PROVISIONAL CORE MONITORING PLAN

FINAL DRAFT

PREPARED BY

U.S. GEOLOGICAL SURVEY

SOUTHWEST BIOLOGICAL SCIENCE CENTER

GRAND CANYON MONITORING AND RESEARCH CENTER

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GCMRC Core Monitoring Plan

Table of Contents

FIGURES:

TABLES (Chapter 2):

CHAPTER 1

Overview

A. Introduction

One of the primary objectives of the Glen Canyon Dam Adaptive Management Program (GCD-AMP) is to meet the environmental and monitoring commitments of the Glen Canyon Dam Final Environmental Impact Statement (Bureau of Reclamation Department of Interior, 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 (GCMRC) was created to fulfill the mandate in the GCPA 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 GCPA also allows 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 of other management actions 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.

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 can range from traditional field sampling techniques to multispectral remote sensing designed to identify stability or trends in key resources or indicator species.

The need for a long-term core monitoring plan for the GCDAMP has been identified as a critical program need since the Adaptive Management Program's inception in 1996. Despite the recognition that such a plan is essential for the program to function effectively, completion of a long-term core monitoring plan has remained an elusive goal for a variety of reasons. One important factor was a decision made at the outset of GCMRC's inception to undertake a systematic development of monitoring programs that involved the establishment of protocol evaluation panels for each key resource area, followed by four to five years of piloting monitoring protocols, then a period of analysis, synthesis, and revaluation, culminating in the

implementation of long-term monitoring protocols. This process, which requires approximately 4-5 years of research and development (R&D) for each key resource, got underway in 1998, starting with the physical science program, and is still in progress for some elements of the program today (e.g., terrestrial ecosystems, archaeological and tribal resources, aquatic foodbase, recreation and socioeconomics.) Other factors that have hindered rapid progress in the development of a core monitoring plan include: 1) lack of agreement among AMP stakeholders about purposes and objectives of monitoring in general; 2) lack of agreement among AMP stakeholders and scientists about what should be included within a core monitoring plan (i.e., what defines core monitoring as opposed to other kinds of monitoring, such as monitoring effects of experimental actions or monitoring the effectiveness of specific management actions); and 3) lack of agreement about the required levels of precision and accuracy in monitoring data that is necessary to achieve program goals.

This document constitutes a step in an ongoing process towards definition of a long-term core monitoring plan for the Colorado River ecosystem. This FY06 provisional plan identifies the current monitoring program elements that are considered by GCMRC scientists to be fully functioning at the present time. As noted above, many other monitoring program elements are currently undergoing R&D but have not yet been fully vetted through a peer-review process. Because this document does not contain the final version of the envisioned long-term Core Monitoring Plan, it is termed provisional and is specific to Fiscal Year 2006.

B. Summary of Decisions Leading up to the Development of the Current Provisional Plan

To address needs of the AMP for a long-term core monitoring plan, a core monitoring ad hoc committee composed of members of the GCD Technical Work Group (TWG) and staff of the USGS Grand Canyon Monitoring and Research Center (GCMRC) was convened by a decision of the Adaptive Management Work Group (AMWG) in March, 2004. This group of individuals, subsequently referred to as the Core Monitoring Team (CMT), represented a cross-section of many GCDAMP resource management concerns and scientific disciplines. It was envisioned by AMWG that the CMP would be developed collaboratively by this team. While GCMRC would retain primary authorship of the Core Monitoring Plan (CMP), other members of the AMP would contribute sections. The CMT was chaired by Jeff Lovich, then chief of the GCMRC. The CMT formally met five times between April 2004 and April 2005: April 9, May 4, and September 13 of 2004 and March 10-11 and April 11- 12 of 2005. In addition there was one conference call among a CMT ad-hoc sub-group on March 23, 2005.

An outcome of the April 9, 2004 meeting was a position statement that articulated decisions, roles and responsibilities, definitions, and basic principles the group endorsed related to the process for how the CMP would be developed. The CMT reviewed and adopted the definition of core monitoring proposed in the AMP Strategic Plan:

> *"Consistent, long-term, repeated measurements using scientifically accepted protocols to measure status and trends of key resources to answer specific questions. Core monitoring is implemented on a fixed schedule regardless of budget or other circumstances (e.g., water year, experimental flows, temperature control, stocking strategy, non-native control, etc.) affecting target resources."*

Although there was clear recognition and acceptance that emphasis was to be placed on *key* resources and *specific* questions, CMT members eventually identified most resource categories evaluated in the EIS as being necessary components of the plan. A popular metaphor subsequently identified the plan as a Christmas tree in which everyone wanted to hang their favorite "ornaments".

On May 4, 2004, the CMT was assembled again in an attempt to reduce the scope (i.e., reduce the number of ornaments) of the CMP. This goal went largely unrealized. The general consensus of those present was that the GCMRC had already been given sufficient information to begin working on the plan, and GCMRC was instructed to do so without further delay. GCMRC interpreted this outcome as direction to move forward developing the Christmas tree with all of its adorning ornaments. A draft plan was prepared and delivered to the Science Advisors on June 9, 2004. The science advisor comments and a draft core monitoring plan were delivered to the CMT on September 9, 2004.

The first draft of the CMP presented monitoring activities as a comprehensive list of 18 projects grouped by resource area. The list was comprehensive in that it contained both monitoring activities for which acceptable methodology currently existed to provide the needed monitoring data, as well as monitoring activities in which methodology was under development or needed further development in order to provide the needed data. Projects were linked to AMP goals through tables that identified AMP goals and Core Monitoring Information Needs (CMINs) that proposed projects either directly or indirectly addressed.

During the September 13, 2004 meeting of the CMT it was decided that monitoring activities for which methodology needed to be developed should not be handled the same way as projects that already were underway. Therefore, it was proposed and accepted by consensus of the CMT that the proposed monitoring activities would be classified as either "green", "yellow", or "red" depending on where they fit within the development cycle. Green projects were existing monitoring projects that had been evaluated by a Protocol Evaluation Panel and implemented for one to several years using methods deemed adequate for long-term monitoring. Yellow referred to projects that had undergone a PEP review and were scheduled for completion and external peer review in the near future (FY05 or FY06). Red referred to projects that still needed a PEP evaluation and/or were slated for a period of research and development in FY 2005 and beyond. Incorporating the input from the CMT, a third draft of the CMP was distributed to the TWG on September 24, 2004 and, among other things, reflected this change in perspective.

The third revision of the CMP was discussed at the March 10-11, 2005 meeting of the CMT. During this meeting, it was decided that monitoring activities that were still under development should not be included in the core monitoring plan, but should be included in a research plan. Therefore, it was decided by the CMT members that all "yellow" and "red" projects would be removed from the CMP and placed in a yet to be developed research plan. A second outcome of this meeting was the recognition that even "green" projects still required refinement with respect to clear linkages to AMP goals, Management Objectives (MOs), Information Needs (INs), and compliance mandates, and with respect to issue of data quality, accessibility, and analysis. To help identify and document the potential shortcomings of projects included in the draft CMP, a list of criteria were developed that collectively addressed the concerns of CMT members in

attendance for evaluating each project. An ad-hoc sub-committee was formed to develop a more refined process for addressing the evaluation criteria and subsequently transmit that information to the CMT. Initially, at the March 10-11, 2005 meeting, the CMT developed seven criteria with which to evaluate how well each "green" project met an existing AMP goal. Evaluation criteria were compiled from CMT discussions, flip charts, and notes from individuals in attendance at the meeting. These seven criteria assumed that scientific methodology exists to accomplish all or part of the monitoring activity. Whether or not acceptable methodology exists was later added as criteria 8.

On March 23 2005, a conference call was held among the CMT sub-committee members and an outline of the process was developed. It was decided that a complete revision of the current CMP was impractical within the timeframes allowed in the current development schedule and that a provisional plan would have to suffice for 2005-2006.

A fourth draft of the CMP, this time composed only of the "green projects", was sent to the Science advisors for review on April 5, 2005 and distributed to the CMT on April 9, 2005. The fourth draft of the CMP was discussed at the April 11-12, 2005 meeting of the CMT. At this meeting, some CMT members expressed the opinion that the existing draft plan was fundamentally flawed in both format and content. General criticisms included:

1. The plan did not provide the level of detail desired by AMP members.
2. The plan lacked information on accuracy, precision, and frequency needed to ascertain change over time.
3. The plan did not provide an ecosystem perspective.
4. The plan was not integrated between scientific disciplines.
5. There was continuing confusion over what is core monitoring vs. other kinds of monitoring.
6. There was confusion over whether yellow and red projects should be part of the plan or part of a different plan.
7. The plan did not provide enough detail as to how monitoring projects addressed AMP goals.

Some of these issues reflect the concerns of individual stakeholders while others reflect group consensus. For example, the group agreed with the opinion of one CMT member that the entire CMP need to be reoriented to around the AMP goals and the data necessary to support those goals, rather than continuing along the path of attempting to evaluate the existing GCMRC monitoring program on a project-by-project basis. In addition it was recognized that an essential component of the plan was still missing – an ecosystem perspective. Furthermore, the CMT determined that the plan was hampered by the lack of a clear definition by stakeholders of what core monitoring was trying to achieve within the AMP, including fundamental requirements such as how much change in a resource needed to be detected over what period of time, and that these issues needed to be resolved through additional future engagement with TWG members.

During this meeting, some of the decisions articulated in the position statement resulting from the April 9, 2004 meeting were revisited. In some cases, earlier decisions were reaffirmed, while others were modified to reflect current thought processes regarding monitoring goals. For

example, there was debate as to whether the term "core" pertained only to key resources themselves or to key indicators of resource conditions. Although this issue was not resolved, it was decided by group consensus that the CMP should address at least some aspect of all the resources identified in the AMP goals, minus goals 3 and 12.

The CMT subsequently determined that even if existing projects met all the evaluation criteria, budget realities would continue to constrain AMP monitoring activities and that therefore, a process needed to be developed that prioritized AMP Strategic goals and CMINS so that rational decisions could be made relative to which monitoring activities would be funded at what levels and which ones would receive less funding or none at all. The CMT decided that subsets of the evaluation criteria would be used to prioritize CMINs and AMP goals. The CMT also decided that some additional criteria, such as relative importance of a given resource for ecosystem function, needed to be added.

Once the CMT recognized that they needed to undertake an entirely new process for evaluating proposed monitoring activities relative to the prioritized CMINs and AMP goals, the group decided that GCMRC should complete a provisional plan for FY06 quickly and with minimal additional effort so that the team could focus their full attention on developing an entirely new, AMP goal-oriented core monitoring plan.

B.1. The FY06 Provisional Core Monitoring Plan

The FY06 Provisional Core Monitoring Plan includes only those projects that have undergone a PEP evaluation, have been piloted and results peer-reviewed, and that have been implemented for one to several years using methods deemed adequate for long-term monitoring. Projects in this category included: 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. These "green" projects constitute the core elements of this draft.

Project described in earlier drafts of the CMP that lacked fully defined monitoring protocols and that were scheduled for completion and external peer review in FY 2005 were formerly highlighted in YELLOW, while the remainder of the projects (formerly highlighted in RED) were scheduled for additional research and development in FY 2005 and beyond to identify monitoring protocols required to meet information needs in the long-term core monitoring program. These "yellow" and "red" projects are included as placeholders in this draft (Appendix B), but are not discussed in any detail in this provisional plan. They will be discussed in greater detail in the developing Research Plan.

The provisional plan (this plan) contains the following updates from the previous draft:

1. Red and yellow projects have been removed from the plan. A placeholder has been retained in Appendix B, along with a tentative timeline for completing these projects.
2. Discussions about remote sensing and data storage are folded into individual project descriptions, where applicable. These sections have been updated to include the

status of current data, whether or not it is in the database, whether or not it is good data, and how readily available it is.

3. Discussion about the PEP evaluations and how PEP recommendations were implemented have been added to the project descriptions.
4. The geographic scope of Lake Powell hydrology and water quality project was updated in Draft 4 to include the entire lake, not just the forebay. This geographic scope has been retained in the current plan, pending resolution of issues surrounding the Lake Powell monitoring program by the TWG
5. A new section has been added in Part 1 that explains linkages of the core monitoring plan to other GCMRC planning documents.
6. The general comments table has been removed.
7. Sections on dam releases and power and revenue have been eliminated, pending future evaluation of these program elements.
8. A section in Draft 4 of the plan that described the proposed process for evaluating each of the green projects over the next year has been removed from the plan and incorporated into a separate document.
9. The budget table has been updated as needed to reflect plan revisions.

B. 2. Next Steps

The FY06 provisional plan defines the current core monitoring programs that will be implemented at some level in FY06. This will serve as interim guidance while a final CMP (FCMP) is being prepared.

To facilitate the development of the final core monitoring plan, a separate document has been created that outlines specific changes and responsibilities for updating the provisional plan and completing the revised plan. This document is referred to as the "Proposed Core Monitoring Plan Development Process", or more colloquially as "the Plan for the Plan."

The final CMP will document the extent to which the current monitoring data satisfies the evaluation criteria, and it will describe the process whereby other core monitoring elements will be integrated over time. The format will be organized by AMP goals, rather than GCMRC projects. This approach will describe monitoring data within the context of AMP goals, a paradigm more intuitive to resource managers. It will also more readily lend itself to the "integration" of diverse scientific activities into a common environmental theme.

B. 3. Final Process

The outline of a process to evaluate monitoring programs and data needs was developed at the March 10-11, 2005 CMR meetings and refined during a subsequent conference call on March 23. The process is outlined in a separate document called the "Proposed Core Monitoring Plan Development Process." The evaluation process and final CMP development will occur as follows:

1. The GCMRC will compile the information identified in the evaluation criteria for each AMP goal and present the information to the CMT as part of a formal presentation. This information will effectively describe how well the current monitoring data meet the AMP goal and our "ability" to monitor that goal. The first formal presentation will take place before the August, 2005 AMWG meeting.
2. Using a "Delphi process", CMT members will rank the CMINs and help separate core monitoring information needs from other monitoring needs. This will be completed before the next TWG meeting in May.
3. The GCMRC will reformat the PCMP from project based descriptions to AMP goal-based descriptions in conjunction with the data presentations for each goal. Loose leaf binders will be distributed containing preface materials and tabs for the inclusion of the reformatted goal-based descriptions as they are developed and presented.
4. During the detailed presentations, the CMT will determine how well current monitoring approaches meet the AMP goals based upon the evaluation criteria, efficiency (i.e., cost effectiveness), and what makes sense to monitor based upon priority, ability, and budget.
5. Simultaneous with this process, the AWMG/TWG will work to address priorities, targets, metrics, and required accuracies and precision (to include how much change needs to be detected over what period of time) for each AMP goal. GCMRC would agree to allow metrics to suffice on an interim basis while TWG and AMWG are working towards establishing targets.
6. The Science Advisors will review the provisional plan. They will also review the process outlined here to develop the revised final plan, and the final plan itself in 2006.

The science advisors will be consulted to identify the best way to transmit the knowledge obtained from monitoring data to the AMWG and TWG in a meaningful way, keeping in mind that if knowledge is not absorbed, it has not been transferred. The formal presentations and plan revisions will begin in June of 2005 and continue for nine months at which point monitoring activities for all goals will have been evaluated. It is intended that this process will lead to a fully revised and reformatted core monitoring plan by March 31, 2006.

C. History of Monitoring Programs in the Colorado River Ecosystem

The most recent effort to define a long-term core monitoring program for the Colorado River ecosystem is the latest in a series of efforts focused on this goal. 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. The selection of appropriate monitoring variables has been hampered by challenging logistics, poor understanding of the ecology of constrained rivers (Schmidt et al. 1998, Stevens in press), limited biological resources data (Stevens 1989), limited data synthesis, 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 Glen Canyon Environmental Studies (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 the Colorado River in 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).

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 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 among 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 1992; Brown and others 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 Geographic Information Systems (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, (2) 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 Patten plan). The Patten 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 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 Patten 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 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. These projects are presented in more detail in the developing Research Plan, as information is still required to reliably define the monitoring methods and strategies for the above resource areas. As these projects become further developed with respect to methodologies and protocol evaluation, they will be moved into the Core Monitoring Program.

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: Goals, Definitions, and Assumptions

D. 1. Defining the Goal

At the Core Monitoring Team (CMT) convened through the AMP Technical Work Group on April 9, 2004, the CMT determined that the ultimate goal of the team effort 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.*"

D.2. Defining Core Monitoring

The CMT also 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 GCDAMP, all three reasons have been cited as driving the need for monitoring. We are concerned with meeting the legal mandates of the GCPA, 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 GCDAMP 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 GCDAMP 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 question that continues to be debated in the AMP is whether all these reasons for monitoring are equally "core" to the program, or if some monitoring objectives are more "core" than others. The AMP Strategic Planning Ad Hoc group grappled with this issue during their development of the 2003 AMP Strategic Plan Information Needs, but declined to prioritize the core monitoring information needs on the grounds that they were all essential to the program. Instead they distinguished two monitoring categories: Core Monitoring and Effects Monitoring, the latter being defined as:

> *"the collection of data associated with an experiment performed under the Record of Decision, unanticipated event, or other management action. Changes in resource conditions measured by effects monitoring generally will be short-term responses. The purpose of effects monitoring is to supplement the fixed schedule and variables collected under core monitoring. This will both increase the understanding of the resource status and trends and provide a research opportunity to discover the effect of the experiment or management action."*

Recently (April 2005), the CMT revisited the definition of core monitoring in the AMP Strategic Plan, and they concluded that the definition should be further constrained to focus specifically on

meeting the needs of the program to detect change in the status and trends of key resources with sufficient accuracy and precision and within a time frame appropriate to the needs of the AMP.

One stakeholder member of the CMT proposed the following definition of core monitoring:

"*Long-term repeated measurements using scientifically accepted protocols to measure status and trends of key resources to answer high priority management questions (CMINS) contained within each of the goals (and respective MOs) set forth in the AMP Strategic Plan. Monitoring is considered core when it is essential to assess the long-term health and well-being of a high priority CRE resource (either directly or by using a relevant surrogate). Core monitoring is implemented on a fixed schedule with scientifically valid methodologies that provide robust data using defined metrics with appropriate accuracy and precision to describe an appropriate level of change over time frames specified by AMP stakeholders.*"

Although not explicitly stated, the assumption in this definition is that AMP goals (resources) and monitoring priorities will need to be established for the adaptive management program. The Plan for Developing the Final Core Monitoring Plan outlines a process for prioritizing AMP goals and core monitoring information needs, but at this time (April, 2005), the proposed process had not yet been vetted or approved by the TWG or AMWG. This definition of core monitoring may therefore require further refinement through the AMP consensus process.

D. 3. Defining Key Resources

The EIS 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 EIS 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 define the resources of concern that need to be tracked by a long-term core monitoring program.

At the outset of the latest effort to define a core monitoring program, 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. Subsequently, some CMT members questioned this resource based focus, and argued for the development of a core monitoring plan focused around AMP goals.

The GCDAMP 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 EIS. The 12 goals of the GCDAMP Strategic Plan focus on the following topics: aquatic food base; native fish; rainbow trout; Kanab ambersnail; 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.

D.4. Defining an Ecosystem-based Approach

The GCDAMP Strategic Plan calls for "an ecosystem management approach, in lieu of an issues, species or resources approach". The AMP 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 GCDAMP Strategic Plan have been interpreted by GCMRC scientists 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 GCDAMP Strategic Plan are largely focused on measuring individual resource status and trends, rather than on ecosystem functions, biodiversity, or ecosystem integrity in a broader sense. This conflicting orientation within the program makes it difficult for GCMRC scientists to succeed in a developing a core monitoring plan that is simultaneously oriented towards addressing AMP goals and monitoring ecosystem function.

The need to understand status and trends of resources in a contextual sense requires that the future core monitoring plan consider and track potential interactive relationships, not just the status and trends of individual resources under individual AMP goals. For example, it would not make sense to track status and trends in sediment supply apart from hydrology, nor can we hope to understand the factors affecting status and trends in humpback chub without reference to their habitat conditions, such as water temperature, water quality, and so forth. Currently, however, the GCDAMP lacks a fully developed conceptual model of the CRE, which would allow us to identify and map the key trophic and processual linkages between CRE resources and help us identify the most critical ecosystem components and functions to monitor. Until such a model is completed, an ecosystem-oriented core monitoring plan will remain an elusive goal.

D. 5. Defining the Main Questions and Objectives of the Core Monitoring Program

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 GCDAMP 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 GCDAMP 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 GCDAMP 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 GCDAMP 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.

D. 6 Assumptions

Development of the Core Monitoring Plan (CMP) has been 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.

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 GCDAMP 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, GCDAMP 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 CMP. 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 and other Planning Documents

The Core Monitoring Plan is an integral component of a comprehensive planning framework linked to the GCMRC Strategic Science Plan. Other components of this framework include a Research Plan and a Humpback Chub Comprehensive Action Plan.

This FY06 Provisional Core Monitoring Plan contains only projects that are currently implemented using existing, peer reviewed methodologies that provide acceptable accuracy, precision, and frequency of data. Other core monitoring elements are still undergoing research and development. These projects are listed in Appendix B of this plan and will be described in more detail in a companion Research Plan that is yet to be developed. Inclusion of any of these projects in the Final Core Monitoring Plan is dependent on their evaluation through the process described in the document "Proposed Process for Developing the Final Core Monitoring Plan."

Currently, there are three categories of research being programmed at the GCMRC: 1) research focused on the development of long-term monitoring protocols (Appendix B), 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. The proposed Research Plan will address all three categories of research.

E.4. Linkage to Inventory, Monitoring, Planning, and Management Activities outside of the AMP

Outside of the AMP, additional research and monitoring programs are being implemented to meet specific resource management needs at Glen Canyon NRA, Grand Canyon NP, and on Hualapai and Navajo Nation lands. NPS and Tribal Resource Management Programs relate to on-going mission driven and/or mandated management actions. On NPS lands, such actions form the core of park activities related to management of natural, cultural and recreational resources. Similar programs may be found on tribal lands adjacent to the parks along the Colorado River. All of these activities, although occurring outside of the formal AMP, nonetheless may provide critical information that could and should be linked to on-going AMP efforts.

The National Park Service is responsible for protection and management of the Colorado River ecosystem within GLCA and GRCA and for providing assistance and information to adjacent land managers (e.g. neighboring American Indian Tribes, US Forest Service, Bureau of Land Management, etc.) on management issues or concerns relative to the Grand Canyon ecosystem. Currently, a host of research and monitoring programs are underway within Glen and Grand Canyons that address key resource concerns of the two Parks, and indirectly address interests of the AMP. Included are baseline inventory programs such as mountain lion inventories, tamarisk eradication in side canyons, archaeological inventory and monitoring (adjacent to the CRE), brown-trout predator control, T/E species inventories (e.g., condors, SWWFC), springs hydrology and ecological processes, and monitoring of neo-tropical birds. In addition to natural and cultural resource inventories and monitoring, considerable research is underway related to recreational use of the Colorado River. Associated with the issue of visitor use is the development of the Colorado River Management Plan, Backcountry Management Plan, and Aircraft Management Plan. Information from AMP efforts have assisted NPS in quantifying camping beach availability and condition, while previous NPS beach inventories form a core component of AMP related campsite assessments. The NPS works collaboratively with a host of state, federal, tribal and private partners in furthering agency mission goals and policy directives relative to conservation and protection of resources of the parks

E.5. Linkage to ESA and NHPA Compliance

Although compliance with various federal laws related to natural and cultural resources is generally outside the purview of GCMRC, federal and state managers involved with the AMP are responsible for meeting compliance mandates in a number of specific program areas. The Endangered Species Act requires compliance related to threatened and endangered species found within the Colorado River system. Certain endangered species such as Humpback chub, Kanab ambersnail, and Southwestern Willow Fly Catchers, that are dependent on habitats located within

the CRE, are being directly addressed within the AMP (California condors, on the other hand, are not considered within the AMP, because their primary habitats lie outside the CRE.) Ancillary programs exist in both the upper and lower basins such as the Upper Colorado River Recovery Program and the Lower Colorado Multi-species Conservation Program. These programs have similar compliance efforts that relate to and may impact AMP commitments.

Compliance with provisions of the National Historic Preservation Act occurs both within and outside of the AMP. A Programmatic Agreement for Glen Canyon Dam operations was signed in 1994 by Reclamation, NPS, Arizona State Historic Preservation Officer, Advisory Council on Historic Preservation and five affiliated American Indian Tribes. This agreement specifically addresses BOR's commitments relative to compliance with Section 106 of the Act, while also acknowledging the ongoing responsibilities of NPS, Hualapai Tribe, and Navajo Nation for Section 110 compliance on their respective lands. All federal agencies operating within the AMP have responsibilities that potentially overlap with NHPA compliance requirements.

CHAPTER 2

Monitoring of Ecosystem Resources

This chapter describes the monitoring programs for ecosystem resources in the CRE of concern to GCDAMP stakeholders and the public, as identified in the EIS, GCDAMP Strategic Plan, and through the efforts of the TWG AD Hoc Core Monitoring Team. This chapter describes monitoring programs that are currently underway in the CRE and are considered to be fully developed. Appendix B lists future monitoring programs for other resources that are still under development. It is anticipated that these projects will be fully developed in a Research Plan for the program.

Current Core Monitoring

The following section describes existing Core 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.

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 1). Lake Powell began filling in 1963 and reached a full pool elevation in June of 1980.

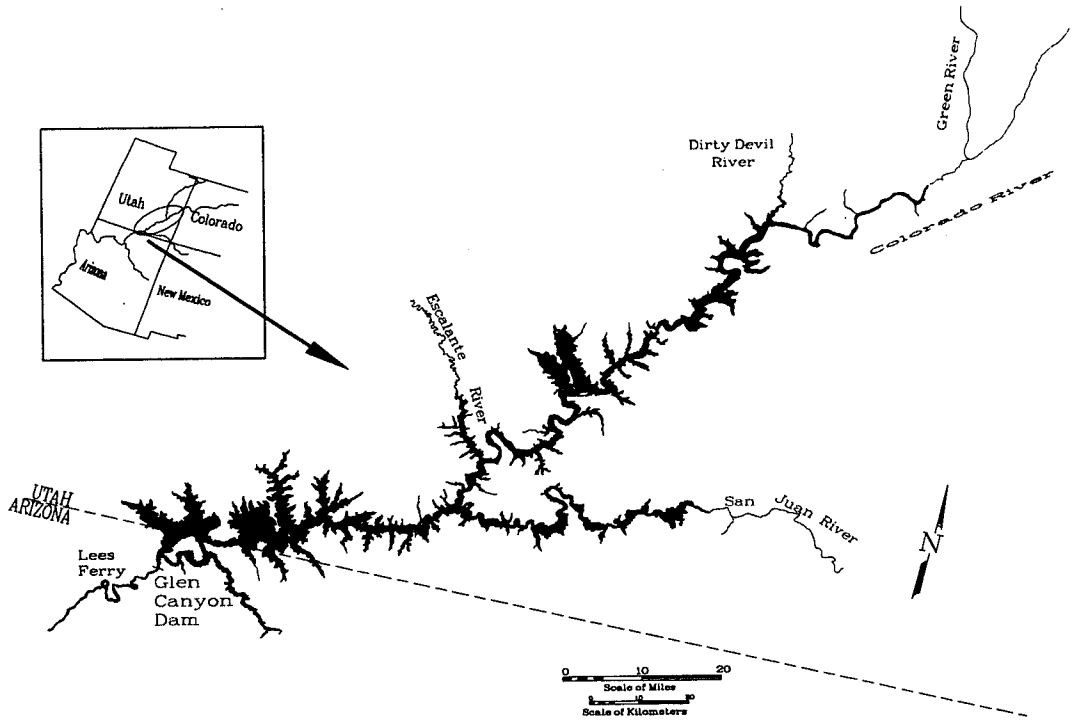

Figure 1. Lake Powell geographic setting and major tributaries

Core Monitoring Information Needs

Several CMINs exist that relate directly or indirectly 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 forebay of Lake Powell are used by the Bureau of Reclamation for their reservoir monitoring program and for feasibility and compliance of a Temperature Control Device on Glen Canyon Dam. All monitoring work in the reservoir is funded separately from GCDAMP funds by the Bureau of Reclamation through an interagency agreement. For the purposes of this document, monitoring of the entire reservoir, its inflows, and releases will be the focus of monitoring approaches. With respect to monitoring for contaminants, at this time, the expense of processing and analyzing samples for trace elements, organic pollutants, radionuclides, and endocrine disrupters has precluded this type of monitoring in the current water quality program.

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?

PEP Review of the Lake Powell Monitoring Program

The PEP for Lake Powell and downstream water quality was conducted in November 2000. The panel commented on the Lake Powell monitoring program in relation to other monitoring needs

of the Glen Canyon Dam Adaptive Management Program (e.g., downstream water quality), as well as providing specific comments associated with technical aspects of sampling in Lake Powell. Some recommendations were quickly incorporated into the sampling program, while other recommendations were programmatic in scale and will require a shift in emphasis as data are assessed and new programs come on line (i.e., the food base program). The latter issue requires that the strategy for Lake Powell monitoring be explicitly linked to the downstream resource monitoring program as a whole to ensure that data collection efforts are complimentary, rather than duplicative or extraneous. This being the case, some of the PEP recommendations for water quality cannot be implemented until other resource monitoring programs are further developed.

The major findings and recommendations of the Lake Powell PEP were as follows:

- *The existing program has produced a sound basis upon which a general understanding of the lake dynamics has been established.*

- *Shift emphasis from Lake Powell to downstream over the next few years.*

In response to this recommendation, the role of one GCMRC employee associated with Lake Powell monitoring was shifted to working on downstream water quality monitoring in 2002. One result of this shift was that there was less staff to implement other PEP recommendations on Lake Powell. Following this shift, the food base program was identified as needing an overhaul with more integration between water quality and fisheries work, so in 2003, the food base program moved into a new research and development phase. In fall 2004, recognizing that some parameters associated with water quality could be better defined through development of the food base program, the downstream water quality data collection efforts were reduced to standard measurements at established gaging stations, with the intent of incorporating temperature data into a modeling effort for the river corridor. It is anticipated that following development of the food base program, the downstream water quality monitoring program will be expanded to meet the needs of the aquatic resources program.

- *The PEP recommended that Integrated Water Quality Program (IWQP) reactivate the water-quality sampling of the three main tributary inflows to Lake Powell-- the Colorado River near Cisco, Utah; Green River at Green River, Utah; and San Juan River near Bluff, Utah—in proximity to where they are gaged for flow.*

In 2003, the feasibility of reactivating the water quality sampling at the inflow gaging sites was assessed. The results indicated that re-activation was possible, but monetary constraints did not permit this to take place. Additionally, since 2001 the reservoir elevation has dropped and inflow levels have changed, precluding the ability to deploy continuous monitoring equipment at a fixed site. Water quality samples for major ion and nutrient content of the major tributary inflows to Lake Powell continue to be collected during quarterly lake wide survey trips.

- *Current CE-QUAL-W2 modeling results by the Bureau of Reclamation (BOR) and additional sensitivity analyses should be used to determine additional primary data needs as soon as possible.*

Work with BOR on the model has been slow to progress as there are differing opinions of the extent of primary data needs for the model. The GCMRC staff has also experienced shifts in staff availability and a redirection of work efforts that have reduced the staff's opportunity to address this recommendation while also addressing others. Currently, the model has been developed specifically to address questions concerning a proposed temperature control device on Glen Canyon Dam. No work has been performed to use the model to simulate or supplant the monitoring information currently being collected. Efforts are proposed during the remainder of FY 2005 and FY2006 to explore development of this model to enhance its predictive capability for a broader range of reservoir water quality conditions and to identify important processes in the reservoir that would affect release water quality.

- *The absence of complete chlorophyll profiles and TOC measurements is a major shortcoming of the present sampling program.*

Complete chlorophyll profiles have not been added to the program due to the lack and expense of required instrumentation. The current program of collecting chlorophyll samples at most of the sampled stations on Lake Powell gives an adequate representation of the trends, patterns, and ranges of surface chlorophyll concentrations for the scope of the biological monitoring program on Lake Powell.

- *IWQP should review the adequacy of the number of samples that are currently collected at the Wahweap station to ensure they are sufficient.*

This recommendation will be part of the review criteria process associated with the CMP. It is anticipated that the review for this program will take place in FY06. Prior to this review, in FY 2005, an evaluation and restructuring of the locations, depths, and frequencies of sampling efforts will be conducted, resulting in a revised sampling plan with rationale for any needed revisions.

- *The use of the USGS Seabird SBE-19 profiler should be vigorously pursued. Also, consideration should be given purchasing of a Seabird SBE-25.*

This option has been explored, and pending the availability of funds, could be implemented. Currently, water quality parameters are measured through the water column at a particular station by use of a Hydrolab H20/Surveyor 3 instrument. Each measurement is determined manually at operator-specified depths to achieve a balance between adequate depth resolution and time required for the measurements. This effort usually requires 1 to 1.5 hours to complete. The Seabird profiler collects measurements on an automated basis as it is lowered and raised through the water column. The Seabird has the potential to reduce the amount of time spent for water quality profiling by approximately half; however, concerns have been raised about the possibility of the Seabird instrument not fully equilibrating each measurement and inaccurately reporting minimum and maximum values.

While improvements could be made to the current program, it is adequate to determine the location and strength of stratification boundaries and provide accurate measurements of all parameters through the water column and also provides consistency with historical data. Potential use of a Seabird instrument is still a viable option and will be evaluated during the June 2005 Lake Powell water quality survey.

- *Phytoplankton and zooplankton sampling could be cut to quarterly collections at the Wahweap site, a mid-lake site in the main channel, and at an up-lake site until it is determined if this information is needed for modeling efforts.*

Sampling for these parameters was reduced starting in 2002. How these efforts fit into a lake-wide and downstream monitoring program still remains to be determined pending outcomes of the food base initiative.

- *The absence of meteorological data at several locations on the lake could be a major shortcoming of the existing data set.*

The feasibility of installing meteorological stations on the lake has been assessed and it was determined to be possible, subject to the availability of additional funding. At this time, additional funds have not been programmed to implement this recommendation. The absence of detailed meteorological data close to the reservoir impedes the development, calibration and verification of the CEQUAL-W2 simulation model.

- *The Panel believes that a timescale of one to two years will be required to collect sufficient inflow, meteorological, chlorophyll, and organic data to produce a useable lake data set for model calibration and application.*

The status of how these data are being used in the CEQUAL W2 model needs to be determined by BOR.

- *The forebay profile represents the best approximation of lab parameters for the river model. This profile also allows forecasting potential water quality problems for the downstream.*

A river model has not been developed beyond the conceptual model developed by Ecometric. Further model development specific to river warming and discharges is needed and may be initiated in fall 2005.

The panel also broke down areas within the lake and parameters that could be collected into essential sites and priority or lower priority parameters.

Essential monitoring sites:

- *Glen Canyon Dam forebay, monthly samples.*
- *Tailwater down to Lee's Ferry.*
- *Downstream samples as needed to apply most important model parameters and to address INs and hypotheses developed on the basis of MOs and INs and to track changes that result from Glen Canyon Dam operations and the TCD.*
- *Inflow samples for modeling water quality in the reservoir and the downstream river.*
- *Meteorological data for supporting the downstream and reservoir models.*

For the most part, these elements have remained intact, though downstream elements have been curtailed pending food base development.

Parameters that are considered essential:

- Total Nitrogen (TN)
- Total Phosphorus (TP)
- *Chlorophyll*
- *Total organic carbon, Particulate organic carbon (TOC/POC)*
- *Temperature, salinity/conductivity, DO and pH, turbidity*

For Lake Powell, these elements are being collected, but downstream, collection of data other than temperature, conductivity, DO and pH have been curtailed.

Lower Priority monitoring sites:

- *Up-lake sites, quarterly samples*
- *Sampling arms of the reservoir*

These lower priority sites have continued to be monitored with quarterly samples, pending analysis of data and restructuring of the monitoring program. This is scheduled to occur in FY06 in association with review of monitoring programs.

Parameters of lower priority:

- *Major ions (have sufficient information)*
- *Plankton data*

Collection of these data has been reduced, and the existing data are awaiting further analysis to determine frequency and utility of sampling for these parameters. A review of the current sampling program will be conducted during FY2005 to evaluate the locations, depths, and frequencies of chemical and biological sampling and parameters measured to improve the cost-effectiveness and quality of information collected from this program. This will result in a revised sampling plan with clear rationale for any needed revisions.

Data Acquisition

The Lake Powell Core Monitoring Plan consists of two components: (1) quarterly reservoir water quality surveys; and (2) monthly forebay water quality surveys above Glen Canyon Dam. Data from these Bureau of Reclamation sponsored activities 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

Forebay Monitoring

The objective of monthly forebay surveys is to characterize the physical, chemical, and biological conditions of the Glen Canyon Dam forebay and describe monthly variations in stratification patterns, mixing processes, planktonic community structure and abundance, and quality of water released downstream. Sampling at frequencies less than monthly provides more anecdotal information about forebay conditions than the monthly time series resolution. Information from forebay monitoring forms a baseline from which the immediate effects of management actions at Glen Canyon Dam can be evaluated. Timing of the arrival of the inflow plume at the dam and depth of winter mixing are examples of information obtained in this monthly effort that would otherwise be lost. Sampling focuses on characterizing conditions of 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 forebay 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 forebay surveys on an approximately monthly basis, with the exception of the period 1982-1990.

Inter-monthly variations in stratification of the Lake Powel forebay are significant, and monthly forebay monitoring was recommended to be continued by the PEP reviewers. Monitoring 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 continuous thermal monitoring stations in the reservoir forebay. Chlorophyll sampling protocols have been amended under recommendations of the PEP. Total organic carbon measurements have been added to dissolved organic carbon measurements already being taken.

Reservoir Monitoring

The objective of quarterly reservoir-wide surveys is to characterize physical, chemical, and biological conditions of the Lake Powell reservoir and describe seasonal variations in stratification patterns, mixing processes, planktonic community structure and abundance, and their affect on the quality of water released downstream. Sampling will focus on characterizing conditions of the major strata of the reservoir and any significant advective currents flowing through the reservoir. 20 to 25 stations are visited on a quarterly reservoir survey and are located in the main channel of the Colorado River and two major tributaries of the San Juan and Escalante Rivers, as well as the inflows to these tributaries and the tailwater below Glen Canyon Dam. Chemical sampling is performed at approximately half of these stations. The quarterly

sampling frequency provides seasonal resolution of conditions existing in the reservoir, at a frequency less than that of forebay sampling so that it describes the status of the reservoir and potential conditions that could adversely affect the water quality of the reservoir and Glen Canyon Dam releases. An example of this would be an anoxic or hypoxic inflow plume that could move through the reservoir and eventually affect the quality of dam releases. A thirty-four-year period of record exists for reservoir surveys, which have had frequencies ranging from monthly to annually since 1965 and describe the entire water quality history of Lake Powell. As per PEP panel recommendations, modeling efforts are being pursued in order to replace some monitoring activities by model predictions. A significant reduction in the number of chemical samples collected has occurred in the past several years. In 2005, the data from this sampling will be further analyzed, verified and published, with the intent of making further restructuring to the sampling program to increase cost-effectiveness while maintaining the integrity of the monitoring program.

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

Objective	Parameters	Methods	Location(s)	Frequency	Accuracy & Precision
7.3.1 Monitor the status and trends of water quality releases from Glen Canyon Dam	Physical parameters Water temperature, Specific Conductance, Dissolved Oxygen, Turbidity,	Profiling with multi-parameter water quality sensor	Forebay	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.
			Reservoir-wide (20-25 stations)	Quarterly	
	Chemical parameters - Nutrients, major ions, dissolved organic carbon, total organic carbon	Physical water samples	Forebay (3-4 samples)	Monthly	
			Reservoir-wide (10-12 stations/1-3 samples per station)	Quarterly	
	Biological parameters - chlorophyll and phytoplankton,	Residue from filtered water samples	Forebay (1 surface sample)	Monthly	
			Reservoir-wide (20-25 stations/1 surface sample)	Quarterly	
	Biological parameters - zooplankton	Net samples from vertical tow through water column	Forebay (2 samples)	Monthly	
			Reservoir-wide (10-12 stations/1-2 samples per station)	Quarterly	

Quality Control
The multi-parameter water quality profiling sonde is calibrated in the lab prior to and after 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 the U.S. Bureau of Reclamation Regional Lab for analysis. Water samples include replicates, blanks, and spikes for purposes of quality control/quality assurance.

Data Management, Analysis, and Dissemination
Data are managed and analyzed using SAS data structures and stored in the MS Access WQDB database. These data are made available to the DASA group for incorporation into Oracle database. Currently the database is complete for the last 14 years and updated regularly, but has not been fully incorporated into Oracle and available on-line. The entire database or parts of the database are readily available by request to GCMRC, though the data are considered provisional. These data following review, evaluation and adjustment and formal publication by USGS 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.

Explanation of Differences in Lake Powell Budgets in the PCMP and FY06 Work Plan
The PCMP budget for Lake Powell monitoring is different from the budget in the FY06 Work Plan. This discrepancy reflects an identified need in the PCMP for an additional technician to assist with fieldwork. The technician would free up time that the two staff members currently spend in the field collecting data, so that they could analyze the historic monitoring data and devote more time to modeling of Lake Powell. Also, there are additional costs associated with processing plankton samples that are not included in the laboratory services provided by the BOR, and USGS assessment costs also contribute to the increased costs associated with Lake Powell monitoring. In the absence of the additional requested funds in FY06, monitoring will continue but analyses and modeling will proceed at a slower pace.

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[1]: 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 (near mouth)	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.

[1] Discharge from Glen Canyon Dam is currently compiled by BOR and electronically transferred to GCMRC on a daily basis and maintained in accessible datasets.

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). Therefore, temperature, conductivity, and suspended-sediment concentration are the only QW parameters proposed for core monitoring. Other parameters, such as oxygen and nutrients, may be included in core monitoring in the future pending results of the aquatic food base research program.

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.

Protocol Evaluation Process (PEPS) for Physical Resources below Glen Canyon Dam

The most recent Protocol Evaluations Panel for the Physical Resources Program (PEP-SEDS) was conducted over two meetings, initially in August 1998 and again in August of 1999, with a final report issued by the Panel dated November 1, 1999. In general, the Panel provided a very positive review of the physical sciences program during the era of initial post-EIS (1995-1996) and early GCMRC (1996-1999) efforts. In the summary section of the report, it states:

"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 Panel then goes on to list nine primary tasks of most importance for the physical resources program to tackle in the future. In response to the final report, GCMRC resolved to initiate several new research and development projects through competitive solicitations in FY 2000. The objective of these projects was to conduct field research to evaluate new and revised

standard methods so as to identify the most effective approach to long-term monitoring of coarse and fine-sediment resources associated with the Colorado River ecosystem. Three research & development projects aimed at defining long-term monitoring with respect to sediment were initiated through awards in FY 2001. The intention of the GCMRC program was to provide funding for these efforts through completion in FY 2005, so as to derive robust recommendations from rigorous field efforts that might also possibly be associated with potential High-Flow experimental treatments. At the start of the fifth and final year of these three projects, just such an experiment occurred.

Projects started in 2001 that focused on sediment research and monitoring include: 1) Fine-Sediment storage change detection, 2) Mass-Balance of Suspended-Sediment Transport, and 3) Coarse-Sediment storage changes resulting from tributary floods and debris flows.

An additional physical science research project was initiated in FY 2002. This project was aimed at development of a predictive capability for estimating the fate of discrete sand inputs from the Paria River under a range of Glen Canyon Dam operations. It was hoped that such a capability would provide: 1) utility in evaluating the current operation of the dam, 2) support in planning high-flow experiments, and 3) help to managers to better anticipate the influence of future planned and unplanned high flows from the dam on downstream sand resources. All four of these science efforts were advocated by the SEDS panel in their final report.

The nine tasks identified by the PEP-SEDS are summarized below, along with descriptions of the progress that has been made by the program since 1999.

1) *Development of a conceptual framework that will guide research and monitoring efforts through workshop exercises aimed at development of the Grand Canyon Model (a conceptual model with subcomponents for estimating ecosystem response with respect to river flow, stage and fine-sediment dynamics).* The results of the conceptual modeling project are described by Walters and others (1999), and the effort involved in development of the physical resource sub-modules provided a great deal of insight into the approaches that might be utilized in long-term monitoring of fine-sediment resources, such as suspended-sediment measurements related to influx, storage and efflux of sand, as well as topographic and grain-size mapping of the channel with respect to sand storage.

2) *Integration of the physical resources, biology, and cultural/socioeconomic programs*

   Progress: In 2003/2004, the GCMRC went through a reorganization that created the Integrated Science Program in an attempt to more fully integrate studies from the various resource areas. Monthly science meetings are held to discuss and facilitate integrated efforts.

3) *Clarification of information needs identified by the SEDS panel in their report.*

   Progress: Through development of the AMP strategic plan, stakeholders were able to better define needs related to sand and gravel resources, through articulation of

Information Needs related to Goal Eight of that document. These information needs were essential in helping scientists identify what parameters of sediment were desired for monitoring with respect to stage and longitudinal distribution throughout the ecosystem, relative to their charge in evaluating dam operations. During the course of the 2001-2005 research and monitoring projects, physical scientists have attempted to focus their efforts relative to the stated information needs. These needs are again being reviewed as the physical scientists draft reports on their research findings and monitoring recommendations.

4 and 5) *Development of a synoptic picture of the river bed. Selection of monitoring reaches.*

Progress: These tasks are being addressed through award of a cooperative agreement in 2001 for the project titled "Long-Term Monitoring of Fine-Grained Sediment Storage throughout the Main Channel of the Colorado River Ecosystem", commonly referred to as the FIST (Fine-grained Sediment Team) project. This project is using a variety of techniques to map the river bathymetry (multi-beam sonar) and topography (LiDAR), and characterize the bed surface (underwater photography and video, acoustic backscatter). A reach-based approach is being employed (11, ~2-3 mile reaches) as recommended by the Panel. Final reports for this project are due in FY2005-2006.

6) *Continuation of 1D and 2D sediment modeling in the main channel*

Progress: Modeling efforts have continued through the award of a cooperative agreement in 2001 to the proposal titled "Development of a management tool for predicting multi-dimensional sand-bar evolution and 1-dimensional sand transport in the Colorado River ecosystem". This project is in its final stages, with final reports and models due in FY2005-2006. Once completed, these models will be valuable tools for testing sand-bar response to alternative flow release patterns from Glen Canyon Dam and possibly for tailor designing high-flow releases to maximize benefit while minimizing sand export.

7, 8, and 9) *Collection of daily sediment samples along the main channel. Expansion of sediment sampling and monitoring for principal tributaries. Greater emphasis on event-driven monitoring and sampling.*

These tasks are being addressed through a cooperative agreement, awarded in 2001, for the project titled "Monitoring and research of streamflow, sediment transport, and water quality in the Colorado River ecosystem between Glen Canyon Dam and Lake Mead", commonly referred to as the Mass Balance project. This project is developing and testing continuous monitoring protocols for suspended-sediment transport using surrogate technologies (optics and acoustics) at several locations along the mainstem, combined with traditional sampling. Detailed sampling of tributaries, organized around significant events, has also been implemented, with the

goal of computing a continuous "mass balance" of fine sediment for several reaches of the river. Final reports for this project are also due in FY2005-2006.

The Integrated Water Quality Program Protocol Evaluation Panel final report was delivered in February 2001. The PEP covered both Lake Powell and downstream water quality. The primary recommendation of the panel, with respect to downstream as well as Lake Powell, was the development of numerical simulation water quality models. This recommendation is being pursued but is not relevant to the Core Monitoring Plan. The primary recommendation relevant to the core monitoring was to continue temperature monitoring throughout the ecosystem. This recommendation has been followed in this plan.

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. Temperature and conductivity data will be collected using multi-parameter continuous water quality monitors as well as stand-alone temperature loggers. 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, SSC = suspended-sediment concentration

Objective	Parameter(s)[1]	Method(s)	Locations	Frequency	Accuracy and Precision
Monitor water quality conditions in	WT, SC	Water quality sensors	**Colorado River** at river miles: - 15 and 0	15-minutes for water quality sensors;	Temperature: ±0.15°C Conductivity: ±0.5% of reading + 0.001 mS/cm ±10% for mainstream sediment loads. ±20-30 for tributary sediment loads.

Objective	Parameter(s)[1]	Method(s)	Locations	Frequency	Accuracy and Precision
	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 (near mouth)	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; event-based water samples for SSC and grain-size	
	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.).

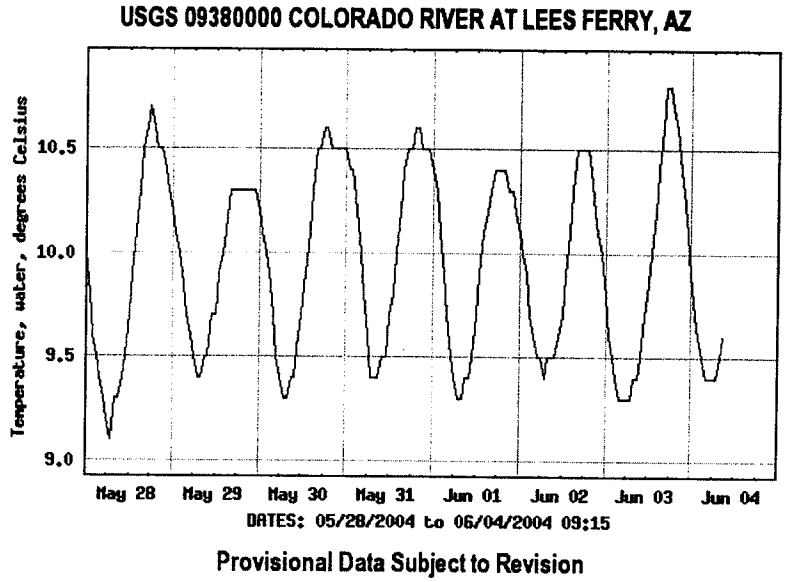

Figure 2. Example of real-time temperature data from Lees Ferry (http://waterdata.usgs.gov/az/nwis/uv?09380000)

The 15-minute data 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.

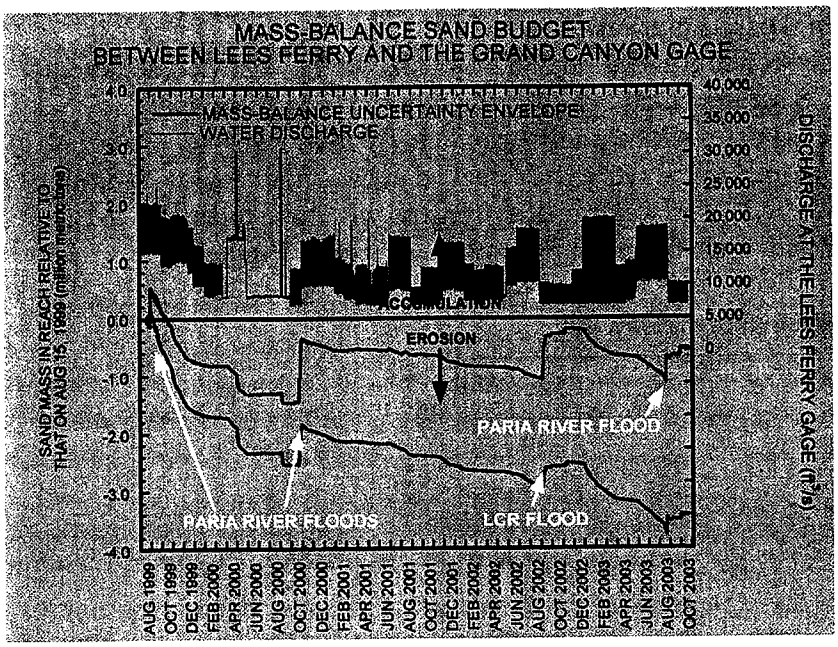

Figure 3. Example of suspended-sediment mass balance

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.

Explanation of Differences in QW Budgets in the PCMP and FY06 Work Plan
In the FY06 work plan, GCMRC salaries are built into the budgets project by project, whereas in this Provisional Core Monitoring Plan, GCMRC salaries are a separate line item and are not included in the individual monitoring project budgets. Also, the FY06 work plan encompasses the entire science budget for downstream water quality work, including some research elements, whereas the budget for this plan encompasses only core monitoring activities. However, this plan envisions work along the entire length of the river corridor, whereas the work proposed in the FY06 budget is focused on the upper reaches of the CRE to the Grand Canyon gage. Therefore, although the FY06 work plan includes a more restricted spatial scope and less monitoring than is laid out in the PCMP, the budgets end up being roughly comparable.

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 (GCES) 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 GCDAMP 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 GCDAMP.

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 GCES 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 several of the recommendations of the PEP panel have been incorporated into the sampling program including increasing sampling sites to cover more habitat and decreasing time spent at each site, and maintaining whirling disease monitoring.

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.

PEP Review of Lees Ferry Trout monitoring

The PEP for the Lees Ferry Trout fishery was conducted in May 2000 from the 22nd to the 25th. The panel provided recommendations relative to the adaptive management program in general and specifically for the sampling in the trout fishery.

Programmatically the reviewers recommended:

- That an integrated view of the river, that includes both upstream and downstream areas as well as terrestrial habitats, be employed for adaptive management of its resources.

- That GCMRC develop an explicit set of ecologically-based Study Objectives, based on desires of stakeholders, that will drive all activities, including design of Requests for Proposals, and that the Arizona Game and Fish Department take an active role in communicating the process to stakeholders.

Lees Ferry fishery protocol commented on sampling, assumptions associated with population estimates, and potential diseases that might affect the fishery. Regarding sampling, the panel stated the following:

"Because current sampling sites are not representative of all available habitats, electrofishing results cannot be extrapolated to provide an independent estimate of population size. Similarly, the rainbow trout's tendency to stay in one place violates an important assumption of the use of tagging studies to measure total population size, namely that tagged fish mix randomly with the total trout population."

The Panel recommended the following:

- *The specific sampling protocols could be improved by increasing the number of electroshocking sampling sites back to 15, while sampling at each site for a shorter period of time, and adopting a truly random sampling site selection approach.*

  Following the review, GCMRC released an RFP that initiated a revised sampling approach. The approach retained the historic 9 sites, but reduced sample runs within sites. In addition, sampling was expanded beyond these sites to randomized sites along specific shoreline habitats. The sampling is an augmented, serially alternating design. A total of 33 sample runs are conducted each trip. The results have been an increase in sample power and an ability to detect change in CPE within a year's time. The sampling methods have been in place since 2001. The information associated with improving sampling efforts has been conducted through collaboration with Arizona Game and Fish Department, the agency responsible for the trout fishery.

- *The current sampling protocol is biased against small rainbow trout and those fish living in the main channel and along steep canyon walls, and habitats that might be viewed as "poor" trout habitat.*

  Randomized sampling methods were implemented in 2001 to reduce bias and to provide a more comprehensive picture of the trout fishery and its population dynamics. A result of the new approach has been the identification of an overstocked fishery and over-estimate of the fish population and the identification that the management objective associated with age II+ adults may be too large (Speas and others 2004). These findings may require revision of AMP management objectives associated with non-native fish.

- *Creel sampling should be continued because it provides important information on the fishery from the perspective of the fishermen.*

  Arizona Game and Fish Department and the National Park Service conduct creel surveys and these data are incorporated into a population dynamics model for the trout fishery that uses electrofishing CPE from tri-annual surveys.

- *Juvenile trout should be sampled using traps or other appropriate gear, since they will be affected first by changes in discharge.*

  During the 2003-2004 experimental flows, a project associated with redds and the fate of early life history stages of rainbow trout was implemented. The project used

backpack and boat electroshocking methods on a monthly basis following spawning. It also incorporated otolith work to confidently assign age to lengths of fish (because fish growth can be influenced by temperature and density). This report is in review but the methods appear to provide an approach to track YOY fate in association with changes in discharge. Though it is not incorporated into the monitoring program, it is proposed as an approach that should be implemented when discharges change in association with experimentation.

With respect to disease and parasite work:

- *Whirling disease will profoundly affect the Lee's Ferry trout population should it become established, so monitoring for this disease should be initiated.*

  Arizona Game and Fish Department work cooperatively with the National Wildlife Health Center in monitoring whirling disease and diseases and parasites that might affect the fishery. AGFD provides samples of fish and potential vectors to the NWHC for subsequent analysis.

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. The 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 based on power analysis to detect change at rates reported.	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 4.1.4	Fish length and weight to estimate Proportional Stock Density (PSD), growth rate, and Condition Factor	All fish captured during electrofishing sampling are measured to the nearest mm. Fish larger than 100mm are weighed to the nearest	27 stratified random and 9 fixed electrofishing transects between Glen Canyon Dam and Lees Ferry	3 times per year	4-10% linear 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	Approximately 40 fish per year are assessed for	27 stratified random and 9 fixed electrofishing	Annually	Current design appears adequate to

Objective	Parameters	Methods	Location(s)	Frequency	Accuracy & Precision
	infestation	whirling disease and nematode infestation	transects between Glen Canyon Dam and Lees Ferry		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 held by the GCMRC library so that future problems encountered with fish databases may be checked against field data sheets. Data must meet GMCRC data standards.

Data Management, Analysis, and Dissemination

Data records are tied to river mile, and date of field event, which is a common to all data stored at GCMRC. Data retrieval provides all data associated with a field effort that corresponds to data entry on standard field data collection forms. Analysis and dissemination of core monitoring activities (the parameters described in the above table) will be available primarily through annual reports prepared by principal investigators associated with this monitoring element. As needed, GCMRC will also request that 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. Electronic data are provided to GCMRC by cooperating scientists and are stored and archived on GCMRC's Oracle database. Data are available by request following review and approval of annual reports. The long-term goal is to have these monitoring data available from GCMRC's website. Currently data are available for dates 2000 – 2004 upon request to the database manager.

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 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.

PEP recommendations related to Humpback chub monitoring in the LCR

An aquatic pep panel was convened in May 2001. The review included components of the aquatic system downstream of the Paria Riffle. Humpback chub was included as a specific component of the review. Below is a general comment associated with the HBC review

> *"Humpback Chub: The Panel recommends that further work be conducted to develop a conceptual model of the metapopulation biology of chub in the GCE to provide a context for a long-term monitoring program. Consideration should be given to the inclusion of genetic concerns in the monitoring program. GCMRC needs to develop explicit linkages between the results of annual monitoring and the management goals to ensure that the monitoring programs produce results appropriate to review progress to the goals. The Panel supports the completion of the current review of existing data, and the development of population models as these programs will yield sufficient information to make decisions about sampling programs for chub."*

- *The Panel believes that the resolution of the population biology of HBC to be a critical information need for the implementation of a long-term monitoring program.*

  The genetics project initiated in 2001 is aimed at addressing this issue, and the report for this work is scheduled to be received in January 2006.

The PEP also identified several key issues of uncertainty requiring resolution, including:

- *Whether the timing of the sampling mid-May and re-sampling in June will yield reasonable estimates of the total number of spawning fish, given the complexities that arise because of the immigration and departure of some spawners (especially larger ones) from the LCR.*

This comment has been the source of further review in 2003 by the Kitchell and others report (http://www.gcmrc.gov/library/reports/PEP/Anders2001.pdf.) Since that time, additional modeling efforts have been conducted (Coggins and others, In Prep.) and are currently being explored in association with concurrent estimates.

- *Bias caused by tag loss (either through the mortality or emigration of repeatedly handled fish, or expulsion of tags). In controlled experiments 5-10% of PIT tags are lost soon after application; higher figures might be expected in the field.*

  PIT tag loss was studied in controlled experiments associated with hatchery fish. Alternative methods to mark fish are being explored, although alternatives are limited given the long-term use of PIT tags and their incorporation into the database and balancing this with adding more marks to fish that are endangered.

- *Whether this program needs to be conducted annually, given the longevity of adult fish and the likely slow changes in the abundance over time.*

  Assessment of this question will be determined in the course of the monitoring review occurring in FY06.

The panel concluded their review with the following:

> *"In summary—Two decades of investigation on the biology of humpback chub has left a body of information that is perhaps unparalleled for a non-game fish. The Center is thus well-positioned (after investigation of some of the outstanding uncertainties listed above) to design a monitoring program that should allow the evaluation of the management goals with reasonable reliability.*
>
> *The Center should refine the links between management goals for HBC and each of the monitoring activities by specifying how the outputs from monitoring will be used in decision making. Quantitative analyses of past and currently collected data should yield estimates of the precision of the various*

programs, allowing calculations of the power of different types and intensities of monitoring programs to detect change in the population."

This portion of the recommendations will also be revisited as part of the data evaluation review in FY06.

Data Acquisition for Specific Components of the Humpback Chub Monitoring Program

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 (April and May) and fall (September and October) HBC abundance assessments in the lower 15km of the LCR; (2) annual spring HBC relative abundance assessment in the lower 1200m of the LCR (April and May); (3) annual spring/summer collection of HBC mark recapture information in the LCR Inflow (RM 57-65.4) (July); and (4) annual assessment of the overall LCR HBC population abundance and recruitment (utilizing data collected in items 1-3). 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 (April and May) and Fall (September and October) 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. Other types of sampling gear are not used in the LCR because they have been shown to be less efficient at capturing HBC > 150mm TL in 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 potential impacts of monitoring activities on LCR HBC population dynamics will also have to 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 (April and May) using hoopnets set in standardized locations distributed throughout the reach. In general, this effort represents the longest and most consistent relative abundance dataset available to infer trends in the LCR HBC population. Importantly, it provides an independent comparison to the mark-recapture based assessments. 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 (June and July) 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 the LCR Inflow 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 (April and May) and Fall (September and October)	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 (May)	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 (June/July)	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 following data submission from cooperators.	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 held by the GCMRC library so that future problems encountered with fish databases may be checked against field data sheets. Electronic copies of data are submitted to GCMRC on a CD/DVD format. Data must meet GMCRC data standards.

Data Management, Analysis, and Dissemination

Data records are tied to river mile, and date of field event, which is a common to all data stored at GCMRC. Data retrieval provides all data associated with a field effort that corresponds to data entry on standard field data collection forms. Analysis and dissemination of core monitoring activities (the parameters described in the above table) 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. Electronic data are provided to GCMRC by cooperating scientists and are stored and archived on GCMRC's Oracle database. Data are available by request to the database manager following review and approval of annual reports. The long-term goal is to have these monitoring data available from GCMRC's website. Data from this work is available electronically from 2000 – 2004.

Future Core Monitoring Program

See Appendix B for a list and brief description of monitoring programs under development.

CHAPTER 3

Program Support for Core Monitoring

This chapter describes several GCMRC programs that provide technical and logistical support for monitoring work. These programs are not dedicated exclusively to supporting core monitoring activities, but they are critical for implementing the work described in Chapter 2, as well as the monitoring programs that are currently undergoing research and development for future implementation (Appendix B). Differences between the budget figures presented in this plan (Appendix A) and in the FY06 work plan reflect that these programs support research as well as monitoring activities; hence the budget figures shown in Appendix A are an estimate of the percentage of total effort expended by each of these support programs on core monitoring, whereas the figures in the FY06 work plan cover the entire scope of each program.

A. 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 2005. 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.

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.

B. 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.

B.1 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.

B.2 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.

B. 3 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.

B.4 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.

B.5 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.

B.6 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.

B.7 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.

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**-Researchers 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 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.

CHAPTER 4

Implementation

A. Roles and Responsibilities

As a preliminary step in developing the long-term Core Monitoring Plan, 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 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. Reporting Process and Feedback

B.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.

B.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 GCDAMP 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 GCDAMP 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 GCDAMP. 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.

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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	(445,500)	Estimated Need for Annual Cost (from Non-AMP funding, including salaries & DOI burden @ 15%)
Downstream Integrated Quality-of-Water – Temperature and conductivity	Continuous Main stem/Tributary	115,000	Current Annual Cost also Equal to AZD est. (includes DOI burden @ 15%)
Streamflow & Suspended-Sediment Transport (Mass Flux)	Continuous stage/discharge & Weekly suspended sediment	989,000	This is AZ District WRD Estimate for FY 2006 (includes DOI burden @ 15%)
	IQWP Subtotal	**$1,104,000**	Not including Lake Powell portion
Sediment Storage, Geomorphology & Biological Elements			
Rainbow Trout in the Lees Ferry Reach	Seasonally - Related to Life History	184,000	Cost Based on Current Annual Efforts (includes DOI burden @ 15%)
Humpback Chub in the Little Colorado River	Seasonally - Related to Life History	402,500	Cost Based on Current Annual Efforts (includes DOI burden @ 15%)
	Integrated Science Program (w/o DASA component) Subtotal	**1,690,500**	(includes DOI burden @ 15%). (Total is $2,136,000 after adding Lake Powell.)
Data Acquisition, Storage and Analysis (DASA) - Support			
Airborne Remote Sensing (Digital, Orthorectified Imagery	System-wide Digital Imagery Every 4-Years	138,000	Mission Cost Estimated at $808,500 (w/ overhead). (includes DOI burden @ 15%)
DBMS - Storing New Core-Monitoring Data (See Appendix E for a detailed breakdown on this component)	Annual added Storage Costs for Monitoring Data	115,000	Current Oracle License Costs & Ongoing Storage Needs (includes DOI burden @ 15%)

Geographic Information System - Support Fieldwork & Overflights	Annual Support of Core Monitoring Activities	5,750	This is Ongoing Annual Equipment, Storage & Supplies Costs (includes DOI burden @ 15%)
	DASA Subtotal	**$258,750**	
Core Monitoring Share of Annual Physical, Modeling & DASA Personnel Costs	Varied Approximations of the Total Annual Salary Cost projected for FY 2006 is devoted to core monitoring	372,620	Salaries Projected for 2006 on Basis of 2004 (includes DOI burden @ 15%)
Core Monitoring Share of Annual Biology Program Personnel Costs	Varied Approximations of the Total Annual Salary Cost projected for FY 2006 is devoted to core monitoring	76,500	Salaries Projected for 2006 on Basis of 2004 (includes DOI burden @ 15%)
SUBTOTAL INTEGRATED SCIENCE PROGRAM (Core-Monitoring)	**Biology + Physical, Modeling & DASA Core-Monitoring Support**	**$2,398,370**	(includes salaries + DOI burden @ 15%)
Socio-cultural Program			
	Probably annual field visits and 4-YR Over flights		Research Initiated in FY 2005
	Probably annual field visits by each tribe		Research Initiated in FY 2005
	Surveys, probably every 4 or 5 years per user group/topic		Research initiated in FY 2005
	Probably biennial field visits and 4-YR Over flights		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		
SUBTOTAL SOCIOCULTURAL PROGRAM		**0**	
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		**$230,000**	(includes salaries + DOI burden @ 15%)
SUBTOTAL INFORMATION OFFICE	**Annual - Serving Core Monitoring Data**	**$267,950**	(includes salaries + DOI burden @ 15%)
TOTAL CORE MONITORING BUDGET		**$2,896,320**	Includes "CM" only, as currently defined in this draft plan

Appendix B. Core Monitoring Programs Undergoing Research and Development

(Red and yellow highlights indicate the projects' R&D status, with yellow projects being those closest to being ready for full-scale implementation in FY06 or FY07.)

Aquatic Resources

[redacted]

Monitoring Program B.2 for Quality of Water Measurements for Biological Resources Programs is under review and development and will be linked to aquatic food web research program (see Project B.6).

B.4 Fine Sediment (Sand and finer) in the Aquatic Zone (below 25,000 cfs)
Monitoring Program B.4 for Fine Sediment in the Aquatic Zone Program is in finalization and early review stage. Includes remotely sensed data and ground based surveys tied to habitat and stage elevation to evaluate operational affects on sand storage.

B.5. Coarse Sediment in the Aquatic Zone (below 25,000 cfs)
Monitoring Program B.5 for Coarse Sediment in the Aquatic Zone Includes remotely sensed data and ground based surveys tied to habitat and stage elevation to evaluate operational affects on gravels and cobbles.

[redacted]

Monitoring Program B.6.1 for Aquatic Food Web Program is under development. RFP for to study linkages and determine monitoring variables is to be released in Spring 2005. Review of previous approaches recommended an overhaul of aquatic food base program. See research plan for details.

[redacted]

Monitoring Program for downstream fishes. Program is under development. Requires testing alternative sampling gear types for exotic and native fishes. Includes components B.7.1 a. b, c, d listed below. See research plan for details.

[redacted]

[redacted]

Monitoring Program for fish disease and parasites. Program is under development. Research is scheduled to begin in late summer and continue into 2007. Focus is on humpback chub. See research plan for details.

Terrestrial Resources

C.1. Fine Sediment in the Terrestrial Zone (above 25,000 cfs).
Monitoring Program C.1 for Fine Sediment in the Terrestrial Zone Program is in finalization and early review stage. Includes remotely sensed data and ground based surveys tied to habitat and stage elevation to evaluate operational affects on sand storage.

C.2. Coarse Sediment in the Terrestrial Zone (above 25,000 cfs)
Monitoring Program C.2 for Coarse Sediment in the Terrestrial Zone Program is in finalization and early review stage. Includes remotely sensed data and ground based surveys tied to habitat and stage elevation to evaluate operational affects on gravels and cobbles.

C.3 Terrestrial Vegetation

Monitoring Program for vegetation Program is in finalization and early review stage. Focus is on landscape and local scale change detection. Includes remotely sensed data and ground based surveys tied to habitat and stage elevation to evaluate operational affects on vegetation change. See research plan for details

C.4 Wildlife

Monitoring Program for wildlife. Program is in early review stage. Focus is on terrestrial vertebrates and principle riparian birds, though other vertebrates inventoried. Utilized remotely sensed imagery for location and habitat parameters and is tied to vegetation monitoring program. See research plan for details.

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

C.5.a Kanab ambersnail

Monitoring Program for Kanab ambersnail at Vaseys Paradise. Program is in development with review anticipated in 2006 as to efficacy of alternative monitoring methods for habitat. See research plan for details.

C.5.b. Southwestern Willow Flycatcher

Monitoring Program for Southwest Willow Flycatcher. Program utilizes standard US FWS protocols and is ready for implementation, though consideration should be made about inclusion of this program with wildlife monitoring to make the work more integrated. See research plan for details.

[redacted]

Monitoring Program C.6.1. National Register Eligible Historic Properties (Archeological Sites and Traditional Cultural Properties). Program is under development. See research plan for details. Review of current archaeological site monitoring data planned for 2005. Workshop to design monitoring protocols for TCPs scheduled for April, 2005

Monitoring Program C.6.2. Cultural Resources Not Eligible for Listing on the National Register (Traditionally Valued Resources). Program is under development. See research plan for details. Workshop to design monitoring protocols for tribally valued resources scheduled for April, 2005

[redacted]

Monitoring Program C.7.1. Quality of Recreational Experiences. Program is under development. See research plan for details. Recreational PEP review scheduled for June, 2005.

Monitoring Program C.7.2.Campsite Monitoring. Program is under development. See research plan for details. Recreational PEP review scheduled for June, 2005.

Monitoring Program C.7.3. Recreational Economics. Program is in development. See research plan for details. Recreational PEP review scheduled for June, 2005.

Appendix C

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) **Articulate Management Objectives/Information Needs, and Current Protocols** - 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 GCES (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) **Evaluation/Selection of Protocols to be Implemented** - 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 D
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 E
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.