western-most boundary of Grand Canyon National Park.

The monitoring protocols evaluated will include: (1) those related to physical resources, including tributary and main channel sediment input, storage and transport; (2) streamflow and water quality below GCD to river mile 276; water quality in Lake Powell; biological resources, both aquatic and terrestrial; cultural resources in all categories; and a variety of remote sensing technologies (ground-based, airborne and hydrographic) appropriate for addressing stakeholder information needs in all of the above-mentioned areas.

The main goal of the PEP is to identify an optimal design for an efficient and effective long-term monitoring program for the CRE, to be implemented by the GCMRC. A highly effective long-term monitoring program is required to provide Glen Canyon Dam Adaptive Management Work Group (and Technical Work Group) members (stakeholders) with information needed to make recommendations to the Secretary of the Interior (or Designee) on management-action decisions and impacts of GCD operations under the existing Record of Decision (ROD)-imposed dam operations, initiated in December 1996. Although the PEP strategy will be generally followed regardless of individual protocol differences, the process will likely be tailored to meet program objectives of each resource area.

Individual resource-area PEP objectives shall be accomplished through a multi-step process over two to three years in which systematic articulation, scoping, review and testing/evaluation efforts will identify the most effective and feasible methods of measuring CRE resource attributes and their long-term responses to GCD operations under the ROD. Following these steps, the most effective monitoring approaches will be identified and PEP results will be reported to the stakeholders. After final consultation with the Science Advisors and the Technical Work Group, GCMRC program managers and the Chief will implement changes to the long-term monitoring program as indicated by need, and allowed by cost and other considerations.

The proposed time line over which these evaluations will take place and be implemented in the GCMRC monitoring program is estimated to be Fiscal Year (FY) 1998 through FY 2003. Following the initial PEP, additional evaluations may need to occur as new information needs are identified, new knowledge is gained, and as new techniques/technologies become available for monitoring riverine ecosystems. The PEP planning team also believes that a periodic review of the overall GCMRC monitoring program should be reviewed and evaluated at about five-year intervals to identify areas where improvements or small changes in focus are needed. Finally, the need for consistency in monitoring data sets for purposes of comparability is recognized as important as decisions to alter protocols are made by the GCMRC. The systematic nature of the PEP process will guarantee that paired tests leading up to changes in long-term monitoring are conducted in such a way as to ensure that data from past studies are comparable to future efforts.

Key Components of the PEP

In drafting the prospectus for the PEP, the GCMRC planning team considered the following issues to be important:

A) **<u>Articulate Management Objectives/Information Needs, and Current Protocols</u>** - Just as it is critical to identify details of new and existing monitoring protocols, it is also critical for PEP participants (external and internal) to have a clear and detailed understanding of present stakeholder-derived management objectives and information needs. Originally drafted in 1995 by the Glen Canyon Transition Workgroup, CRE management objectives were reviewed and revised by a sub-group of the Technical Workgroup, and the GCMRC Chief and his staff during a series of five scoping meetings in spring 1998. Information needs were originally stepped down from the draft objectives during summer 1996, and were reviewed and modified as needed in 1998. Information needs derived from the management objectives are the basis for procurement of CRE science activities by the GCMRC through its competitive RFP process.

In addition to describing information needs and objectives, past and presently used monitoring protocols need to be clearly articulated on the basis of existing literature and discussions with present/former project chiefs and PIs who conducted monitoring and research during phases I and II of the Glen Canyon Environmental Studies (GCES, 1983 through 1996). Information on existing protocols, including methods sections of reports and articles that describe various uses in the CRE or other rivers, must be reviewed and made available to external review panels and scoping workshop participants in advance of all PEP workshops/meetings. This information will be collected, compiled and distributed by program managers during the scoping phase of the PEP as they lead each of the individual protocol evaluations. Although the PEP will eventually address monitoring needs in all program areas, initial workshops held during the FY98 phase of the PEP will focus on the effectiveness of ground-based and airborne remote-technology sensing (GARST), and previously used protocols associated with physical resources, such as those used to monitor sediment transport and sand bar changes.

Outside experts, identified through GCMRC scoping activities, will also be invited to participate in review-oriented workshops. The GCMRC will solicit participation from experts qualified to provide external critical review of the PEP process, as well as those who may offer information and demonstrations on new technologies and methods from both private and public sectors.

B) <u>Define the Range of Optional Alternatives Under Existing Technologies</u> - Alternatives to existing protocols will be identified by in-depth GCMRC scoping of monitoring techniques that are presently used in other long-term programs for river ecosystems. Methodologies will also be considered that are presently used in monitoring of other ecosystems (i.e., near coastal marine settings, forests, etc.) where the protocols might be adapted to a large river, or technologies/methods that are still in developmental stages, but intended for large rivers.

The PEP scoping process is intended to be wide-ranging, and will glean information from multiple sources such as: reports, journal articles, professional presentations, and displays at professional meetings. Attending national meetings frequented by ecosystem-monitoring experts, and conferences that attract technological innovators by GCMRC staff is encouraged as a means of conducting pre-workshop scoping activities. To increase the effectiveness of the PEP, the limitations and capabilities of new technologies of interest must be screened against information needs by the GCMRC/PEP planning team in advance of the first workshop. New technologies that hold great promise but are mismatched with stakeholder/GCMRC information needs should be easily identified. In cases where innovation has led to new approaches that have not been recognized by stakeholders, the PEP can act to update managers on areas where new information could be easily obtained. This will hopefully eliminate consideration of inappropriate new protocols early in the process. Agencies and private-sector firms identified through the scoping process will be invited to the workshop(s) for demonstration and discussions of new methods and technologies.

Regardless of the diversity of monitoring approaches considered, other topics such as replication, sampling interval and spatial distribution for a long-term monitoring program also need to be evaluated by CRE-resource category. For instance, during FY 1998, external review panels will also assist the GCMRC-PEP in reviewing and identifying ideal sampling strategies for existing efforts such as channel-storage changes, monitoring channel-bed grain-size evolution and bed coverage through time (SEDS), Lake Powell water quality monitoring (WETS), and for GARST. Information from recent high-flow experiments suggests that monitoring data on grain-size evolution of channel-stored sediment may significantly influence management decision making, but has not previously been a component of physical-resource monitoring.

The PEP process also recognizes that new information gained from experiments such as controlled high releases from GCD, as well as evolving information needs, will likely drive additional new needs for monitoring methods of the CRE through time. Therefore, although the PEP may have formal start and end dates, the GCMRC mission will require program managers, stakeholders and the SAB to revisit the long-term monitoring strategy (including individual protocols) on a periodic basis—perhaps as a five-year review.

C) <u>Evaluation/Selection of Protocols to be Implemented</u> - The PEP aims to identify which of the past, currently used, or new-but-untested protocols best meet the objectives of what a long-term monitoring program should accomplish for any ecosystem management program. Second, the program aims to design a river-monitoring program with protocols capable of assessing long-term ecosystem trends, as well as be able to document the impacts of discrete events, such as high-flows from GCD. Protocols must also be able to provide information to stakeholders in a timely manner useful for supporting the adaptive management process (recommendations to the Secretary of the Interior). The selected protocols also must work within the unique settings of the CRE, be minimally intrusive to the environment, demonstrate cost effectiveness, stand as scientifically defendable, provide suitable accuracy/precision (depending on level of information need), and be highly repeatable and reproducible regardless of changes in contractors over time. Most importantly, the selected approaches must directly address the management objective-derived stakeholder information needs.

Where existing data occur in the databases of the GCMRC or its former/present cooperators, initial evaluations will be undertaken internally by staff members and scientists already involved in monitoring under existing agreements (Phase I). However, existing data sets that may foster comparative assessment will only be analyzed after the articulation and scoping steps have been accomplished. In cases such as the FY 1998 evaluation of the SEDS, WETS and GARST, existing interagency and cooperative agreements will be modified during FY 1998-1999 to enlist help in conducting paired test evaluations with collaborating scientists.

Any assessments conducted on existing data will be subjected to internal and external review and will be presented and discussed during initial workshop(s) held by GCMRC during spring/summer 1998, and beyond for other resource categories. The PEP external review panel(s) will be invited to attend the scoping workshop(s), and its members will be comprised of experts derived from the GCMRC list of reviewers established by discipline during the scoping phases. Membership will be determined competitively on the basis of expertise (initially, physical and remote sensing technologies), and on willingness and availability to participate in the scheduled time line of the PEP. Following the articulation/scoping steps (Phase I), committed PEP review panel members (3-5 persons per phase/program area) will be paid a stipend and travel for attending workshop(s), and will be required to provide individual and group reports on protocols evaluated, presentations/reports on assessments of existing data, results of field testing (Phase II), and critical review of trial implementations (Phase III). A key component of each report will consist of recommendations to the GCMRC Chief and the Science Advisors on what changes in monitoring protocols are warranted. The results of each

PEP evaluation will be reviewed by the Science Advisors, and comments will be forwarded to the GCMRC Chief for consideration before new or modified monitoring procedures are implemented by program managers through a competitive RFP-driven process.

For any given resource-program area, there will likely be at least three workshops held (minimum of one per year) throughout the PEP process. Although FY 1998 will be devoted mostly to scoping and evaluation of protocols relating to the GARST, WETS and SEDS, etc., the GCMRC's PEP planning team intends that all protocols in all program areas be evaluated over a staggered schedule lasting 3-5 years (FY 1998 through FY 2003). Following PEP initiatives, the GCMRC anticipates that its long-term monitoring program shall be fully underway in the time frame of 2006-2008 and beyond.

Appendix C
GCMRC Core Monitoring Plan
Stakeholder-identified Priorities

Name – Agency/Organization – Comments Dated

Dennis Kubly, BOR, May 20, 2004:

1. Protect or improve the aquatic foodbase so that it will support viable populations of desired species at higher trophic levels.

2. Maintain or attain viable populations of existing native fish, remove jeopardy from humpback chub and razorback sucker, and prevent adverse modification to their critical habitat.

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

Bill Persons, AGFD, May 13, 2004:

1. Maintain a wild reproducing population of rainbow trout above the Paria River, to the extent practicable and consistent with the maintenance of viable populations of native fish.

2. Maintain or attain RBT abundance, proportional stock density, length at age, condition, spawning habitat, natural recruitment, and prevent or control whirling disease and other parasitic infections.

3. Limit Lees Ferry RBT distribution below the Paria River of the Colorado River ecosystem to reduce competition or predation on downstream native fish

Bill Davis, CREDA, May 12, 2004:

1. Threatened and endangered species included in the Biological Opinion and their Critical Habitats affected by dam operations (<45,000 cfs level). This tracks CMINs under Goals 2, 5 and 6 for T/E species.

2. Cultural resources affected by dam operations (<45,000 cfs level). This tracks CMINs under Goal 11.

3. Hydropower capacity and energy under the MLFF or other operating scheme in contrast with original design. This tracks CMINs under Goal 10.

Jeff English, Federation of Fly Fishers, May 14, 2004:

1. Food Base: The aquatic food base is the first link in the food chain of any rivers ecosystem. Its vitality is crucial to successfully sustain an ecosystem along the river corridor. This foundation of life must be monitored at all times, to realize its condition. Future experimental designs should focus on its development and be restrained from eroding the first link in the web of life.

2. Fish: Maintain a self-sustaining population of rainbow trout above the Paria, in the Lees Ferry reach. Below the Paria, and within the Grand Canyon we should strive to protect the native species, especially the endangered.

3. Recreation: This is where people and the greatness of all the natural resources unite. The rafters of Grand Canyon and anglers of Lees Ferry represent decades of loyal fans that generate millions annually into Arizona's economy. These two neighboring venues share worldwide acclaim that is part of Arizona's legacy. Science must respect the needs of people, and monitor their desires, and work to preserve both resources human and natural, together.

Ken McMullen, GRCA, May 5, 2004:

1. Humpback Chub population estimation and predation effects (and other T&E issues/species).

2. Cultural Resources Monitoring and mitigation as proposed by PA Ad Hoc.

3. Water quality as it relates to contaminates, food base, and ecosystem function.

Mike Yeatts, The Hopi Tribe, May 11, 2004:

1. Identify if national register properties that are losing integrity.

2. Identify if population numbers and health of adult endangered species are increasing or decreasing

3. Track relevant trends of other resources identified in the ESI/ROD and GCPA. This includes not only physical and biological aspects of the ecosystem, but also power, economics, and social values.

Norm Henderson, NPS, May 12, 2004:

1. The basic premise of these needs is the information that is required to adequately manage the resources within the two park units below Glen Canyon Dam.

2. The timeframe considered for core monitoring should be decadal.

3. Additional information is needed to answer specific questions regarding the effects of dam operations and other management actions carried out through the AMP.

Mark Steffen, Federation of Fly Fishers, May 10, 2004:

1. The Aquatic portion of the FOOD BASE
   a) Monitor standing crop and species diversity
   b) Monitor impacts on the aquatic food base from HFF, MLFF, steady flows, aerial flight flows and any water temperature changes.
   c) Monitor damage done to the aquatic food base by sudden, drastic changes in flows.
2. FISH:
   a) Trout above the Paria.
   b) Trout and Native Fish below the Paria.

3. RECREATIONAL FISHING above and below the Paria:
   a) Guided: Lees Ferry fishing guides and downriver rafting companies.
   b) Non-Guided: Lees Ferry fishermen, Private Grand Canyon river running trips and Grand Canyon back packing hikers.

Gary Burton, WAPA, May 12, 2004:

1. Determine and track the abundance and distribution of native (emphasis on humpback chub) and (predatory) nonnative fish species in the CRE (combined CMINs 2.1.2 and 2.4.1).

2. Track, as appropriate, the annual sand bar area, volume and grain size changes within and outside eddies between 5,000 and 25,000 cfs stage by reach (combined CMINs 8.2.1 and 8.4.1).

3. Determine and track the composition and biomass of benthic invertebrates in the CRE in conjunction with measurements of flow, nutrients, water temperature and light regime (combined CMINs 1.2.1 and 1.4.1). Benthics could be surrogate (indicator) species for primary producers and more indicative of fish diet.

John Ritenour, GCNRA, May 6, 2004: 1. Recreation: GLCA legislation lists the purpose of the area is to provide for outdoor recreation enjoyment so you need to consider monitoring the recreation experience, fishing, camping, safety on the Glen Canyon reach, concessioners and incidental business permit holders. 2. Recreation leads right into economics: there must be a better picture of the economics and it must be bigger than just poser revenue. Include all money generation that stems from activities on or associated with the river that are impacted by dam operations to include impacts to concession and guide activities. 3. Along with listed species we are concerned about native species such as flannelmouth suckers, leopard frogs, waterfowl and raptors dependent on the river environment for a food base, etc. We need to monitor so that we can detect trends – this is particularly true for species that we want to avoid listing.
Glen Knowles, U.S. FWS, 5-12-04: 1. Provide a consistent long-term data set for key resources identified in the AMP strategic plan such that data are comparable over long periods (decades). 2. Provide baseline ecosystem monitoring (i.e. physical foundations (sediment, water quality, hydrology), biological foundations (food base, vegetation), higher trophic levels (fish, wildlife), human environment (recreation). 3. Provide annual compliance monitoring (e.g. threatened and endangered species? Kanab ambersnail population levels, humpback chub survival, recruitment and abundance, willow flycatcher surveys, cultural resources).
Phil Lehr, Nevada, 5-11-04: 1. One of the most fundamental aspects of monitoring a riverine environment is to collect accurate and complete measurements of the river's flow rate and basic water quality attributes. GCMRC should monitor this basic data, not only because of the effects upon the immediate environment, but also because it affects the quality/quantity of flows into Lake Mead. In addition to flow rate, the water quality data should include but not be limited to specific conductance, temperature, and turbidity. This data should not be subject to the fickle nature of budget cutbacks as has been the case throughout the west. These gaging and water quality stations need continuity of record and everything should be done to maintain their operation. 2. The State of Nevada is involved in a broad-based state/federal/tribal/private regional partnership, which includes water, hydroelectric power and wildlife management agencies in Arizona, California and Nevada. Among the wildlife management concerns, GCMRC needs to consider is monitoring native and endangered species which include humpback chub, southwestern willow

flycatcher, and razorback sucker. Regular population surveys of these species are necessary to make informed decisions about their survival in the Grand Canyon Area. This data should be exchanged with the MSCP Program since the Grand Canyon is integral to and immediately adjacent to the MSCP Study Area.

Note: only two were submitted

Lisa Force, Grand Canyon Trust

Resources of Greatest Concern:

Native Fish: Goal 2. Maintain or attain viable populations of existing native fish, remove jeopardy from HBC and Razorback Sucker, and prevent adverse modification to their critical habitat. MO 2.3 HBC recruitment in the LCR and mainstem

Beach Communities: Goal 6. Protect or improve the biotic and spring communities, including threatened and endangered species and their critical habitat. MO 6.2 Maintain new high water zone community (related to BHBFs)

Flow dynamics and Sediment: Goal 7. Establish water temperature, quality and flow dynamics to achieve GCDAMP ecosystem goals. MO 7.1 Attain water temperature range/seasonal variability in the mainstem. Goal 8. Maintain or attain levels of sediment storage within the main channel to achieve GCDAMP ecosystem goals. MO 8.1 Maintain or increase sediment in the main channel

Top Core Monitoring Priorities

CMIN 2.1.2 determine and track abundance HBC in mainstem and LCR

CMIN 6.2.1 Determine and track NHWZ parameters

CMIN 7.1.1 Determine water temperature dynamics… throughout the Colorado River ecosystem

CMIN 8.1.1 Determine and track biennial fine-grain sediment…. by reach

Appendix D
Excerpts from Protocol Evaluation Program (PEP – SEDS) "Final Report of the Physical Resources Monitoring Peer Review Panel" - Finalized on November 1, 1999

Monitoring requirements - The Panel finds that the monitoring requirements developed by the Technical Work Group (TWG) for the physical resources program are, in general, imprecise, repetitive, and difficult to understand. Inasmuch as the monitoring requirements are used by the Technical Work Group and the Adaptive Management Work Group (AMWG) to prioritize research and monitoring needs, it is imperative that the monitoring requirements be clear, precise, and complete. Before further decisions are made regarding research priorities, the Panel suggests that GCMRC staff be given the opportunity to redraft the monitoring requirements into a more consistent and clear form.

GCMRC long-term monitoring and research elements

A. Glen Canyon geomorphology vs. Marble/Grand Canyons

* A key question with respect to the Glen Canyon reach is whether there are any limits to terrace retreat. The monitoring program needs to develop and test hypotheses of the processes of bank erosion at culturally important sites (such controls could include boat wakes, rates of flow rise and recession, and underlying coarse substrate), determine which sites are presently eroding, and estimate how far and how fast the terrace erosion might proceed.

* The Panel suggests that the program consider reconnaissance-level mapping of in-channel sand deposits anchored by macrophytes, and the effectiveness of this vegetation anchoring during high and low discharges.

B. Main channel and gaged tributary streamflow and fine sediment discharge

* Steve Wiele's research on 1d and 2d sediment modeling is critical to this element, and should continue. The evolving outcomes of his work should drive both monitoring and study-site selection. The Panel recommends focusing on multiple-kilometer (perhaps-10 km-long) reaches for which bathymetry obtained from multi-beam sensors during high flow and LIDAR or stereo-photogrammetry data obtained during low flow are merged. Monitoring during times of rapid change (event-driven monitoring and sampling) is likely to be most useful, and resulting data should be used to evaluate the accuracy of the sediment models. It would be useful to define triggering events in response to which monitoring and sampling would be initiated, and to define the necessary monitoring response protocols.

* Daily suspended sediment samples should be collected at the lower Marble Canyon and Grand Canyon gages until the inputs from a time period incorporating at least two sizeable tributary floods have been sampled. These samples can be used to track the input of sediment and evolution of sand waves as modeled by Wiele. Bed-material samples and grain-size distribution data should be collected over the same time period and at a high temporal resolution (daily).

C. Main channel and shoreline fine-sediment storage

* Interstitial spaces and pools may provide important sediment storage space in the channel bed. It is important to develop and implement a method to quantify this storage.

* The Panel was impressed that Wiele's 2d model may be able to predict bar geometry as a function of flow recession. The model, or an alternative research approach, should be used to evaluate the effects of hydrograph characteristics on habitat availability; for example, how do bar morphology and grain size affect vegetation and aquatic ecology?

* Shoreline sampling should be stratified into frequently (ground-based cameras, focusing on campsites) and less frequently (aerial photographs of reaches) visited sites. Sites downstream from Phantom Ranch may be less intensively monitored using the Adopt-A-Beach program or daily photographs (without photogrammetry) from ground-based cameras. The Panel suggests that reaches downstream from Phantom Ranch not be completely neglected because the habitat dynamics in these reaches may exert an important control on secondary populations of humpback chub.

* The frequency of aerial photographs suggests that the monitoring program is oversampling above-channel features relative to below-channel features. It may be appropriate to use different types of imagery, such as color infrared every year for in-water features, vegetation mapping above water, and debris-flow features, and normal photographs every third year for other above-channel features.

D. Ungaged tributaries and geomorphic framework

*It would be appropriate to sample a subset of ungaged tributaries by establishing staff gages and expanding the Adopt-A-Beach program to include sediment sampling. Placing buckets in tributary channel beds, to be emptied by river-guide volunteers as available, is one example of how the program could include sediment sampling.

E. Construction of high-resolution 3d channel-geometry data for the main channel

* A high priority should be given to developing a one-time, continuous topographic-bathymetric map for use as a base map. The bathymetric component of this map will be the most important component, and should be obtained during high flow.

* The Panel recommends that the program consider the SHOALS option for above- and below-water imaging during conditions of low flow and low sediment influx. SHOALS is a LIDAR system designed for bathymetric information rather than above-water topography if dense vegetation is present.

* After the multi-beam sensor has been used to map the length of the channel, 1-pass LIDAR could be used along the length of the channel, with multiple passes at sites of interest if the budget permits. With the relatively low vegetation cover along the main channel, a test might be useful to determine whether under-water and above-water topography with acceptable resolution can be collected simultaneously during a single flight through the Canyons. The Panel

recommends that the biology program contribute to the cost of obtaining LIDAR data because of the usefulness of these data in monitoring tamarisk.

* The Panel concurs with most of Schimdt's recommendations, including
- consolidating monitoring efforts to the level of approximately 10-km-long reaches
- focusing monitoring on geomorphic processes
- the use of metrics to indicate the direction of change

* In general, the Panel recommends that a joint workshop of ecologists and geomorphologists might be convened to select the study reaches. The Panel also recommends that someone be designated "sand master" and tasked with overseeing all the components of channel morphology research within the context of a sand budget. The frequency/intensity of sampling should be decreased downstream from Phantom Ranch, but this portion of the Grand Canyon should not be completely neglected.

SUMMARY

The impacts of the Glen Canyon Dam originate in processes that are primarily physical; changes in flow magnitude, timing and temperature, and changes in sediment supply. The suite of management options available to address impacts of the dam are also primarily physical; the timing, magnitude and, possibly, temperature of the released water. Prescription of any changes in dam operations must ultimately be translated into physical conditions in the tailwaters reach. Therefore, an understanding of the ecosystem response to dam operations must begin with an understanding of the controls on its physical condition. Information on the nature of the physical setting and its controls also provides the framework needed to formulate and test hypotheses regarding the controls and mechanisms of biological response to dam operations.

The key resources in Grand Canyon are endangered species, riparian vegetation, cultural resources, campsites, navigable rapids and, in the reach between Glen Canyon Dam and Lees Ferry, introduced trout. In order to balance management of flow regime for these resources, the GCMRC will need to develop hypotheses about how flow regime will affect each resource. These hypotheses must be articulated within a consistent ecosystem description encompassing all resources. In developing these hypotheses, it is important that the full range of release options be considered, regardless of current restrictions on the magnitude and timing of releases.

The Panel finds that excellent progress has been made in developing an understanding of the physical behavior of the Colorado River in Grand Canyon. The physical resources program is currently very well managed and integrated. The quality of the overall research and monitoring effort is exceptionally high. The primary tasks now facing the program managers are discussed in this report: development of a conceptual framework that will guide research and monitoring efforts, integration of the physical resources, biology, and cultural/socioeconomic programs, clarification of information needs, development of a synoptic picture of the river bed, selection of monitoring reaches, continuation of 1d and 2d sediment modeling in the main channel, collection of daily sediment samples along the main channel, expansion of sediment sampling and monitoring for principal tributary channels, a greater emphasis on event-driven monitoring and sampling.

Certain parameters should always be measured with consistent methodologies for long-term monitoring. In addition, it will be critical to maintain flexibility in monitoring such that the monitoring is focused on evolving research questions and hypotheses. The complex and continuously changing Grand Canyon ecosystem cannot be adequately characterized or managed as a static "landscape scene." As the system continues to respond to changing physical conditions and biological interactions along the main channel and its tributaries, and as new technology becomes available for monitoring, the GCMRC and its associated scientists and stakeholders will need to maintain a breadth of vision and an awareness of possibilities suitable to one of the grandest landscapes on Earth.

Appendix E. DASA 10-year Budget for Annual Support of Core Monitoring Activities

Annual Recurring			*** Numbers shown in thousands of dollars**		
Oracle License	80.0		ESRI License	15.0	
Embarcadero License	1.5		Supplies	7.0	
PhotoShop (4) (Upgrade)	4.0		Training	19.0	
ERDAS License	10.0		**Total Annual Recurring Costs**	**136.5**	
Hardware year 2006			**Hardware Year 2011**		
OverFlight File Server	18.0		BlueDisk Archive (replacement)	50.0	
Tape Backup	22.0		Mapping Tablets (2)	10.0	
Mirror File Server	18.0		GIS Work Station (Replacement)	7.0	
DVD Archive	26.0				**67.0**
Process Server (analysis)	6.0				
GIS Laser Printer	2.0		**Hardware Year 2012**		
GIS Plotter	15.0		OverFlight File Server (Replacement)	18.0	
GIS Work Station	7.0		Tape Backup(Replacement)	22.0	
Mapping Tablets (4)	20.0		Mirror File Server (Replacement)	18.0	
Satellite Telemetry	8.0		DVD Archive (Replacement)	26.0	
		142.0	Process Server (analysis) (replacement)	6.0	
Hardware year 2007			GIS Laser Printer (Replacement)	2.0	
GIS Work Station	7.0		GIS Plotter (Replacement)	15.0	
Satellite Telemetry	8.0		GIS Work Station (Replacement)	7.0	
GISServer (Replacement)	6.0		Mapping Tablets (2)	10.0	
DataBase Server (Replacement)	4.0		Satellite Telemetry (Replacement)	8.0	
File Server (Replacement)	18.0				**132.0**
		43.0	**Hardware Year 2013**		
Hardware 2008			OverFlight File Server (effort 2) (replacement)	18.0	
Satellite Telemetry	8.0		Tape Backup (effort 2) (replacement)	22.0	
Mapping Tablets (4)	20.0		GISServer (Replacement)	6.0	
BlueDisk Archive	50.0		DataBase Server (Replacement)	4.0	
		78.0	File Server (Replacement)	18.0	
Hardware 2009			BlueDisk Archive (replacement)	50.0	**118.0**
OverFlight File Server (Replacement)	18.0				
Tape Backup(Replacement)	22.0		**Hardware Year 2014**		
Mirror File Server (Replacement)	18.0		OverFlight File Server (Effort 3)	18.0	
DVD Archive (Replacement)	26.0		Tape Backup (Effort 3)	22.0	
Process Server (analysis) (replacement)	6.0		Mirror File Server (Replacement)	18.0	
GIS Laser Printer (Replacement)	2.0		Process Server (analysis) (replacement)	6.0	
GIS Plotter (Replacement)	15.0		GIS Laser Printer (Replacement)	2.0	
GIS Work Station (Replacement)	7.0		GIS Plotter (Replacement)	15.0	
Mapping Tablets (2)	10.0		GIS Work Station (Replacement)	7.0	
Satellite Telemetry (Replacement)	8.0		Mapping Tablets (2)	10.0	
		132.0	Satellite Telemetry (Replacement)	8.0	
Hardware Year 2010					**106.0**
OverFlight File Server (effort 2)	18.0				
Tape Backup (effort 2)	22.0		Budget Cycle total		**2251.0**
GISServer (Replacement)	6.0				
DataBase Server (Replacement)	4.0		**Annual Cost**		**225.1**
File Server (Replacement)	18.0				
		68.0			