Review of the Draft Federal Long-Term Monitoring Plan for the Colorado River below Glen Canyon Dam

Committee to Review the
Glen Canyon Environmental Studies

Water Science and Technology Board

Commission on Geosciences, Environment,
and Resources

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COMMITTEE TO REVIEW THE GLEN CANYON ENVIRONMENTAL STUDIES

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Summary

The Glen Canyon Dam, which was completed in 1963, is one of several multipurpose storage reservoirs on the Colorado River system. The initial operating rules for the Dam were designed to meet requirements for the delivery of water and to yield maximum hydropower revenues through the production of peaking power. Since the early years of its installation, however, the Dam has created new concerns about environmental resources in the Grand Canyon. The Glen Canyon Environmental Studies (GCES), which have been in progress since 1982 under sponsorship of the Bureau of Reclamation, are intended to support the scientific evaluation of relationships between the operations of Glen Canyon Dam and the natural resources of the Grand Canyon. The results of the GCES have been used recently in evaluating a range of possible operating rules for the Dam, in supporting the analysis of alternatives to be listed in the Glen Canyon Dam Environmental Impact Statement, and in setting the stage for long-term monitoring of environmental resources in the Grand Canyon.

Since 1986, the NRC's Committee to Review the Glen Canyon Environmental Studies has evaluated GCES reports as well as other documents produced by the Bureau of Reclamation. The present NRC report provides a review of the Bureau's Draft Federal Long-Term Monitoring Plan for the Colorado River below Glen Canyon Dam. The committee's review deals with all aspects of the draft monitoring plan, including scope of work, protocols for acquisition and archiving of environmental data, organization, justification, and implementation.

The NRC committee believes that the draft monitoring plan will be of great importance in providing a rational basis for protection of environmental resources in the Grand Canyon. In addition, because of the national and international prominence of the Grand Canyon, as well as the intensive studies that have been sponsored through GCES, the plan may serve as a blueprint or model for other riverine ecosystem monitoring plans in the United States and other countries. For this reason, it is important that the plan be

well-designed, clearly explained, and efficient in its proposed collection of data and use of financial resources. The NRC committee believes that the present draft of the long-term monitoring plan does not yet meet all of these criteria.

The present version of the long-term monitoring plan does not contain any estimates of the costs of environmental monitoring, nor does it make any firm recommendations for research that would complement monitoring. The NRC committee believes that these two critical elements should be added to the plan. Given the extensive experience of GCES program personnel with the cost of working in the Grand Canyon over the last decade, it seems reasonable that the plan should provide an estimate of the expenses of monitoring. Failure to specify costs may result in arbitrary omissions from the list of essential variables to be monitored, which would undermine the effectiveness of the monitoring program. As an adjunct to the estimate of cost, it may be necessary for the plan to show in more specific terms what limits of error are acceptable for key variables to be monitored.

Research is also important because monitoring will probably demonstrate some unexpected results; program managers should support research that may help to explain these unexpected results. The draft plan correctly indicates that an important role of research is to improve the efficiency of monitoring. The plan is tied specifically to the preferred alternative for operation of the Dam as derived from the Environmental Impact Statement. The NRC committee believes that the program should extend beyond this to include information that would be relevant to analysis of other potential operations of Glen Canyon Dam that might arise as the preferred alternative is revised or changed due to other causes within the scope of dam operations.

The committee finds a number of problems with frequency of measurement and scope of data collection, both of which may be inadequate for components of the environmental system. In addition, the plan indicates that monitoring should be conducted by noninvasive means, but offers limited guidance in support of this objective. The committee supports greater emphasis on noninvasive methods for studying the Colorado River and is particularly interested in removal of permanent physical installations that are now used in monitoring.

Many parts of the draft monitoring plan are not sufficiently specific about monitoring requirements. For a number of resources, the frequency of monitoring, the sites for monitoring, and the methods for monitoring are not described or are described only in vague terms. Given the long-term commitment that will be essential, and the necessity for stability in data collection, it is important that the monitoring plan be more specific.

In a number of instances, the draft monitoring plan subordinates specific requirements for information to administrative initiatives that will be developed in the future by various resource management agencies outside the long-term monitoring program. The committee believes that the long-term monitoring program must take full

responsibility for decisions about the kinds of data to be collected, sites at which data will be collected, and methods for data collection. Blanket delegation of this responsibility to other entities is undesirable and should be avoided.

Unfortunately, the NRC committee finds much of the present version of the draft long-term monitoring plan to be confusing. The plan needs to be extensively revised for improvement of clarity, logical cohesion, and degree of specificity with which monitoring requirements are described.

Finally, the draft monitoring plan does not contain any proposal for administration or management of long-term monitoring. Strategies for administration and management are critical to the success of the program, and should be incorporated in the plan. If the plan does not include a specific proposal for administration, then criteria that must be satisfied by any proposed administrative scheme should be specified. The authors of the plan should consider the advantages of requiring administrative independence for the long-term monitoring program, and open contracting procedures that will allow the managers of the program to maximize cost efficiency and maintain direct control over the scope and quality of data collection in the Grand Canyon.

1

Introduction

In 1956 Congress passed the Colorado River Storage Project Act, which authorized construction of Glen Canyon Dam on the Colorado River above Lees Ferry. In identifying purposes for Glen Canyon Dam, the Act specifically mentions requirements for the storage of water for beneficial use, reclamation of arid and semi-arid lands, control of floods, and, as an incident of other specifically mentioned purposes, the generation of hydroelectric power. The Bureau of Reclamation, which assumed responsibility for managing the Dam following its completion in 1963, developed a management plan that reflected the legislative statement of purpose. The operating rules for the Dam were based upon two principles: (1) scheduling of annual and seasonal releases as necessary to deliver water for consumptive use, and (2) scheduling of daily and monthly releases in such a way as to maximize revenues from hydroelectric power production.

The Colorado River Basin Project Act of 1968 broadened the purposes for operation of the Dam by referring not only to storage and delivery of water, but also to water quality, outdoor recreation, and fish and wildlife; the 1968 Act again listed power production as a purpose incident to the other purposes. Even more recently, the 1992 Grand Canyon Protection Act has specifically mentioned the need to "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."

The Bureau's principles for operation of Glen Canyon Dam remained essentially unchanged from 1963 into the 1980s, even though legislation had broadened the purposes of operation. As a result, critics charged that the Bureau's operating rules for Glen Canyon Dam were excessively focused on water delivery and power production. However, modification of the operating rules was inhibited partly by lack of information about the effects of operations on recreation, aquatic life, culturally important sites, and

physical attributes of the river channel. The need for information on these resources led the Bureau of Reclamation to authorize the Glen Canyon Environmental Studies (GCES) in 1982. The Glen Canyon Environmental Studies have continued, with support from the Bureau of Reclamation, to the present.

As the GCES program matured, the Bureau of Reclamation authorized substantial expansion of its scope, which originally was limited to the immediate surroundings of Glen Canyon Dam. By 1986 it was clear that GCES must extend at least over the 255 miles from the forebay of Lake Powell to the upper end of Lake Mead. The GCES also expanded conceptually to include such subjects as cultural resources of Native Americans and non-use values as applied to the Colorado River in the Grand Canyon. With its broader objectives, the GCES reached a peak expenditure of $11-$12 million per year in 1990 to 1993.

The majority of GCES work has been conducted by employees of the Bureau of Reclamation, the National Park Service, the U.S. Fish and Wildlife Service, the Western Area Power Administration, the Arizona Game and Fish Department, and the U.S. Geological Survey. In recent years, Indian tribes and a few consultants have also played a significant role in GCES.

ROLE OF THE NRC REVIEW COMMITTEE

In 1986 the Bureau of Reclamation requested that the National Academy of Sciences, through the National Research Council's Water Science and Technology Board, conduct a review of the Glen Canyon Environmental Studies and provide advice on alternative operation schemes for Glen Canyon Dam. Since 1986, the NRC committee has produced numerous short reports as well as an extensive analysis of GCES Phase I (NRC, 1987) and a symposium volume that was designed to summarize ecological, legal, physical, chemical, and biological knowledge of the Colorado River in the Grand Canyon as of 1990 (NRC, 1990). The committee's current scope of work includes: (1) assessment and formulation of recommendations for the research strategy of the GCES and, more generally, for the application of scientific principles to the management program for the Colorado River below Glen Canyon Dam; (2) assistance to GCES in the development of a long-term monitoring program within the zone of influence for operations of Glen Canyon Dam; and (3) recommendations for the development of criteria to be used in the protection of the riverine ecosystem in the Grand Canyon below Glen Canyon Dam, within the constraints of operating criteria for Glen Canyon Dam.

In 1989 the GCES assumed new significance as a result of the Interior Secretary's decision to authorize an Environmental Impact Statement (EIS) on the operation of Glen Canyon Dam and a concurrent EIS of the production and marketing of power from

Glen Canyon Dam. Because the GCES was the only broad-ranging source of current scientific information on the Colorado River below the Dam, it provided much of the technical support for the multi-agency team that prepared the Draft Environmental Impact Statement under direction of the Bureau of Reclamation.

Even prior to the authorization of the two Draft Environmental Impact Statements, which were released in January 1994, the Bureau of Reclamation had acknowledged the need for long-term monitoring on the Colorado River between Glen Canyon Dam and Lake Mead. The need for such a program was reinforced by the Grand Canyon Protection Act of 1992, which explicitly requires knowledge and protection of the natural resources of the canyon as impacted by water supply and power production.

As the Draft EIS (DEIS) on operations was being prepared, the Bureau of Reclamation instructed the Manager of the GCES to create a draft plan for long-term monitoring of environmental resources that would be affected by the operation of Glen Canyon Dam. The GCES Program Manager then asked the NRC committee to sponsor and organize a workshop on long-term monitoring. The purpose of the workshop was to provide input to the GCES senior scientist, who would be drafting the GCES long-term monitoring program plan, from a variety of people with experience in long-term monitoring. The workshop was held in October, 1992. The NRC committee invited 50 participants, all of whom were selected on the basis of their direct experience with long-term monitoring programs or with the state-of-the art-in measurement of environmental variables of concern below Glen Canyon Dam. A transcript of workshop discussions was forwarded to the GCES Program Manager and the GCES Senior Scientist with the understanding that it would be used in developing the long-term monitoring plan, which is to be included in the DEIS.

Part of the NRC committee's charge is to review the draft monitoring plan, which is reproduced in this report as Appendix B. The review includes all aspects of the draft, including scope of work, protocols for acquisition and archiving of environmental data, organization, justification, and implementation. The review deals first with individual segments of the plan, and then draws general conclusions.

2

Specific Comments

INTRODUCTION OF THE PLAN

The introduction of the long-term monitoring plan gives a rationale by which expenditures on environmental monitoring might ultimately be determined. Factors to be considered include availability of funds, priorities for components of monitoring, and costs that are derived from contracting procedures (i.e., bids). The NRC committee disagrees with this rationale. The minimum monitoring requirements for the Grand Canyon are legitimately determined by needs for basic information. The present wording of the plan might suggest that the plan subordinate long-term monitoring to the availability of money. This is inappropriate in view of the significance of sound monitoring information for the protection of environmental resources in the Grand Canyon. Similarly, the monitoring plan should avoid stating that the cost of long-term monitoring is dependent on priorities that are assigned to the components of monitoring. This begs the question of responsibility for the assignment of priorities. The plan should assign priorities explicitly. Finally, deference of the plan to the outcome of bidding is unnecessary. The GCES program personnel, having expended millions of dollars on environmental studies similar to those being recommended here, should be in a position to estimate at least a range of costs for specific kinds of environmental monitoring.

The introduction refers to "interests." Similar references appear in other sections of this report. From the context, it appears that this is a reference to individuals, or groups of individuals, who have an interest in the operation of the Dam or the resources that might be affected by operations of the Dam. The meaning of this term needs to be explained more clearly.

EXPLANATION OF PURPOSE

The opening paragraph stating the purpose of monitoring is concise, but not entirely clear. For example, is it true that one purpose of monitoring will be to study the "implementation" (as opposed to the effects) of a decision? This needs to be explained. Each of the items that are listed as purposes should be reviewed for clarity. The references to "attributes," "project impacts" and "model efficacy" are particularly unclear.

This section of the monitoring plan also makes reference to adaptive management. Adaptive management will undoubtedly be described in the DEIS, of which this monitoring plan will be a part. However, it is also likely that the monitoring plan will be used separately from the DEIS. For this reason, it is important for the monitoring plan to explain the meaning of adaptive management as it applies to the operation of Glen Canyon Dam. The plan gives one paragraph of explanation, but this paragraph is not sufficiently clear. For example, it is not clear what the "goals" of the DEIS would be. The DEIS will presumably give a preferred alternative, and the Record of Decision (ROD) may specify that the Dam will be operated according to the preferred alternative. How does adaptive management fit into this framework? Will operations stray outside the boundaries of the preferred alternative, or is adaptive management merely a way of making minor adjustments within the framework of the preferred alternative?

The last paragraph of the section on purposes of monitoring explains the conceptual basis for defining the geographic scope of monitoring. This is an important section, and it comes across clearly and reasonably.

The long-term monitoring plan explains some differences between monitoring and research. This is necessary because the purposes of monitoring and research are frequently confused. Although the plan recommends research, it is not very specific in doing so. The committee believes that the long-term monitoring plan should specifically request support for long-term research that would be complementary to monitoring. Monitoring will probably demonstrate unexpected trends, and management should be in a position to support research that will demonstrate why monitoring has produced unexpected results. Some examples of research that could be included in the plan are: (1) research that would improve understanding of water flow, sediment transport, or biotic resources; (2) research that would lead to reduction of the cost of monitoring; and (3) research that would demonstrate the effects of operations on specific environmental components. In the absence of any specific recommendations, the prognosis for research is poor. It will prove difficult to allocate money for research that is not requested by experts.

PHILOSOPHY FOR MONITORING

The opening segment of the section on philosophy for monitoring explains the necessity for collection of data on a wide variety of environmental variables. The rationale here is sound, and reflects the spirit of the NRC's 1992 workshop on long-term monitoring.

SYNOPSIS OF MEASUREMENTS

The plan lists a number of "attributes" that should be included in the long-term monitoring plan. Some of these seem vague and difficult to interpret. For example, what is "area and species composition of a riparian habitat for associated vertebrates and invertebrates?" (page A-3, number 5 of the plan) Is the species composition that of the plants, the vertebrates, the invertebrates, or all of these? Also, there appear to be some obvious omissions from the list of items to be monitored. For example, backwaters are considered to be critical habitat for some elements of the aquatic biota, and yet they are not specifically listed for monitoring. The section on sediment dynamics does not list measurement of sediment transport; is this an intentional omission? The list should be rechecked for clarity and coverage of essential variables.

The plan indicates on page A-4 that monitoring should be conducted by noninvasive means. This is an important goal, but the plan does not provide sufficient guidance for achieving it. In subsequent sections that give detailed recommendations, the plan could suggest, where appropriate, use of long-term recording instruments that would reduce the frequency of trips through the canyon, use of high-volume data loggers, use of remote sensing imagery from low-flying aircraft, automated time-lapse photography from ground stations, and extraction of data from photography by photogrammetric techniques.

The plan mentions complementary monitoring programs such as the Lake Powell studies and studies in compliance with Section 106 of the National Historic Preservation Act. While avoidance of duplication is laudable, the plan should set forth specific goals for long-term monitoring. In its present form, the plan appears to defer to other programs for the collection of critical data. The long-term data monitoring program should be self-sufficient and should use other programs only when they have the proven capacity to produce information that meets the requirements of the long-term monitoring program.

OBJECTIVES

The summary of objectives for the National Park Service (NPS) indicates that the NPS is committed to management that "to the extent possible, simulates the ecosystem that existed prior to the construction of the dam." This is inconsistent with the NPS endorsement of operating plans that involve daily fluctuation in river discharge as justified by the maintenance of hydropower revenues. Other kinds of flow regimes might more closely resemble the natural hydrograph of the Colorado River, but at the cost of reduced efficiency in hydropower marketing. While the NPS may have had good reasons to endorse fluctuating flows, its choice seems inconsistent with the statement of objectives in this section.

Later in this section (page A-5), the plan mentions the Hualapai Tribe. The plan should explain why this tribe is treated explicitly, while other tribes are treated in aggregate.

GEOGRAPHIC SCOPE

The explanation of geographic scope seems sound and well reasoned.

INFORMATION MANAGEMENT

A geographic information system (GIS) provides an excellent basis for organizing information that is collected through long-term monitoring. It is unfortunate that the present GIS coverage does not extend over the entire reach between the Glen Canyon Dam and Lake Mead. The long-term monitoring plan should recommend completion of GIS mapping for the Colorado River between Lake Powell and Lake Mead in support of long-term monitoring.

The first paragraph on page A-7 is not clear. Presumably the zone to be included in monitoring extends at least to the elevation corresponding to a discharge of 100,000 cfs. Some rewording would clarify this.

DESCRIPTION OF THE LONG-TERM MONITORING PROGRAM

Lake Powell

Restriction of the long-term monitoring program to the forebay area of Lake Powell seems well justified in view of the objectives of the monitoring program.

However, sampling the forebay area on a quarterly basis will not provide sufficient information for interpretation of events in the Colorado River downstream of the Dam, nor will it create a sound basis for projection of the effects of changes in operation of the Dam. Temporal changes in Lake Powell are so large that samples must be taken at least monthly in order to provide a sound basis for interpretation.

The reference to "statistical variability" (page A-8) appears to be misplaced. The purpose of the vertical profiles is to describe the vertical structure of the water column in terms of the water quality variables that are of interest in connection with the river downstream of the Dam. It would be useful here, as in many other parts of this plan, for the monitoring requirements to be given more specifically: about how many points in the water column would be reasonable for definition of the vertical profile for Lake Powell? Similarly, would there be more than one station or just one?

The plan for monitoring of Lake Powell is unclear or insufficient in several other respects as well. For example, the plan should specify fractions of nitrogen and phosphorus to be analyzed. It is not clear why measurement of dissolved organic matter is excluded from lake monitoring, given that it is recommended for the river. The rationale for replacement of taxon-specific counts of zooplankton is not defensible because no monitoring protocol other than the enumeration of zooplankton will provide the necessary information. For phytoplankton, enumeration is important and cannot be replaced by measurement of chlorophyll a and should be reconsidered.

Mainstem Water and Sediment

The monitoring plan refers to geomorphically distinct reaches on page A-9, but does not define these until later (page A-14 of the plan), and then only incidentally. The classification of Schmidt and Graf (1990) is referenced, but the reader is left with the impression that many such classifications are available. The plan must, for practical reasons, select a classification, explain it clearly and briefly, and then apply it consistently.

The plan suggests that an additional gage might be added upstream from Nankoweap Creek, but does not make a clear recommendation. The plan should recommend a specific number of gages to be used in monitoring. The opinion of the NRC committee is that no new gage needs to be added, but if the Bureau of Reclamation disagrees, the plan should clearly justify the addition of a gage. In either case, the plan should not leave this matter undecided since administrators will not be in a position to make an informed decision about inclusion of the gage.

No gaging sites should be removed, but the plan is correct in stating the National Canyon gage is the least important of existing gages. Because of its established record the committee believes that it should remain for the foreseeable future, and that the discussion of its elimination should be deleted from the draft.

The plan should make more forceful statements regarding the development of alternative sediment and water sampling at gage sites, in recognition of the fact that the National Park Service is required to manage the inner canyon as a wilderness area . The plan should specifically call for the removal of towers and cables, and the initiation of alternative sampling methods. The use of boats attached to temporary cables may be a reasonable alternative for the short term. Eye bolts embedded in the canyon walls to secure lines for use by sampling boats would be relatively small and unobtrusive alternatives to the massive structures in place now. A specific date should be established for the transition to alternate methods that will allow removal of cables.

Sediment quality is now measured at some locations on the main stem, but is not discussed in the draft long-term monitoring plan. Sediment quality is important in this system because sediment is one means by which heavy metals, radionuclides, herbicides, and pesticides move into and through the system. Suspended and bed sediments should be collected on an annual basis in a few locations (including gaging sites, the head of Lake Mead, and Lake Powell) for chemical analysis. A major surface spill into the lower Colorado River occurred on July 16, 1989 at Church Rock, New Mexico when the containment dam of a uranium mill tailings pond collapsed, releasing about 100 million gallons of mixed solids and liquids containing a variety of toxic materials, including the radionuclides thorium-230 and radium-222. In addition, the Little Colorado River passes through agricultural areas that use many pesticides and herbicides that wash into the river. Measurements at Lake Powell now show high concentrations of mercury and selenium. Many pollutants likely to affect aquatic life may be first detected in sediment rather than in water. A small number of fish tissue samples should also be assessed each year for contaminants.

According to the monitoring plan (p. A-9), modeling of sediment transport "represents a long-term alternative to continuing widespread gaging presence in Grand Canyon." Modeling may enhance the value of empirical information, and may be important in adaptive management, but cannot substitute for collection of data. While visible field support for data collection (cableways) should be reduced, continued collection of field data on sediment transport and discharge is critical to the protection of resources in the Grand Canyon and should continue indefinitely.

The monitoring plan recommends measurement of sediment transport from tributaries to the main stem of the Colorado River. This is a sound recommendation. However, the plan specifies that the U.S. Geological Survey (USGS) collect the data. While the USGS is clearly the leading contender to perform this work, the program should not be bound to use any specific agency or group. Without the ability to direct data acquisition, the program managers will have difficulty controlling the cost and scope of monitoring.

The new plan for operating the Dam will probably include provisions for beach-building flows (controlled floods). The purpose of these flows will be to lift sand from the bed of the river to the beaches as a means of offsetting beach erosion. Although the

exact specifications of the beach-building flows are not yet evident, it is clear that such flows would need to be in excess of 30,000 cfs, and possibly considerably higher, and that they could cause substantial reconfiguration of sediment deposits. Monitoring of such events should be discussed in the plan.

The last paragraph of the section on water and sediment transport makes reference to a possible need for additional discharge data on tributaries. If this data is needed the monitoring plan should make a case for the importance of measurements on specific tributaries. Vague references to future possibilities are not appropriate in a document that must select and justify important measurements to be made over the long term.

Water Chemistry

The plan needs to be more specific about measurements of nitrogen and phosphorus. The committee believes that measurements should include total N, nitrate N, and dissolved organic N, as necessary to support estimates of total transport as well as conversion of fractions along the river. Phosphorus measurements should include particulate P, total soluble P, and soluble reactive P, for similar reasons. In addition to the variables that are mentioned in this section, chlorophyll a and algal counts should be included because they will indicate mass transport of algal biomass along the river and the species composition of the main taxa entering the river.

The plan calls for seasonal measurements of water chemistry and temperature on the main stem of the Colorado River. A major purpose of the monitoring program is to provide a basis for the assessment of change from year to year in the properties of the river. Quarterly measurements of water chemistry and temperature will be insufficient to provide a sound basis for the assessment of change from year to year because the amplitude of seasonal variation and irregular variation in critical variables is sufficiently large that the characteristics of a particular year cannot be defined on the basis of four sets of samples. The sampling frequency should be at least bimonthly and probably monthly for these variables. The same is true of measurements on tributaries that are dealt with in the following section.

Some minor changes would also improve this section of the plan: (1) the section should be retitled to include temperature, (2) a list should be included specifying all of the "recommended gages."

Tributaries

Measurements at junctions of tributaries with the main stem are justified by the plan through the sensitivity of tributary junctions to changes in operations of the Dam. However, another reason for monitoring tributaries is equally important and should be brought out more explicitly. Because the main stem receives dissolved and suspended solids from tributaries and shows an interchange of organisms with them, the main stem cannot be understood without information on tributaries. Study of the largest tributaries is justified to a great extent by the need to construct a comprehensive picture of the main stem.

The end of the section on tributaries refers to other "selected tributaries." Again, the monitoring plan needs to be specific. How many and which tributaries should be sampled? This monitoring plan is the product of an intensive assessment of monitoring requirements that included consultation with numerous experts on monitoring. If specific recommendations are not possible now on the basis of such intensive study, when will they be possible?

Sediment Dynamics

The opening paragraph of this section attempts to establish some connection between predictions of sediment accumulation given by the DEIS and actual accumulations that will be observed in the future under the new operating regime that is established from the Record of Decision. This explanation is not clear and convincing. To begin with, the DEIS does not really make predictions; it only gives qualitative guesses about the possible outcome of various operating regimes. In other words, almost any outcome would be generally consistent with the DEIS. The long-term monitoring program should be viewed simply as a commitment to collect information on critical environmental variables that may be affected by the operation of Glen Canyon Dam. Specific connections to the DEIS are not necessary, especially in view of the language that is given in the Grand Canyon Protection Act of 1992.

This section also makes general references to "selected campsite beaches." How many beaches need to be monitored? How will these beaches be selected? Will the selection of beaches be reviewed periodically and, if so, how?

Aquatic Food Base

The plan lists "dominance and habitat requirements" as characteristics to be measured for benthic and suspended organisms near the Dam. However, dominance is not a measurement, nor is habitat suitability. What will actually be measured?

Presumably, measurements of dominance would be based on quantitative estimates of species composition, i.e., numerical information on suspended and attached organisms. Similarly, the reference to habitat requirements might imply measurements of substrate characteristics. The reference to "biotic" categories is also difficult to interpret. Are the categories ecological, phylogenetic, or something altogether different? These questions must be answered explicitly in the plan.

The plan suggests continued use of protocols from GCES II "when appropriate." This plan is a reflection of the deliberation of experts, and should define what is appropriate or at least specify who is qualified to make that judgement.

The plan also refers in this section (page A-12) to "statistical reliability," a reference with no definite meaning. The GCES group has been collecting samples for years. Surely at this point the group must be in a position to make specific recommendations on the number of samples to be taken, and to indicate what degree of certainty could be associated with a particular sampling strategy. Adjustments can always be made after the program begins, but a firm framework needs to be established in this plan.

Fishes

The section on fishes mentions loss of trout spawning habitat which, according to the plan, "may also be of consequence." Presumably the plan refers to the consequences of certain operational patterns, but which?

The plan states (page A-12) that pre-adult life stages are to be treated in a way that is "less complete." This is also vague. Presented in this way, data collection on pre-adult stages seems almost incidental or casual. Specifics are needed here: in what ways will the treatment of pre-adult life stages be less complete, and why? The plan's explanations of monitoring needs should be clear enough to be followed by the many individuals outside the GCES who will review, oversee, and implement parts of the plan.

In general, there is not much discussion of what the monitoring program will accomplish besides occasional counting of fish. The United States Fish and Wildlife Service (USFWS) has expressed some reservations about operations of Glen Canyon Dam that involve daily fluctuations in flow, given that other flow regimes might provide better protection of endangered fishes. Given the breadth of informed opinion on this issue, the monitoring program should give more attention to measures of the welfare of endangered fish species.

The section dealing with trout is also disappointing. The plan seems committed in specific terms only to creel census and surveys of fishing guides. These two kinds of information, while useful and important, will provide no basis for the analysis of changes in trout populations. Growth rates, feeding habits, fish distribution, age structure, and

spawning success need to be measured directly in the field. Given the accessibility of the canyon above Lees Ferry, where the trout populations are concentrated, it would seem feasible at a reasonable cost to produce a sound set of monitoring data on trout populations.

Reference is also made in this section to a schedule of "activities" that will be determined by "resource management agencies." As this report has repeatedly stated, the purpose of the plan is to specify monitoring requirements on the basis of an intensive review of future needs for information. The decisions that are referred to management agencies should have been made while the plan was being formulated and stated specifically in the document.

Vegetation

The plan appears to confuse quadrants with quadrats. This needs to be addressed. Also, there is vague reference to a "statistically significant number of sampling sites." (page A-14) There is no such thing as a statistically significant number of sites. The plan needs to be more specific about the meaning of this phrase in this context.

Terrestrial Organisms

The section on terrestrial vertebrates and invertebrates is inadequate. Specifically, what kinds of information should be collected over the long term on these organisms, what should be the frequency of collection, and at what sites should the data be collected? Many possibilities are left hanging. On page A-15, the plan states that information on avifauna may be available "if synthesized." How does this relate to long-term monitoring needs? What will happen if the data are not synthesized? Similarly, monitoring of invertebrates is described in hypothetical terms, i.e., "if determined to be essential." The committee believes that the present plan should include this determination, or specifics on how it will be made and by whom.

Physical Sites of Special Importance and Tribal Concerns

The section on physical sites needs to be strengthened. Reference is made to "delicate situations relative to Indian tribes," an oblique statement that needs to be made more directly. The concerns of the tribes should not be inherently more resistant to explicit description than the concerns of any other group.

On page A-17, the plan indicates that monitoring cannot be done effectively unless baseline information is complete, but then fails to answer the question: is it complete, or will it be complete in the near future?

The plan states that "not all sites will be monitored," but should go on to propose a specific number of sites to be monitored in each category, and outline criteria to be used in the selection of these sites.

The nature of the monitoring information to be collected at these sites is not clear. Photographs and videotapes are mentioned. Is the archive of photographic materials the only product of this portion of the monitoring program? If not, what other items will be included?

The separation of responsibilities between the National Park Service protection program and the long-term monitoring program is not clear. The long-term monitoring program should not be expected to produce all the information necessary for proper protection of sites, and this portion of the plan may be going too far in transferring NPS responsibilities to the long-term monitoring program. However, given that the number of sites is unspecified, it is difficult to tell whether this is the case or not.

This section must be augmented with more detail before it is finalized. The monitoring plan for cultural resources should indicate which resources will be monitored, how often this should occur, and what techniques will be used. Many archaeological sites along the Colorado River corridor are of low significance; monitoring should be selective. Also, care must be taken to monitor only those sites or properties that can be assessed objectively. The plan implies that historic sites are just as important as those attributed to prehistoric Indians. This is a valid and important point; historic sites along the river corridor must be given substantial weight.

Reference is made to "visitations." This is not a scientific or technical term. Information on cultural and spiritual values and tribal concerns must be produced according to standard methodology that will be broadly useful and interpretable. There is little use for anecdotal or casual information in a long-term monitoring program. Individuals other than Native Americans may regard the river corridor as "cultural property;" their concerns should be recognized, possibly through the passive-use value studies. How will the environment be assessed on behalf of people who value the Canyon but do not use it recreationally?

Recreation

The section on recreation implies that the programs now operated by various agencies will be used as sources of information. While there is no need for replication of data collection efforts, the monitoring plan needs to make commitments to the collection of particular kinds of data on recreation. Then, if an agency happens to be collecting this kind of information, and if the managers of the long-term monitoring program independently judge this information to be of appropriate quality, a transfer of information can reduce monitoring costs. However, summary transfer of responsibility to

a cluster of other agencies is not advisable. The long-term monitoring program should assume direct responsibility in perpetuity for the acquisition of specific kinds of information, and should be prepared to arrange for data collection if information from agencies that collect the data for other reasons becomes inadequate.

Power, Economics, and Financial Considerations

The collection of data on power production and economic factors is described only briefly, but appears to be limited to information that is routinely collected by the Western Area Power Administration, Bureau of Reclamation, or other parties. The plan should provide more detail on what information is needed, how often it needs to be recorded, and who is responsible for collecting it. The Bureau of Reclamation's Power Resources Committee could easily provide suggestions for the specifics.

The NRC committee previously has commented extensively on estimation of nonuse values connected with operations of Glen Canyon Dam (NRC 1992). Given the special value that is attached by the public to the Grand Canyon and its surroundings, nonuse values could prove to be an especially important element affecting judgments on alternative operations of Glen Canyon Dam. The Bureau of Reclamation has already taken important steps toward support of an expert assessment of nonuse values as part of the preparation of the DEIS on operation of Glen Canyon Dam. The current assessment of nonuse values, which are likely to evolve over time, deserves more attention in the monitoring plan. Nonuse values should be covered under a specific subheading, and should be discussed more extensively.

3

General Comments

STYLE AND PRESENTATION

The style and presentation of the plan would benefit from extensive revision. Weaknesses in the present draft include: (1) poor writing, (2) weak logical coherence, and (3) lack of specificity. The mechanics of good writing are much more than a matter of cosmetics; they interfere with clear presentation of the monitoring plan.

Poor writing is responsible for much confusion in the present draft. The writing is too often convoluted, syntactically difficult or incorrect, and often employs words in a technical context that have no precise technical meaning. Examples of poor usage include such words or phrases as "attribute inputs," "visitations," "statistical reliability," "value evaluation," and many others.

A second problem is weakness in the logical thread that should connect monitoring objectives, needs for information, and protocols for data collection. These three elements are present in the draft, but they do not follow as necessary to make a clear argument for the collection of specific kinds of data. The use of addenda in this plan is ineffective, fragmenting the plan and separating items that should be together. The information within the addenda should be integrated throughout the body of the plan.

Perhaps the most serious problem of all is the failure of the monitoring plan to be sufficiently specific. In some cases, numbers of sites and kinds of measurements are listed, but even so must be extracted from the narrative. In other cases, sites, frequencies, and even variables to be monitored are left to other decisionmakers or dismissed in a general way. Throughout the text, subjunctive statements stand in place of declarations or assertions; priorities are not stated forcefully. Even the introduction is not sufficiently positive or assertive to set the stage for firm recommendations.

The monitoring plan should set forth a specific blueprint for collection of data. The contributors to the plan have benefited from over a decade of experience with

GCES studies and from more than a year of consultation and study of long-term monitoring strategies. At this point they should formulate a very explicit plan. If they do not, there is little hope that individuals less familiar with the environment and with the requirements for information will do so successfully at a later date.

The long-term monitoring plan is a very important document. It will be used by the Bureau of Reclamation and other agencies, and perhaps by other countries, as a prominent example of a monitoring program for rivers downstream from dams. It should be a model of clarity and it should be explicit and definite in its recommendations. The plan should be understandable not only to specialists, but also to any educated person, and should be easily translatable into an actual data collection program.

The NRC committee recommends that the plan be rewritten with emphasis on clarity of expression, logical consistency, and specificity of recommendations. Although the plan may legitimately allow latitude for minor adjustments in data collection, it should not defer judgment on monitoring. The committee also recognizes that the plan, while requiring specificity, must allow for later changes. A clear process must be established for making these changes in long-term monitoring as new information indicates that some monitoring components no longer are needed and that other data not previously collected are needed.

The revised plan should include a comprehensive table that lists by category each kind of information that will be collected as part of the long-term monitoring program, as well as the frequency of data collection and the number and location of sites. In addition, the revised plan should include maps showing the geomorphic reaches that are referenced in the plan, the locations of gages, and the monitoring sites mentioned in the text.

OBJECTIVES OF MONITORING

Many sections of the monitoring plan contain a paragraph that gives broad justification for the long-term collection of data. This justification is consistently based on gaging the validity of the preferred alternative for dam operations. This statement of objectives is too narrow. The long-term monitoring program in the Grand Canyon, as viewed from the perspective of the 1992 Grand Canyon Protection Act, is not specifically geared to the draft EIS or to present operating regimes. Its purpose should be to produce a constant flow of reliable basic information that will be useful for assessing any environmental change in the Grand Canyon between Lake Powell and Lake Mead under any operating regime, whether actual or hypothetical. To tie the plan to the draft EIS is overly restrictive. The committee believes that long-term monitoring is critical for adaptive management and that the plan is an indispensable part of the management of the Dam.

DISTINCTIONS BETWEEN MONITORING AND RESEARCH

In its opening sections, the long-term monitoring plan draws distinctions between monitoring and research. These distinctions are correctly stated, but they should be sharpened. The monitoring plan should state explicitly that a continuously funded research program is an important complement to the long-term monitoring program. The plan needs to explain that monitoring is likely to produce unexpected results that create a need for research, and that new research might dictate changes in monitoring. The plan should indicate the approximate size of a continuous research effort to serve as an adequate complement to the long-term program.

EMPHASIS ON NON-INVASIVE METHODS

The plan should deal more explicitly with the conflict between: (1) the need to monitor the canyon ecosystems closely, and (2) the need to preserve the systems in as natural a state as possible. While it is true that the river is highly regulated, it flows through a portion of the national park that is managed as a wilderness area. According to the 1964 Wilderness Act, works of man shall not be visible, and evidence of human activities will not be apparent. The monitoring plan should deal directly with this conflict. The monitoring plan should specifically state a commitment to: (1) taking samples in sufficient quantity to meet monitoring objectives but not in excessive numbers; (2) monitoring processes in the canyon by remote sensing wherever possible; (3) camouflaging recording devices and physical equipment so that they are not disruptive to the visual landscape; (4) avoiding use of sensors or measuring devices likely to be encountered by recreational users of the canyon; and, (5) avoiding repetitive use of access routes that may develop into new trails. The monitoring plan should also point out that the objective of minimal visibility does not mean the elimination of scientific monitoring, measurement, and collection of data. These activities are required by the 1992 Grand Canyon Protection Act, and are essential components of the Bureau of Reclamation's plan to operate Glen Canyon Dam in a fashion that protects the resources of Grand Canyon.

ADMINISTRATION, CONTRACTING, AND COST

The monitoring plan does not discuss administrative strategies, contracting, or cost. The committee believes that these omissions will undermine the success of the long-term monitoring program.

Administration and reporting authority for the long-term monitoring program will be critical in determining its quality, stability, and cost-effectiveness. Administrative

models that are under consideration are described only superficially in the plan, but it appears to be based upon a committee of representatives from federal cooperators. The NRC committee does not believe that this is an effective scheme for management of a long-term monitoring program. The cooperators should provide advice to the program, but should not control it. The program should be administered independently of any specific agency or agency cluster; it should report directly to, and have its budget determined by, a higher authority because the program involves the resources and responsibilities of multiple agencies of the Interior Department, the Department of Energy, the EPA, and the Indian tribes. Independence for the long-term monitoring program is essential if the program is to remain stable through changes in management philosophies, conflicts among agencies, and fluctuating degrees of enthusiasm for long-term monitoring.

The long-term monitoring program should take into account not only reviews and guidance from cooperators, but also reviews and guidance from specialists outside the cooperating agencies. In addition, the long-term monitoring program will probably maximize its cost efficiency and its flexibility by restricting its operations to issuance of contracts, archiving of data, and coordination of administrative and scientific review, rather than employment of a monitoring staff.

An objective process needs to be specified for review and approval of proposed changes in the long-term monitoring program. Changes will be desirable as the program matures and as scientific methodologies and understanding evolve. The process for making changes needs to be protected from agency politics, insofar as possible, by use of an outside review panel to evaluate proposed changes, and through administrative independence of the program.

Contracting policies are also important to the success and efficiency of the monitoring program, but are not addressed in the present plan. The committee's experience with GCES indicates that cooperating agencies have a strong tendency to contract internally, or to recognize reciprocal contracting rights that reflect management responsibilities for the particular resource being monitored. While this is appropriate and efficient in some instances, in others it leads to a waste of resources. Truly competitive contracting arrangements should be a feature of the long-term monitoring program, and should extend beyond the cooperating agencies to any entity, public or private, that would be well qualified for the work.

In the committee's view, the administrators of the monitoring program should establish an agreement with the cooperating agencies, with help from the Interior Department as necessary, stating that contracts related to long-term monitoring not be held captive for reasons having to do with permits, authorization of access, or use of publicly owned equipment such as gages. Free exercise of contracting authority on the part of the long-term monitoring administrators will avoid the development of entitlements that in turn could produce great cost inefficiencies and programmatic inflexibility.

The plan makes no estimate of cost. Specific estimates of cost should be tabulated for each type of data collection. In the absence of any information on cost, the tendency may be for administrators to allocate insufficient money for the long-term monitoring program. If the size of the program is dictated by an arbitrary allocation, much of the effort that has been invested in defining minimum boundaries for the program will have been wasted, and the program may become ineffective.

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Recommendations

The plan should be revised extensively and rewritten to improve clarity, logical cohesion, and degree of specificity with which monitoring requirements are described. The revisions should also take into account the following recommendations:

1. The plan should include a comprehensive table that lists by category the type of information to be collected, as well as the frequency of data collection and the number and location of sites.
2. The objectives of monitoring should be modified to encompass not only a study of responses to the currently preferred alternative for operation of the Dam, but also responses to other hypothetical or actual operations of Glen Canyon Dam and to environmental changes occurring through other causes within the scope of dam operations.
3. A number of measurements that are to be made seasonally or quarterly may not be useful because of the long gap between measurements. The frequency of these measurements should be increased.
4. The plan should include a more explicit treatment of the relationship between environmental monitoring and environmental research, and should make specific recommendations on a research program that would complement monitoring.
5. The plan should specify that the long-term monitoring program will assume direct responsibility in perpetuity for the acquisition of specific kinds of information; this responsibility should not be delegated to agencies, although use of data from agencies should be possible if the data meet requirements set by the long-term monitoring program.
6. The plan should call for greater emphasis on non-invasive methods for studying the Colorado River; permanent cableways should be removed.

7. The plan should include proposals for administration of the long-term monitoring program and for review and control of its operations. It should also deal explicitly with contracting mechanisms and with estimated costs. Proposals for administration and contracting should take into account the advantages of administrative independence and the importance of stability for the monitoring program, as well as the advantages in cost efficiency and programmatic quality that derive from open contracting procedures.

References

Bureau of Reclamation, July, 1993. Draft Environmental Impact Statement, Operation of Glen Canyon Dam. Salt Lake City, Utah: Upper Colorado Regional Office.

National Research Council, 1987. River and Dam Management: A Review of the Bureau of Reclamation's Glen Canyon Environmental Studies. Washington, D.C.: National Academy Press.

National Research Council, 1990. Colorado River Ecology and Dam Management: Proceedings of a Symposium, May 24-25, 1990, Santa Fe, New Mexico. Washington, D.C.: National Academy Press.

National Research Council, 1992. Letter report to David L. Wegner, April 22, 1992, assessing proposed GCES studies related to economics, hydropower production, and dam operations. Water Science and Technology Board, National Research Council, Washington, D.C.

Pub.L. 84-485 Colorado River Storage Project Act of 1956

Pub.L. 88-577 Wilderness Act of 1964

Pub.L. 90-537 Colorado River Basin Project Act of 1968

Pub.L. 102-575 Grand Canyon Protection Act of 1992

Schmidt, J.C. and J.B. Graf, 1990. Aggradation and degradation of alluvial sand deposits, 1965-1986, Colorado River, Canyon National Park, Arizona. U.S. Geological Survey Paper 1493, Washington, D.C.

Appendix A

BIOGRAPHICAL SKETCHES OF COMMITTEE MEMBERS

William Lewis (Chair) is Professor and Chair of the Department of Environmental, Population, and Organismic Biology at the University of Colorado, Boulder, and also serves as Director of the Center for Limnology at CU-Boulder. Professor Lewis received his Ph.D. degree in 1974 at Indiana University with emphasis on limnology, the study of inland waters. His research interests, as reflected by over 120 journal articles and books, include productivity and other metabolic aspects of aquatic ecosystems, aquatic food webs, composition of biotic communities, nutrient cycling, and the quality of inland waters. The geographic extent of Professor Lewis's work encompasses not only the montane and plains areas of Colorado, but also Latin America and southeast Asia, where he has conducted extensive studies of tropical aquatic systems. Professor Lewis has served on the National Academy of Sciences/National Research Council Committee on Irrigation-Induced Water Quality Problems and is currently Chair of the newly created NAS/NRC Wetlands Committee. He is also a member of the NRC's Water Science and Technology Board.

Garrick A. Bailey earned his B.A. in history from the University of Oklahoma, and his M.A. and Ph.D. in anthropology from the University of Oregon. He is a professor in the Department of Anthropology and is Director of the Indian Studies Program at the University of Tulsa. Dr. Bailey specializes in North American Indians, legal systems, cultural ecology, ethnohistoric methods, and social organization. He is a member of the American Anthropological Association, Plains Anthropological Society, American Ethnological Society, and the American Society of Ethnohistory.

Bonnie Colby is Associate Professor of Agricultural and Resource Economics at the University of Arizona Department of Agricultural Economics. Her undergraduate degree is from the University of California and Ph.D. from the University of Wisconsin. Her

research, teaching and consulting focus is on the economics of water resources management and policy. She has authored over 40 publications in this area, including a number of journal articles and a book, Water Marketing in Theory and Practice: Market Transfers, Water Values and Public Policy, 1987. In addition to her work on water reallocation, she specialized in research on water quality, valuation of water rights and environmental amenities, and natural resource management in developing tribal and rural economies. Dr. Colby served on the NRC's Committee on Western Water Management.

David Dawdy received his M.S. in statistics from Stanford University. His professional experience is with U.S. Geological Survey from 1951 to 1976 as a research hydraulic engineer; Adjunct Professor of Civil Engineering from 1969 to 1972 at Colorado State University, Ft. Collins; and Assistant District Chief for Programming, California District, Water Resources Division from 1972 to 1975. He has served on numerous advisory groups including NRC committees. From 1976 to 1980 he was Chief Hydrologist with Dames and Moore in Washington, D.C., and is currently a private consultant in surface water hydrology.

Robert C. Euler is a consulting anthropologist specializing in the applied anthropology, archeology, ethnology, and ethnohistory of the American Southwest and Great Basin. As such, he conducts research in cross-cultural resources management, social and economic impact assessments, Indian legal claims cases, and archaeological investigations, especially those related to environmental impacts. Dr. Euler is also Adjunct Professor of Anthropology at Arizona State University, Tempe. In addition, he serves as Tribal Anthropologist for the Yavapai-Prescott Indian Tribe. Dr. Euler earned his B.A. and M.A. in economics from Northern Arizona University, and his Ph.D. in anthropology from the University of New Mexico.

Ian Goodman earned his B.S. in civil engineering from Massachusetts Institute of Technology in 1977. Initially in his career, he performed research at MIT where he developed inputs to a policy-specific model of energy use for intercity goods movement. He began consulting in 1978 and was employed with several firms in the Boston area working on various aspects of utility regulation and economics. He is now the principal of his own consulting firm, The Goodman Group, where his work includes assessing electric and gas resource planning, demand forecasts, supply options, and environmental effects. Mr. Goodman also evaluates conservation potential and cost-effectiveness, program design, and utility demand-side management initiatives.

William Graf obtained his Ph.D. from the University of Wisconsin, Madison with a major in physical geography and a minor in water resources management. He specialized in fluvial geomorphology, hydrology, conservation policy and public land

management, and aerial photographic interpretation. He has served as Consulting Geomorphologist for the U.S. Army Corps of Engineers in a research and advisory role concerning the environmental impact assessment of flood control works, Salt and Gila Rivers in Arizona; and for Camp, Dresser, and McKee, Inc. for geomorphology and geology, and the state of Arizona for fluvial geomorphology. His research activities have emphasized fluvial geomorphology and the effects of human activities on streams; public land management, especially wilderness preservation, and rapids in canyon rivers; dynamics and recreation management; and the problems of heavy metal and radionuclide transport in river systems. Dr. Graf has published about 50 articles and book chapters on the impact of suburbanization on fluvial geomorphology; resources, the environment and the American experience; and the effect of dam closure on downstream rapids. His books include The Geomorphic Systems of North America, The Colorado River: Basin Stability and Management, Fluvial Processes and Dryland Rivers, Wilderness Preservation and the Sagebrush Rebellions, and Plutonium and the Rio Grande. Dr. Graf is a member of the NRC's Water Science and Technology Board.

Clark Hubbs received his Ph.D. in biology from Stanford University in 1951. He joined the faculty of The University of Texas at Austin in 1949, became Professor of Zoology in 1963 and the Clark Hubbs Regents Professor in 1989 and has been Regents Professor Emeritus since 1991. He served as Chairman of Biology 1974-76 and Chairman of Zoology 1978-85. He was concurrently Visiting Professor of Zoology at the University of Oklahoma 1973-86 and on the faculty of Texas A&M 1975-81. He has served as Curator of Ichthyology at the Texas Memorial Museum from 1975 to the present. He has received the Award of Excellence from the American Fisheries Society and the Lifetime Achievement Award from the American Society of Ichthyologists. He has published more than 250 papers on aquatic biology. His research interests include distribution and speciation of fishes; hybridization of freshwater fishes; environmental modification of freshwater fishes. Dr. Hubbs has a history of work with endangered fishes and now has a substantial program on predation of adults on their young.

Trevor C. Hughes acquired his Ph.D. in civil engineering from Utah State University. His professional experience includes teaching since 1972 at Utah State University in the Civil and Environmental Engineering Department; research experience as NDEA Fellow at Utah State; Associate Professor of Civil and Environmental Engineering, Utah Water Research Lab; and Research Scientist at International Institute of Applied Systems Analysis, Austria. Since 1971 he has conducted research projects on the management of salinity in the Colorado Basin; drought management analysis and policy design; regional planning of rural water supply systems; economic analysis of alternative water conservation concepts; river system operational models--Sevier River; and application and development of water demand function for domestic water systems at recreation developments.

Roderick F. Nash received an M.A. and Ph.D. in 1961 and 1964 from the University of Wisconsin. He specialized in American intellectual history under Professor Merle Curti. Before his appointment at University of California at Santa Barbara in 1966, he taught for two years at Dartmouth College. Dr. Nash published the first collection of documents relating to environmental history, The American Environment, 1968. His most significant recent work is The Rights of Nature: A History of Environmental Ethics, 1989. A national leader in the field of conservation, environmental management, and environmental education, Dr. Nash has a special interest in problems relating to wilderness and its preservation.

A. Dan Tarlock obtained his LL.B. from Stanford University. His professional experience includes private practice, San Francisco, 1966; professor in residence at a law firm in Nebraska, summers of 1977 to 1979; and consultant. He has been a Professor of Law at Chicago Kent College of Law since 1981. He has authored and co-authored many publications and articles concerning water resources management and environmental law and policy. Mr. Tarlock served as a member of an NRC Committee on Pest Management, is Vice Chair of the NRC's Water Science and Technology Board, and co-authored one of the basic casebooks in water law.

APPENDIX B

LONG-TERM MONITORING IN GLEN AND GRAND CANYON: RESPONSE TO OPERATIONS OF GLEN CANYON DAM

Duncan T. Patten, PhD
Chief Scientist
Glen Canyon Environmental Studies

May 1993

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LONG-TERM MONITORING IN GLEN AND GRAND CANYON: RESPONSE TO OPERATIONS OF GLEN CANYON DAM

INTRODUCTION

Grand Canyon is an internationally significant natural landscape feature. Ironically, the Colorado River, the physical feature responsible for carving Grand Canyon, is now the most heavily regulated large river in North America. The physical hydrology of Colorado stream flow, as with the associated sediment load and dissolved constituents transported by the river, have changed dramatically since closure of Glen Canyon Dam in 1963. Numerous studies, including those sponsored by the U.S. Bureau of Reclamation's Glen Canyon Environmental Studies since 1982, have documented these changes.

The Grand Canyon Protection Act of 1992 has directed the Secretary of the Interior to establish and implement long-term monitoring programs and activities that will ensure that Glen Canyon Dam is 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...". In response to this directive, the Glen Canyon Dam EIS resource management agencies and interests have initiated the planning of a long-term monitoring program which would permit continued evaluation of the effect of Glen Canyon Dam operations, as described in the Record of Decision, on the riverine environment of Grand Canyon.

This document describes the long-term monitoring program. It does not project costs for any of the long-term monitoring program components. These would be determined on (1) availability of funds, (2) priorities assigned to the various monitoring components, and (3) costs proposed by those entities responding to the "Request for Proposals" which would be used to develop and select the detailed methodologies and procedures of this long-term monitoring program.

Purpose of Long-Term Monitoring in Grand Canyon

Long-term monitoring is used for a variety of purposes including, but not limited to, assessing (1) baseline conditions, (2) trends of attributes, (3) implementation of a decision, (4) effectiveness of a decision, (5) project impacts, (6) model efficacy, and (7) compliance to a set of standards. Many of these purposes are attributable to the evaluation of the impacts of Glen Canyon Dam operations.

Long-term monitoring would be designed to provide regular feedback for adaptive management. This permits mid-course adjustments in the operations of the dam to ensure achievement of the goals of the EIS and the management objectives of the resource management agencies and interests.

Long-term monitoring would also be used to determine variability over time and space of the resources being monitored. This needs to be done in conjunction with appropriate controls to evaluate the source of the variability. In addition, long-term monitoring would provide clues for identifying associations, understanding system behavior, and guiding future process-based research.

Long-term monitoring is the "repetition of measurements over time for the purpose of detecting change" (MacDonald et al 1991). These measurements, because they are made over a period of time, are different from an inventory, which is a measurement, or a number of measurements, made at a specific point in time. Inventories, or establishing baseline conditions, are often the first step in conducting a monitoring effort, but the measurement of possible change over time is the distinguishing attribute of a monitoring effort. Research, on the other hand, is used to test or understand the relationships between and among various attributes of the system. Inventory and monitoring information may be used in research. This document addresses only the long-term monitoring program which emphasizes measurement of those parameters, or attributes, that might change with time and whose change might be related to operations of Glen Canyon.

This proposed long-term monitoring program for the river corridor in Grand Canyon would not be considered equivalent to a long-term monitoring plan for all of Grand Canyon, or in fact for the whole river corridor ecosystem. Although the difference between the two objectives may seem to be semantic, it is critical to distinguish this program, whose intent is the monitoring of the effectiveness of the prescribed operations of Glen Canyon Dam in meeting the objectives of the EIS, the 1992 Grand Canyon Protection Act and the management objectives of the resource management agencies and interests, from a general ecosystem monitoring plan for the river corridor. Clearly, the two objectives are closely aligned because it is impossible to interpret change related to dam operations without understanding the broad range of ecological interactions. Nevertheless, the ultimate purpose of this program is to monitor ecological changes that are related to dam operations.

A Monitoring Philosophy for Grand Canyon

Grand Canyon is a unique environment. It is also a highly regulated system, both in terms of river flows and use. Its uniqueness demands careful stewardship. In the face of evolving scientific understanding about Grand Canyon's riverine ecosystem, it is not yet possible to identify only a few attributes that characterize the entire system. In light of this uncertainty, it would be irresponsible to restrict monitoring within the river corridor ecosystem to a very small number of attributes and assume that all other attributes are related to those measured.

This proposed program attempts to strike a balance between the extremes of (1) very restricted monitoring which recognizes the impacts of scientific study on the essence of what Grand Canyon means to most humans, and (2) full measurement of all ecosystem attributes predicated on a belief that an unmeasured parameter might be critical at a later time.

Critical Attributes

This proposed program emphasizes measurement of attributes deemed critical by the resource management agencies and interests (re: Draft EIS), and the scientific community which has studied the system for decades, for evaluating the effects of alternative operations of Glen Canyon Dam. The prediction and significance of the attribute response to dam operations is discussed in the monitoring program section for each attribute. Under the long-term monitoring program, responses of these attributes would be used in adaptive management decisions. These attributes are:

1. Quantity and quality of water from Lake Powell and in the Canyon.
    a. annual streamflows
    b. discharge rates and spill volume and frequency
    c. chemical, physical and biological characteristics of water in Lake Powell and the Colorado River from Glen Canyon Dam to Lake Mead

2. Sediment dynamics and sediment budget.
    a. stored riverbed sand
    b. sandbar topography
    c. elevated sandbar erosion
    d. dynamics of debris fans and rapids

3. Fish.
    a. aquatic food base
    b. reproduction, recruitment and growth of native fishes
    c. reproduction, recruitment and growth of non-native warmwater and coolwater fishes including trout

4. Vegetation.
    a. area of woody riparian plants and species composition
    b. area of emergent marsh plants and species composition

5. Wildlife and wildlife habitat.
    a. area and species composition of riparian habitat for associated vertebrates and invertebrates
    b. aquatic food base for wintering waterfowl

6. Endangered and other special status species, their habitat and food base.
    a. humpback chub
    b. razorback sucker
    c. bald eagle
    d. peregrine falcon
    e. southwestern willow flycatcher
    f. belted kingfisher
    g. Kanab ambersnail
    h. other federal and state species of concern

7. Cultural resources.
    a. archaeological sites directly, indirectly, or potentially affected
    b. Native American traditional cultural properties directly, indirectly, or potentially affected

8. Recreation.
    a. fishing trips and angler safety
    b. day rafting trips attributes and access
    c. white-water rafting trip attributes, camping beaches, safety, and wilderness values
    d. net economic value and regional economics

9. Powerplant supply of hydropower to network and customers at lowest costs.
    a. changes in power operations
    b. power marketing benefits lost or gained

10. Non-use valuation.
    a. Values placed on Glen and Grand Canyon riverine system by the public.

This program also adopts a conservative approach of measuring attributes which reasonably might be affected by dam operations and for which no surrogate attributes exist. However, this program does not propose measurement of those attributes clearly unrelated to dam operations or which are adequately represented by other parameters. It also emphasizes use of data collected in Grand Canyon that are not field intensive. Wherever possible, monitoring should be conducted using non-invasive means.

To reduce the overall impact and cost of this program, data generated from other complementary long-term monitoring programs in the Grand Canyon region (e.g., Lake Powell long-term studies, and the Programmatic Agreement for Compliance with Section 106 of the National Historic Preservation Act) would be used when appropriate for evaluating the effects of the operations of Glen Canyon Dam. There are also background and input data collected from other sources (e.g., climatological and hydrological data) that are critical to interpretation of the long-term monitoring information. These types of data are discussed in the addenda.

Lastly, this program is designed to respond to the long-term missions, goals and management objectives of the resource management agencies and interests. Acceptance of changing conditions of each of the above attributes as it responds to the environment created by the prescribed dam operation is contingent upon these management objectives. A change in an attribute, determined through the long-term monitoring program, may represent a deviation from an acceptable condition (determined by management agencies and interests) that would trigger consideration of suggested changes in dam operations as described in the "Adaptive Management" section of chapter II. The long-term monitoring program would, therefore, use methodologies that offer appropriate information about the response of the critical attributes to enable an Adaptive Management Work Group to evaluate these changes in light of the overall management objectives for "the Canyon".

Management Objectives

The following statements represent an abbreviated version of the management objectives of each of the resource management agencies and interests. For many of these agencies and interests, these management objectives for specific attributes represent goals rather than existing baseline conditions at initiation of long-term monitoring or response conditions at some point after the effects of dam operations have occurred. Although not specifically stated below, they also recognize the importance of existing laws and statutes, for example, the Endangered Species Act, Trust responsibilities to Indian Tribes, and Cultural Acts. A more comprehensive statement for each interest is presented in chapter II of the DEIS.

National Park Service

The National Park Service, represented by Grand Canyon National Park and Glen Canyon National Recreation Area, has management objectives based upon both the ecosystem that existed prior to construction of Glen Canyon Dam and the ecosystem that has developed post-construction. Objectives are to attempt to maintain the essential dynamic elements and processes that existed pre-dam through restoration, maintenance and protection. The NPS is committed to managing the Colorado River ecosystem and its attendant cultural resources as a coherent whole that, to the extent possible, simulates the ecosystem that existed prior to the construction of the dam.

Bureau of Reclamation

As manager of the Colorado River, the Bureau of Reclamation's management objectives are to strike a balance among water releases established under the "Law of the River" and the Annual Operating Plan for Glen Canyon Dam, the hydroelectric power requirements of Western Area Power Administration, and "protection" of the downstream ecosystem under the 1992 Grand Canyon Protection Act. The priorities given to each of these components under the EIS and long-term monitoring program are dependent on potential risk for change in Canyon resources or attributes of concern, and laws and regulations that direct the Bureau's operations.

Fish and Wildlife Service

The management objectives of the Fish and Wildlife Service in the Grand Canyon, as elsewhere, are to conserve, protect, and enhance fish and wildlife and their habitat for the continuing benefit of the public. In the Canyon emphasis is placed on threatened and endangered species, migratory birds, and native fish and sports fisheries.

Western Area Power Administration

Management objectives of Western Area Power Administration (Western) are the marketing and transmission of electricity generated at Federal water power projects.

Bureau of Indian Affairs

The Bureau of Indian Affairs has no management role in the proposed action. However, it has management goals, among which is fostering of self-determination of Indian Tribes. Its goal is to assure that the interests of Indian Tribes are coordinated with other Federal agencies and to supply advice and assistance to Tribes when requested to do so.

Hualapai Tribe

Management objectives of the Hualapai Tribe are long-term sustainable and balanced multiple uses of its resources through natural integrated resource management. These resources include natural and cultural resources including sacred ceremonial and burial sites within the Canyon located outside the boundaries of the Reservation Lands.

Other Indian Tribes

The management objectives of other Indian Tribes with interest in Glen and Grand Canyons, but whose lands do not border the mainstem of the Colorado River, are the preservation of the natural and cultural resources of the Canyon to maintain their values to the tribes. This includes spiritual and ancestral stewardship and management responsibilities to the Grand Canyon and specific places contained therein.

Arizona Game and Fish Department

The management objectives of the Arizona Game and Fish Department are to conserve, enhance and restore Arizona's wildlife and habitats, and to provide wildlife and safe watercraft recreation for the enjoyment, appreciation and use of the public.

The Geographical Scope of Monitoring

The area to be monitored is primarily the Colorado River corridor between Glen Canyon Dam and Lake Mead reservoir. This area is about 255 miles long, as the headwaters of Lake Mead vary with reservoir elevation. Because the overwhelming effect on the ecosystem along the shores of Lake Mead reservoir comes from operations of the reservoir and Hoover Dam, the Grand Canyon monitoring program would end at Separation Canyon (RM 240), the generally accepted head of Lake Mead. However, the affects of fluctuations in Lake Mead and the influence of changes in the Colorado River below Separation Rapids resulting from dam operations might be considered as extensions of the geographical scope of the long-term monitoring program.

Delineation of the upstream boundary of Grand Canyon monitoring is also inexact. Water molecules and dissolved constituents may travel to Grand Canyon from any part of the Colorado River watershed, and sediment particles may be transported to Grand Canyon from much of southern Utah and northern Arizona. Geochemical transformations occur in Lake Powell reservoir that directly affect the chemical quality of water discharged into Grand Canyon.

Many of the relevant upstream data are already collected by the U.S. Geological Survey, National Oceanic and Atmospheric Administration, and the Bureau of Reclamation. Other information, such as from an expanded program of limnological monitoring of Lake Powell, are not available. Despite the linkages that exist between Grand Canyon and the entire upstream basin, the appropriate upstream limit for Grand Canyon monitoring, as related to effects of dam operations, is the forebay of Lake Powell, the intake point for water into the water release structures of the dam. Because of the critical role of reservoir-scale geochemical processes in determining the quality of water at the intake sites, the separate long-term monitoring effort of Lake Powell would continue as a valuable input to this program. The Lake Powell long-term monitoring program would not, however, be considered part of the Glen and Grand Canyon long-term monitoring program. Along this same line, ongoing studies in and along the shoreline of Lake Mead within normal pool fluctuation would not be considered part of the Glen and Grand Canyon long-term monitoring program.

The lateral extent of the monitoring effort is defined by the extent of processes and conditions influenced by dam discharges and river flows. The relevant discharge might be: (1) maximum powerplant discharge (31,500 cfs), (2) maximum regulated discharge and mean annual pre-dam peak flow (100,000 cfs), or (3) maximum pre-dam flood (220,000 - 300,000 cfs). Because this proposed monitoring program is long-term in scope, the minimum discharge considered ought to be 100,000 cfs. However, the old high-water zone vegetation community begins at about this elevation and extends to higher levels and arroyo head cutting may extend above this level. Thus, it is prudent in some areas of the Canyon to include elevations above the stage associated with a discharge of 100,000 cfs.

Thirteen reaches, varying in length between 2 and 12 miles were established by GCES as Geographic Information System (GIS)-reaches, and detailed topographic data at a scale of 1:2400 is available for these reaches. The availability of detailed data for these reaches would lead to integrated resource perspectives in these areas and would necessarily focus data collection in these sites. These sites were selected because they represented reaches of the Colorado River in which there were ongoing studies or potentially important ecological conditions. However, the scientific basis for their selection was not necessarily for the long-term monitoring program because it was anticipated that the whole system would eventually be put into the GIS. As a consequence, additional sites may need to be selected to adequately represent each of the geomorphically distinctive reaches of Grand Canyon.

Information Management

Information management is an integral part of data collection and long-term monitoring. It includes, characteristics of the data base, protocols for data collection and processing, protocols for data analysis and reporting, and the use of GIS and remote sensing. A discussion of information management is intended to give guidance to those who will manage the long-term monitoring program and its extensive data base and will be making adaptive management recommendations and decisions, and those who will prepare proposals and reports as part of their activities relative to this program. The success of the long-term monitoring program depends on the dependability, integrity and credibility of data generation and information management. For this reason, a discussion of information management and how it applies to the Grand Canyon Long-term Monitoring Program is presented in the addenda.

LONG-TERM MONITORING PROGRAM

Quantity and Quality of Water: Lake Powell and The Canyon

Lake Powell

The water discharged from Glen Canyon Dam represents water from Lake Powell whose quality is a product of lake tributaries, level and mixing processes. A model explaining these relationships is being developed by a selective withdrawal study team and the Lake Powell study group. The model is not sufficiently developed to presently be used in long-term monitoring, although data for its development would continue to be gathered.

The quality of the discharge water may influence many of the aquatic biological processes within the Canyon. If these biological processes change, the cause for the change would be better interpreted if the quantity and quality of the discharge stream is known. Thus, the objectives of sampling in Lake Powell are to determine the quality of the water in the dam intake region in order to characterize dam discharges, and to determine whether the prescribed dam operations, especially if a selective withdrawal structure is used, affect the water in the forebay region of the dam as predicted by studies of the selective withdrawal study team. (This research, which includes collecting data on reservoir level and storage, and tributary inputs, is a parallel program to the long-term monitoring program, but it is essential for interpreting the affects of Lake Powell water chemistry and circulation on the below-dam aquatic ecosystem.)

Sampling stations in Lake Powell as part of the long-term monitoring program would be limited to the forebay above Glen Canyon Dam. Information from the long-term monitoring program of Lake Powell would be used to help interpret the findings in the forebay area. The forebay area is the direct input point to the below-dam ecosystem. At these stations physical, chemical and biological parameters would initially be measured monthly during studies of selective withdrawal and then quarterly in the water column at a sufficient number of locations to determine statistical variability. Physical parameters would be limited to temperature and light penetration. Chemical parameters would include pH, conductivity, nitrogen, phosphorus, dissolved oxygen and particulate organic matter. Biological parameters would include algae (especially blue greens and diatoms), zooplankton, total chlorophyll and chlorophyll a. Monitoring protocols would be developed to reduce the taxonomic and biomass studies of phyto- and zooplankton and replace these with chlorophyll a and other surrogate measurements.

Colorado River Mainstem

Dam Discharges. Dam discharges create the physical conditions that control many of the downstream ecosystem processes, for example, sediment dynamics, habitat development, and biotic recruitment and survival. The objectives for monitoring the outputs of Glen Canyon Dam are to determine how closely dam discharge follows the prescribed operations of the dam and the extent of the variability in discharge, should it occur. These outputs, which also include discharges or spills above dam hydropower operations, would be measured both at the dam, based on power production, and at the U.S.G.S. gage just downstream. Outputs to be monitored include, hourly water discharge (both flow rate and volume) and ramping rates (changes in discharge over the hour). From the above data, information on maximum and minimum daily discharges and daily fluctuations, and frequency and volume of spills, can be determined and placed in a perspective of average conditions and variance.

Water and Sediment Transport. The transport of water and sediment through the Canyon are interconnected (e.g., sediment transport curves). Discharge rates and changes in river stage influence the amount of sediment transported and stored in the system; sediment being the primary substrate for many Canyon biological processes as well as camping beaches. The objectives for monitoring changes in water and sediment transport are to determine whether the flux of water and sediment through the Canyon is as at the level predicted by the EIS for the prescribed dam operations, and whether the flux varies as

expected within different reaches of the Canyon. Measurement objectives are: (1) continuously measure the flux of water through Grand Canyon (2) periodically measure flux of sediment through the Canyon, and (3) measure the differences in flux in different reaches. Measurements of flux not only permit comparison of measured differences in fluxes which can be compared with measured storage changes, but the fluxes themselves are critical determinants of biological processes.

Although a water flow and sediment routing model is being developed by the U.S. Geological Survey, it is not yet time to solely rely on this model to estimate fluxes; field measurements must be continued. Gaging stations do not exist at the end points of each geomorphologically distinct reach in Grand Canyon (whether using the classification of Schmidt and Graf, 1990; and others), and new gaging stations would not be established through the main channel to define each geomorphically distinct reach. The emphasis of long-term monitoring would be on maximizing the analysis of data collected at existing gages. Because most river managers have expressed greatest concern about impacts of dam operations on upstream reaches of Grand Canyon, and because those reaches have been shown to have the greatest potential for sediment storage deficit, it is important that gaging stations on the Colorado River at Lees Ferry, above the Little Colorado River, and upstream from Bright Angel Creek be maintained as sediment measurement stations as well as discharge stations. It is also critical to measure outflow from the system and therefore, of existing gaging stations, the station above Diamond Creek would be maintained. It is less critical to evaluate flux differences between miles 87-225, and the gage above National Canyon is considered the least important gage presently existing in Grand Canyon, although it continues to be useful for bed movement studies and sediment transport modelling. If one gage is removed in Grand Canyon, it should be the National Canyon gage although the economy of this decision over the long-term might be questionable.

If one gage were to be added in Grand Canyon, it should be located upstream from Nankoweap Creek (perhaps upstream from Buck Farm Canyon), so that fluxes could be measured through the distinctly different reaches of upper and lower Marble Canyon, reaches in which impacts from upramping waves are greatly attenuated. However, addition of a new gage in Grand Canyon would represent a significant increase in the impact of scientific activities on the Canyon, and the U.S. Geological Survey should explore alternative strategies to installation of permanent cableways for purposes of water and sediment gaging.

The ongoing water and sediment modeling effort, although primarily a research effort, would be included in the monitoring program because the modeling effort represents a long-term alternative to continued widespread gaging presence in Grand Canyon. Such modeling also holds out the hope for calculation of flux differences in short reaches of Grand Canyon. Other modeling efforts, although of possible use in long-term management of Grand Canyon, would not be considered part of a long-term monitoring program but rather long-term research. This is not to imply that development of these models would be discontinued as continued long-term research is essential to success of the long-term monitoring program.

Measurements of sediment fluxes would be the basis for computing annual reach-scale sediment budgets of Grand Canyon. The sediment budget approach to river management has been endorsed by geomorphology and sediment researchers (GCES Fort Collins, 1992). Because there are insufficient gages to compute sediment budgets for all

geomorphic reaches of Grand Canyon, such budgets would only be computed for the following reaches: Lees Ferry to Little Colorado River, Little Colorado River to Bright Angel Creek, and Bright Angel Creek to Diamond Creek.

Calculation of these budgets also necessitates measurement of sediment inflow from tributaries. The Geological Survey would continue to operate its stations on the Paria River at Lees Ferry and Little Colorado River near Cameron. Sediment from Moenkopi Wash, a major sediment contributor to the Little Colorado River, is not measured and consideration would be given to developing a measurement station on this wash. New sediment measurement stations would not be established on other tributaries to the mainstem because sediment input from these tributaries is inconsequential compared to inputs from the Paria and Little Colorado Rivers. This is not necessarily the case for water discharge data, and gages for these measurements on major tributaries might still be considered.

Water Chemistry. Chemistry of water in the mainstem of the Colorado influences most aquatic and riparian biological processes. Changes in water chemistry and temperature may alter physiological processes of aquatic biota potentially triggering changes in the aquatic trophic dynamics of the Canyon. Nutrient trapping by Glen Canyon Dam, changes in nutrient transport within Lake Powell resulting from changes in lake level, and in the mainstem resulting from water transport fluxes all influence the water chemistry of the mainstem below the dam. Thus, the objective of water chemistry monitoring is to determine the aquatic environment of the Canyon and evaluate this in terms of maintenance of those riverine ecosystem components deemed critical by the resource management agencies and interests; that is, fish, aquatic food base and riparian vegetation.

Evaluation of chemical and biological changes in the riverine ecosystem would be dependent, in part, on river discharge, water temperature and sediment data collected at the recommended gages on the mainstem and at the point of discharge from the dam (tailrace). Basic data on water temperature, conductivity and pH would be measured at these gages and the discharge point at the same time interval established for sampling discharge and/or sediment transport. Measurements of dissolved oxygen, particulate and dissolved organic matter, and nitrogen and phosphorus would be made seasonally.

Canyon Tributaries

Tributaries to the mainstem of the Colorado River in Glen and Grand Canyons are influenced by dam operations primarily at their confluence with the mainstem. With the exception of the influence of rising and falling river levels at the confluence, tributaries are an input to the mainstem. As such, the objective for collecting long-term monitoring information on changes in tributary characteristics is to evaluate possible causes of mainstem changes, that is, dam vs non-dam operational causes. Tributaries of the Colorado River are relatively pristine refugia for native fish, trout and other non-native fishes as well as riparian ecosystems. For this reason, they would be included in the long-term monitoring program where they would be considered as "control" for evaluating changes in selected attributes in the mainstem (e.g., aquatic biota), and as a source of attribute inputs.

Tributary inputs to the mainstem include hydrological, sediment and limnological attributes. Not all tributaries can be monitored thus emphasis would be limited to those with

major inputs, either abiotic or biotic. In addition to water and sediment discharges from the Paria and Little Colorado Rivers mentioned earlier, tributary discharges, water chemistry (see parameters above for mainstem) and biological attributes (see aquatic food base) would be monitored at the Paria and Little Colorado Rivers, and Kanab, Bright Angel, and Havasu Creeks. Measurements would be continuous for discharge rates, and seasonally for chemical and biological attributes and would be taken in conjunction with these measurements at the gages in the mainstem. Discharge rate monitoring would require maintenance, reinstallation, or installation of a gaging system in the above tributaries and the significance of the necessity for this invasive technology would be considered. Other selected tributaries, especially with perennial flows, would be sampled quarterly for comparison with primary tributary and mainstem data; measurements being limited to water chemistry and biological attributes.

Sediment Dynamics

Sediment in the Canyon is either in transport or in storage above or below the river surface. Sediment transport flux is monitored periodically at the gage sites in the Canyon. Stored sediment in the channel and eddies is the source and foundation of elevated sediment deposits. The prescribed dam operations in the Record of Decision would consider sediment accumulation in the riverine system, in the channel or eddies and as elevated deposits (e.g., beaches). Therefore, the objective of monitoring changes in stored sediment is to evaluate the sediment budget predictions of the EIS relative to the selected alternative. In order to determine the influence of dam operations on the integrity of these deposits, the measurement objective of the monitoring program is to determine the changes in sediment storage in different reaches of Grand Canyon. The accomplishment of this objective would permit measurement of temporal change in the status of critical bar and bank sediment deposits and in debris fan deposits, and to place that change within the context of measurements of all sediment storage change in Grand Canyon.

Selected campsite beaches would continue to be measured annually. Established survey techniques would be employed by trained surveyors. Measurement of short-term changes on bars, although of interest in determining sediment dynamics, are not the focus of the long-term monitoring program.

Measurement of bar changes throughout the Canyon would be made using air photo interpretation and video imaging analysis strategies. Such measurements permit wider ranging measurements using less invasive measurement strategies. Short-term repeat photography is not recommended as part of the long-term sediment monitoring program except perhaps at sensitive archaeological sites (see Cultural Resources section).

Fishes and Aquatic Food Base

Aquatic Food Base

Many wildlife species, including fishes, depend on the aquatic food base for their survival. Fluctuations in aquatic food resulting from dam operations or other influences would invariably cause changes in some or all of the populations of native and non-native

fish species. The preferred alternative includes prediction of enhancement of the aquatic food base to ensure sufficient food for the endangered fish species and the economically valuable trout population. For this reason, the objective of the long-term monitoring program is to determine whether the biomass, habitat and composition of the aquatic food base is responding to dam operations as expected.

Aquatic food base monitoring would be seasonal and include the mainstem, and tributaries. Quantification of changes in species survival and productivity within categories or functional groups of lower trophic levels in the ecosystem may be used as gross indicators of change. Standing crop (biomass), dominance and habitat requirements of phyto- and zoobenthos, and phyto- and zooplankton would be measured seasonally at the dam, Lees Ferry, Little Colorado River and Diamond Creek and at least two wide-reach sites and two narrow-reach sites between the Little Colorado River and Diamond Creek. When appropriate, sampling protocol would be comparable with the protocols used during GCES II research to ensure compatibility of data.

The sampling protocol would sort the benthos into biotic categories. Numbers of organisms and ash-free dry mass would be determined for multiple samples numerous enough for each biotic category to assure statistical reliability. Complementing biotic sampling, the following abiotic parameters would be ascertained for comparison with abiotic data from gage sites: water temperature, dissolved oxygen, pH, and conductivity. Substratum, microhabitat conditions, turbidity, water velocity, stage, and depth would be recorded at each sampling site.

Fishes

Fishes are an important part of the Colorado River ecosystem because of their intrinsic value if native, the trophic role of both native and non-native taxa, the important recreational value of non-native trouts, and because some native taxa are listed as endangered or candidates for listing under the Endangered Species Act. Fish populations depend on appropriate habitat and an adequate food base. Both of these factors may change as a result of dam operations. Habitat determination for many of the species is a result of the GCES research program. However, reproduction, recruitment and growth of various species in response to the aquatic environments created by dam operations would result in different demographic distributions of native and non-native species within the Canyon. Operations of the preferred alternative are predicted to enhance recruitment of native fish species through reduction of "flushing" of larval fish from tributaries into the mainstem for example, and trout through reduction in loss of spawning habitat (redds) and stranding of young. Loss of spawning habitat through armoring of normal redds areas may also be a consequence. In addition, dam operations are expected to enhance the food base to ensure growth and maintenance of the existing populations. The objective of this program, therefore, is to monitor the condition and population fluxes of native and non-native fish species to evaluate their response, as predicted, to dam operations.

Monitoring would include all native and non-native species. There would be a long-term data base existing for the status of adult fishes when the long-term monitoring program is initiated; information on pre-adult life stages would likely be less complete.

Sampling time-frames would differ for different taxa and life stages. Because information on some of the fish species is not complete, adults of long-lived taxa would be sampled annually. As information becomes more complete, sampling would be on a four-year cycle. Short-lived species and young-of-the-year of all taxa would be sampled twice annually during the period of larval fish presence (spring) and following the period of summer flooding. Sampling locations would correspond as closely as possible to those selected for monitoring of the aquatic food base, but would also include selected tributary sites (e.g., Paria, LCR, Bright Angel, Nankoweap, Havasu, and others to be determined). The assumption is that by the time long-term monitoring is initiated, sufficient understanding of many relationships among sampling sites and ecosystem parameters would have been established to allow use of sampling site data for assessing overall status, trends and changes of fish populations as well as the aquatic food base.

The sampling protocol for adults of long-lived species would be comparable with that used during GCES II research and interim flow monitoring to ensure compatibility of data. Monitoring in the Little Colorado River would be comparable with protocols developed during the GCES II humpback chub research program. Sampling protocols for short-lived species and young of others would be determined through evaluation of monitoring proposals but would produce data compatible with those generated through monitoring of other age classes.

Creel data, regular surveying of fishing guides, and other methods compatible with protocols developed by Arizona Game and Fish Department would be used for assessing trends in trout populations in the Lees Ferry reach, while protocols developed by Arizona Game and Fish and the Hualapai Wildlife Management Department to assess recreational fish populations would be used for lower reaches. Timing of those activities would be determined by the resource management agencies, but would not exceed an annual reporting schedule. Data collection and reporting from the two departments would be compatible.

Riparian Vegetation

Mainstem Vegetation and Habitats

Riparian vegetation along the Colorado River and its tributaries is important for streambank stability, wildlife habitat, campsite modification and aesthetic values. Riparian vegetation along the mainstem comprises three distinct communities, old high water zone (OHWZ), new high water zone (NHWZ), and near-shoreline wetlands (marshes). All of these communities are important ecosystem components; however, only the NHWZ and marshes would be impacted directly by dam operations. Maintenance of these vegetational communities for wildlife habitat is a predicted ecosystem response to the preferred alternative in the EIS. The National Park Service and the Hualapai Tribe consider the OHWZ important in maintaining relicts of the pre-dam ecosystem. The OHWZ may be maintained by periodic habitat maintenance flows through wetting of the substrate in the root zone downslope toward the river. These habitat maintenance flows are recommended for most of the alternatives with low or non-fluctuating discharge. The objective of this long-term program, therefore, is to monitor all three vegetation communities to determine the level of maintenance of these communities by the prescribed dam operations.

The National Park Service has established permanent quadrants along the mainstem and in selected perennial and ephemeral tributaries for the purpose of evaluating long-term responses of riparian and wetland communities to natural and anthropogenic influences (Stevens 1992). Equivalent quadrants have been established by the Hualapai Tribe in the riparian zone during interim flow monitoring. A statistically significant number of these quadrants, distributed throughout Schmidt and Graf's (1990) geomorphic reach designations between Glen Canyon Dam and Diamond Creek, and those below Diamond Creek on the Hualapai reservation, may be the appropriate sampling locations for riparian vegetation because they can be considered baseline information locations. Stage-to-discharge relationships would also have been developed for each by the time the long-term monitoring program begins. The geomorphic settings examined at each area would include marsh, NHWZ (which includes low bar, general beach, channel margin, debris fan) and OHWZ (see Stevens 1992 for stage elevations of these settings).

Because of different response rates to changes in river dynamics, sampling procedures (particularly timing) must differ in the different communities. Marshes and low bar settings would be sampled frequently (e.g., twice a year for the first five years and annually thereafter, except when there are unusual hydrological events, and then immediately after and again twice a year for three years). General-beach, channel-margin and debris-fan settings would be sampled annually, while OHWZ settings would be sampled infrequently (e.g., every five years).

Annual video- or photography of the Canyon would be used to map and quantify changes in cover of riparian vegetation in established (or expanded) GIS reaches. This would be linked with equivalent monitoring of sediment and bar changes.

Tributaries

Riparian vegetation near the mouths of the primary tributaries, but outside the influences of the mainstem, would be characterized and used as reference points for autogenic changes. Characterization would be limited to community structure and species composition and sampled about every five years after a baseline has been established. Tributary quadrants would be located in comparable settings as along the mainstem (i.e., channel margin, and debris flow terrace). Timing (i.e., time of year) of sampling along the tributaries would correspond with equivalent settings along the mainstem.

Riparian Wildlife and Wildlife Habitat

Riparian Habitat

Habitat relations of most riparian fauna in the Canyon have not been well established. Determination of faunal responses to dam operations is extremely difficult and is dependent on known faunal responses to changing ambient conditions. Thus, to achieve the objective of monitoring the response of faunal assemblages to dam operations, it might be best to align these responses with sampling of riparian vegetation, recognizing that not all riparian fauna are associated with vegetation.

Invertebrates

It is unlikely that a completed baseline of invertebrate assemblages will be available when long-term monitoring begins, although there presently exists a large database. Monitoring key taxa, when such are identified, may permit evaluation of responses to dam operations. An inventory of the invertebrate fauna would be established by the National Park Service and Hualapai Tribe as part of a general inventory program, but an extensive and intensive long-term monitoring program would even then disallow more than an estimate of invertebrate responses to variation in river discharges. Thus, as part of a long-term research program, it is essential to establish the invertebrate assemblages (e.g., selected taxa) that are associated with different riverine and shoreline vegetation communities. Long-term monitoring of these vegetation communities may in this way be used as a surrogate for estimating responses of invertebrates to operational changes.

Terrestrial Vertebrates

The intensity of effort required for sampling terrestrial vertebrates (herpetofauna, mammals and birds), and the low potential for distinguishing between responses to non-dam changes and those caused by dam operations, limit usefulness of long-term population studies as indicators of change in the riverine ecosystem. In addition, baseline data to support a long-term monitoring program are minimal (except for avifauna), indicating the need for more inventory of terrestrial vertebrates by the National Park Service and the Hualapai Tribe. When inventory is complete and habitat relations of selected assemblages (especially herpetofauna and birds) are established, data from long-term monitoring of vegetation and other habitat components would indicate the probable status of many terrestrial vertebrate populations.

Avifaunal data are perhaps most extensive (see Brown 1989), and a substantial baseline may, in fact, be available if synthesized with the long-term monitoring program in mind. Avifaunal inventory and monitoring, if undertaken, would emphasize riparian-obligate species, resident non-obligate species, migrant species in a biogeographic/geomorphic/seasonal context, listed or special status taxa (e.g., bald eagle, peregrine falcon, southwestern willow flycatcher, belted kingfisher), and wintering and breeding waterfowl. Locations of birds and nests observed would be mapped on the GIS system within the Schmidt and Graf (1990) canyon reach designations. Intensive sampling would occur at the large sample sites (also to be used for herpetofauna and mammals, see below). Nest sites would be mapped and habitat described. [Annual survey of wintering bald eagles/trout population relationships at Nankoweap, representative of the impacts of aquatic responses on listed avian populations, would continue into the long-term monitoring using techniques compatible with those in Brown and Stevens (1991).]

Monitoring of vertebrates, if determined to be essential, would require large study sites where full descriptions of vegetation, soils and topography are available. Spot sampling elsewhere might also be required to expand the long-term monitoring data base. For herpetofauna and mammals, a seasonal sampling schedule is recommended. Establishment of a baseline is necessary for assessing population changes over time and the expense and effort to do this may be too great to include terrestrial vertebrates in the long-term monitoring program. This does not exclude the necessity of the National Park Service and

the Hualapai Tribe in initiating or continuing its inventory of these taxa, but not as part of the long-term monitoring program.

Endangered and Special Status Species

Information on the response of endangered and special status species to dam operation may be crucial to the species' recovery. In addition to their special status, these species are considered important because many were part of the pre-dam ecosystem. The objective of the long-term monitoring program is to track the populations of these species as they respond to changes in their habitat and food base caused by dam operations and other factors which are expected to enhance the chances of their survival and/or recovery. Of the list presented earlier in this document, humpback chub and razorback sucker would be monitored under the fish monitoring program, while the bald eagle, peregrine falcon, southwestern willow flycatcher, belted kingfisher and Kanab ambersnail would be monitored under the wildlife monitoring program.

Cultural Resources

Cultural resources include archaeological sites, traditional Indian cultural properties, and historical sites. All of these resources have the potential of being altered or lost through processes caused by dam operations as well as other factors, especially those within the discharge potential of the dam or along arroyos that may be influenced by loss of the sediment foundation. It is the objective of this long-term monitoring program to track the integrity of these resources over time and to determine possible mitigating measures when appropriate.

Physical Sites

The long-term monitoring program for physical sites would adopt the Programmatic Agreement for Compliance with Section 106 of the National Historic Preservation Act between the National Park Service, Indian Tribes, Bureau of Reclamation, the Arizona State Historic Preservation Office and the Advisory Council on Historic Preservation, as the monitoring design under this long-term monitoring program. The important aspects of that agreement (from Balsom et al 1991) are presented here.

To effectively monitor impacts of dam operations on cultural sites, baseline information must be complete, with accurate maps, descriptions, and photographs of each site having potential of being impacted. The long-term monitoring program must be sensitive to the fragile nature of sites, the dynamic geomorphic conditions under which they persist, and the delicate situations relative to Indian Tribes and agency responsibilities for their protection and preservation.

The monitoring program must be designed to identify both the present condition of sites and actual changes resulting from dam operations and other factors. (Monitoring data would be used to guide mitigative measures to preserve sites in as pristine a condition as possible.)

Not all sites would be monitored. An extensive representation of sites with evidence of impact by mainstem discharges, including flooding, would be included, while a smaller representative sample of sites not presently impacted by river flows would also be monitored. If observations indicate that specific sites within the population of sites from which the sample was selected show evidence of impacts from dam operations, these sites would be added to those monitored under the long-term monitoring program. Sites to be monitored would be categorized into the following groups from which decisions on intensity of monitoring can be made: (1) direct impact, inundation or bank cutting within the site area in recent years; (2) indirect impact A, bank slumpage or slope steepening adjacent to the site, and B, evidence within the site of accelerated erosion exacerbated by the proximity to river eroded sediments; (3) potential impact A, buried in or located on old river alluvium and below the 300,000 cfs discharge zone, and B, located below the 300,000 cfs discharge zone and not situated in or on river alluvium.

Other impact categories dealing with arroyo cutting (from external causes not head cutting from the river), recreational use (unless evidence of changes in recreation resulting from dam operations), or sites located above the 300,000 cfs discharge zone are not included in this long-term monitoring program, but should be monitored under a continuing cultural site inventory and monitoring program of the National Park Service, the two efforts to be closely coordinated.

Representative samples of sites would be chosen, randomly and non-randomly, within the above categories to insure that sites in the greatest danger of impact are closely monitored and remedial actions taken when required. Sites that have no potential for external impacts would be identified and used as controls.

Schedule for monitoring cultural sites would be dependent on the baseline condition of the site. It is assumed that all sites will have been categorized and described, including geomorphological settings, prior to initiation of the long-term monitoring program. Sites that are directly impacted by river discharges (including loss of sediment foundation) would be monitored quarterly, while a sample of other sites (ca. 20%) would be visited annually. Selection of these latter sites would be based on sensitivity, tribal concerns and other factors determined by archaeologists, respective Indian Tribes and geologists. Sites which are not impacted by river discharges, but show impacts due to such factors as arroyo cutting, would be integrated with the long-term monitoring program. Annual aerial photo- or videographs would also be used to evaluate site changes, especially of those of sufficient size to allow remote sensing of change. This work would be coordinated with the sediment dynamics monitoring program. Sites with potential for rapid degradation would be monitored weekly through the use of oblique photography using hidden time-lapse cameras. If rapid loss is discovered, recovery archaeology and/or mitigation would immediately be initiated.

Tribal Cultural and Spiritual Values and Tribal Concerns.

Monitoring of tribal values and concerns with dam operations and impacts would be an integral part of the long-term monitoring program. Tribal attitudes and values may change over time, both in response to passing years but also as a result of actual or perceived changes in the Canyon ecosystem or other influences or factors. The objective of this program is to monitor these values and attitudes on an ongoing basis and to structure them

to allow for quantitative analytical techniques and to determine possible changes in attitude or values in relation to dam operations.

Each affected Tribe should develop and implement a set of visitations on an annual basis. These visitations should include established sets of questions, determined by the Tribe and comparable over time, dealing with the Canyon resources. Questions and timing of visitations should be determined by each Tribe in cooperation with the organization responsible for the overall long-term monitoring program.

Recreation

Recreational use of the Canyon is of economic and environmental importance. As a major use of the Canyon, recreation creates jobs and financial support within the region, but also is a significant component of impact analysis. The preferred alternative in the EIS has considered impacts on recreation and has attempted to enhance the recreational experience in the Canyon and increase safety. Also of importance are the possible impacts of recreation on Canyon resources. The objectives of the long-term monitoring program, therefore, are to determine whether recreation is enhanced and safety improved over impacts of the historic operation of the dam, and whether changes in recreational patterns resulting from the selected dam operational alternative have any effect on the Canyon.

To determine whether dam operations are affecting the pattern and amount of use in the Canyon, data on use and changes resulting from recreation would be compiled annually. Such data can be utilized to assess changes in use, but also may help determine causes of some changes in other resources (e.g., fish populations, and beach sizes or qualities, etc.). Recreation use data are available from or can be obtained through the National Park Service, Arizona Game and Fish Department, Native American tribes, and fishing guide, angler and boatman surveys, including the following: (1) Whitewater rafting, including commercial, private and tribal enterprises. Data would include user days, length of trip, put-in and take-out points, beaches used, and safety (accident) records. (2) Angler uses, including commercial and private use above Lees Ferry. Data would include angler user days, fish catch data, and safety (accident) records. (3) Miscellaneous uses, e.g., birdwatching, use of riparian habitats (both mainstem and tributaries) for hiking, sightseeing within the Canyon, etc. to be evaluated through National Park Service and Hualapai Tribe permitting records, Game and Fish surveys, and other means. Survey results would be summarized and evaluated annually.

Beach area data would be monitored using aerial video- or photography at the same discharge levels each year. Changes in beach camping area, above high discharge levels, can be determined through digitized video- or aerial photographs and validated on a sample basis through ground truthing coordinated with beach surveys under the sediment dynamics component of the long-term monitoring program.

To determine possible reasons for changes in recreational use, recreationist's values and concerns would be monitored on a five year basis or following unusual events. This information would be gathered using surveys of appropriate user groups. Value evaluation is separate from values determined using non-use value methodologies. The former deals

directly with use and experiences in the Canyon while the latter are based on no direct contact with the Canyon.

Recreationists' values to be monitored using surveys that deal with the relative value of Canyon experiences include: (1) satisfaction with existing discharge levels, (2) perceptions of effects of dam operations, (3) attitudes about congestion at beaches or high level visitor sites, and (4) attitudes toward researcher/monitoring teams in the Canyon. Information gathered during the pre-long-term monitoring period would be used as the baseline for comparison and evaluation of change in these values and perceptions.

Power, Economic and Financial Impacts

Hydropower Supply

Hydropower supply is an integral part of the economy of the region. Changes in power operations resulting from changes in annual dam operations would affect the power supply and its costs. The objectives of this program are to determine the impact of changes in dam operations on hydropower outputs and the concomitant power marketing and economics of the region, a concern of those agencies tied to hydropower production.

Actual power generation would be monitored on an hourly basis as input to assessing the consequences of dam operations on power economics. Power generation is also a method for estimating water discharge rates and volumes.

Economics and Finances

Long-term monitoring would include the maintenance of a current data base for future power resource economic reviews to determine the consequences of the anticipated changes in Glen Canyon Dam operations. A periodic review of the electric power market would determine whether new information supports decisions based upon previous forecasts. The Power Resources Committee (PRC) Phase II effort would be used as the basis for the periodic review. For each review, current measured parameters can be compared to the risk and sensitivity analysis work completed in Phase II studies. If the current measures or assumptions fall within the range of assumptions made in Phase II, then the impacts can be determined from this information. Conclusion can then be made regarding the degree of influence changes in certain measured parameters (i.e., load growth, fuel escalation rates) would have on the economic and financial impacts.

A more detailed review would involve assessing the significance of changes in the value or financial benefits of power and recreational uses which might impact the economic and social benefits of changes in Glen Canyon Dam (GCD) operation. A detailed review would take place when a different operational alternative for GCD is proposed. The decision to go to this level of analysis, based in part on a recommendation of the Adaptive Management Working Group, would be made on a case-by-case basis.

In preparation for these reviews, a data base of revenues, rates, supplies, purchases and loads must be established through monitoring the following parameters: (1) annual revenue requirements of Western Area Power Administration (Western), (2) rate charges for

Western wholesale power, (3) regional power supply adequacy for Western Systems Coordinating Council (WSCC) annual reports (moving, 10-year projection), (4) historical regional power loads from WSCC, (5) annual evaluation of costs of power purchases and sales within and outside the region available from EIA, (6) updates of utility data already collected by the PRC.

Concomitant with evaluation of impacts on power revenues, should be an evaluation of impacts on the economics and revenues of other uses of Glen and Grand Canyon. These uses especially include recreational revenues, but changes in other regional revenue sources resulting from the selected dam operation would be considered.

The detailed review would follow procedures established by the PRC of Glen Canyon Environmental Studies to evaluate the economic impacts of various dam operation alternatives for the Glen Canyon EIS. If required, additional transmission related and short-term operational reviews may be necessary with any further changes at Glen Canyon Dam.

Evaluation of the non-use values of the Glen and Grand Canyon riverine system would also be part of the economic and financial component of the long-term monitoring program. It is possible that the public's perception of the Canyon may change as a result of the future operations of Glen Canyon Dam; thus it is valuable to determine this perception through use of non-use economic methodologies.

LITERATURE CITED

(An extensive reference listing of ecological and environmental impact studies within Glen and Grand Canyons can be found in the EIS.)

Balsom, J., et al 1991. The Grand Canyon River corridor survey project: archaeological survey along the Colorado River between Glen Canyon Dam and Separation Canyon. Report on file, Grand Canon National Park and the Bureau of Reclamation, Flagstaff.

Brown, B.T. 1989. Ecology of riparian breeding birds along the Colorado River in Grand Canyon, Arizona. Coop. National Park Resources Stud. Unit Tech. Report No 25, NPS. Univ. of Arizona, Tucson.

Brown, B.T. and L. E. Stevens. 1991. Influences of fluctuating flows from Glen Canyon Dam and effects of human disturbance on wintering bald eagles along the Colorado River in Grand Canyon, Arizona. NPS Cooperative Parks Study Unit. Northern Arizona University, Flagstaff, AZ. (unpublished annual report).

MacDonald, L.H. 1991. Monitoring guidelines to evaluate effects of forestry activities on streams in the Pacific Northwest and Alaska. United States Environmental Protection Agency, Water Division. EPA/910/9-91-001.

Schmidt, J.C. and J.B. Graf. 1990. Aggradation and degradation of alluvial sand deposits, 1965-1986, Colorado River, Grand Canyon National Park, Arizona. U.S. Geol. Survey Prof. Paper 1493, Washington, D.C.

Stevens, L. E. 1992. Long-term monitoring of riparian biotic resources in the Colorado River corridor, Glen and Grand Canyons, Arizona. In, National Research Council, Long-term monitoring workshop.

ADDENDA

Addendum 1.
Background and Input Attributes and Benchmark (Unaffected) Sites

Background and input attributes are those factors whose variation may be used to help explain changes in the mainstem Colorado River corridor ecosystem. They occur or are located above and/or below the dam, but are not those attributes along the mainstem corridor influenced by dam operations. Information on background and input attributes is important to archive for use by the long-term monitoring program on effects of dam operations, however, gathering of this information is not part of that program.

The Role of External Factors and Benchmark (Unaffected) Sites

Although long-term monitoring of the Grand Canyon ecosystem may detect temporal change which might be associated with dam operations, other possible causative factors, such as climate, will exist. Thus, identification of external factors that may be regularly monitored for other purposes such as climatological data, and identification and monitoring of unregulated analogues to the Grand Canyon ecosystem could provide an opportunity to distinguish "natural" change from dam-related change.

Benchmark (unaffected) sites are locations that might be considered as control sites similar in geomorphology to the Grand Canyon that can be used to analyze differential influences of dam and non-dam variables. Unfortunately, there is insufficient scientific data on which to identify unregulated analogues to the Grand Canyon at this time. Candidate areas include Cataract Canyon and the Grand Canyon tributaries. The latter are only relevant for biological parameters. Research should be considered in Cataract Canyon to determine its possible analogue status as an "unregulated Grand Canyon". At a later time, the National Park Service might propose a companion Cataract Canyon monitoring program as one basis for interpreting environmental change in Grand Canyon.

Some ecological monitoring of tributary conditions in Grand Canyon is included in this program, however, such efforts would be limited. Further research is necessary to determine the nature of appropriate comparisons between the "big river ecosystem" of the Colorado River and the "small river ecosystems" of the tributaries.

The external factors that would be used for differentiating between natural and dam caused changes are discussed below.

Meteorology/Climate

Regional Meteorology/Climate. Hydrology of the Glen Canyon/Grand Canyon region is a consequence of regional precipitation and temperature patterns. Tributaries, especially the Little Colorado River, Paria River and Kanab Creek, are all important in the dynamics of the river. As part of the background data base for long-term monitoring, and for interpreting different causes of change in the Colorado River ecosystem, it is essential to include climatological data from NOAA weather stations that influence major tributaries to the Colorado River above and below Glen Canyon Dam. The minimum set of climatological stations would include: Page, Jacob Lake, Kanab, Cameron, Supai, Pipe Springs NM and Peach Springs. Additional stations at the headwaters of the Little Colorado River, Kanab Creek and Paria River would also be considered. When necessary, data from stations at the headwaters of the San Juan, Green and Colorado Rivers would be archived.

Hydrometeorology. In addition to climatological data, it is essential to archive information on hydrometeorological changes. These include not only precipitation (part of climatological data), but snowpack and runoff in the major tributaries to Lake Powell and the Colorado River below Glen Canyon Dam. Hydrometeorological data are presently collected for some of the tributaries of Lake Powell. Snowpack measurements are also a regular part of the predictive models used by the Bureau of Reclamation in its forecasts for annual and monthly releases of water from Glen Canyon Dam. These data, however, would not only be used for predictive purposes but as part of the overall data set archived for the monitoring program.

Local Microclimate. There is a very limited set of local meteorological stations in the Grand Canyon, the primary one being at Phantom Ranch (Grand Canyon NP). Changes in the Colorado River riverine/riparian ecosystem may be a response to non-anthropogenic environmental changes as well as changes or influences from dam operations. As part of its inventory and monitoring program, NPS would need to upgrade and add to local climatological stations to give adequate coverage for interpreting local climatological influences. The Phantom Ranch station would be instrumented to measure solar radiation in addition to temperature and precipitation. Complete weather stations would be established at Lees Ferry. The Hualapai Tribe should add a complete weather station at Diamond Creek near the river as part of its long-term resource studies. Other stations within the Canyon, for example, Indian Gardens, would be upgraded to full climatological station status. Data from these stations then become part of the background archives for the long-term monitoring program. The importance of upgrading or adding climatological stations for data input into the long-term monitoring program cannot be over emphasized. There is such a critical need for this information, for example, the affects of solar insolation and canyon temperature on water temperature, that this effort would be considered as an integral part of the long-term monitoring program.

Addendum 2.
Information Management

Characteristics of Long-term Monitoring

Essential to any long-term monitoring program is that it addresses management needs, specifically, it would be designed to ensure that management objectives are being met. It would also be designed to recognize the temporal characteristics of the system being monitored. In the case of the Grand Canyon, long-term monitoring in response to operations of Glen Canyon Dam would continue indefinitely, or as long as the dam is operable. Periodic review of the program is necessary to determine the intensity of the monitoring program. The potential longevity of this program would be recognized in the selection or establishment of institutions that can maintain continuity while carrying out monitoring activities. Because continuity in methodology and procedures is essential to ensure comparability of data, no monitoring activity should be based on the sole contributions of any one individual but would be aligned with an agency or long-term organization.

Monitoring activities must also recognize the spatial scale of the resources. The enormity of Grand Canyon requires that projects actually be a sample, and that an hierarchy of spatial scales (e.g., nesting or representative sample units) would be used. Selection of sample units or areas would also consider the sensitivity or fragility of the system, thus methodologies would leave as small a "foot print" as possible. The type, frequency and location of measurements would, however, invariably follow from the objectives of the long-term monitoring program.

Lastly, the long-term monitoring program would be sufficiently flexible to permit initiation of "new" monitoring activities to respond to transient events such as floods or tributary sediment pulses, and to changes in direction which may result from changes in management goals.

Development of Long-term Monitoring Activities

Potential use and integrity of monitoring activities is dependent on their initial procedural design. Each proposed monitoring activity must be reviewed by other workers prior to implementation to ensure comparability of data, prevent overlapping efforts, and to encourage interaction and integration by using comparable spatial and temporal boundaries. Considerable resources would need to be devoted to careful documentation of procedures, quality assurance and quality control (QA/QC), definition of variability (i.e., defining uncertainty), etc. This would reduce the total amount of data which can be collected, but it is necessary to provide the documentation for future data use and interpretation.

All participants in the long-term monitoring program must be required as a condition of participation to have their data internally and externally reviewed and entered into a common data base system on a regular and timely basis. Field data must be carefully referenced to known, consistent locations (georeferenced). These reference points must be consistent among monitoring and research activities, and included as an integral part of the GIS data management system.

Effective monitoring activities must be based on a thorough knowledge of the physical and biological characteristics of the system. Because the baseline information may be limited for some areas and resources, and methodologies may not be fully tested, many activities would be initiated as "pilot projects" and the comparability of the data tested before being settled upon as a major part of the long-term monitoring program. Trade-off between minimum detectable effects and monitoring efforts and costs must furthermore be accepted as part of the evaluation procedures for selection of monitoring projects within the long-term monitoring program.

Protocols for Data Collection and Processing

Each component of the long-term monitoring program must have an explicit, detailed protocol which spells out: (1) objectives, (2) experimental design, (3) procedures for data collection, QA/QC, data analysis, data storage, and reporting. This allows anyone to replicate measurements and to evaluate them in a consistent statistical manner. Where appropriate, each experimental design would be evaluated for statistical integrity. The protocol for each component would specify the level of knowledge and training required for those collecting field data, analyzing samples, entering data, and interpreting the data. There would be a comparable protocol for managing the data base.

Scientists collecting the data would be involved with data interpretation. Although the time frame of the long-term monitoring program extends well beyond the participation period of any one scientist, it is anticipated that those who collect the data would be familiar with the Grand Canyon and may use the data as part of ongoing research programs. This connection of data collection and interpretation would result in data being collected appropriately and efficiently.

Releasing and sharing data must be a requirement for every project. Those collecting original information, however, should be allowed a reasonable time for analysis and publication before releasing the data to the public. Trust must be established among data collectors and managers to ensure transfer and integration of information. Each monitoring project would prepare an annual report using a consistent and defined format, including reports from data base managers.

Data Base Management

A general principle is that all data would be freely available. In some cases, however, such as archaeological-site data, data that Indian Tribes define as sensitive, or information on localized endangered species, a level of confidentiality may be necessary.

A centralized, integrated data base is necessary to avoid duplication of effort and facilitate exchanges of information among projects. This includes incorporation of information from past monitoring, inventories and research. Each file in the data base must be cross-referenced to files which document data-collection procedures, variability, and uncertainties. All data would be copied and stored in at least two locations to maximize security.

Certain kinds of data and collected information are unsuitable for storage in a traditional computerized data base. These include audio and video recordings, for example, as well as biological and geological specimens and copies of historical literature and photographs. This information and collections need to be archived following procedures appropriate to their unique characteristics, and cross-referenced to other information.

Management of the Monitoring Program

The resource management agencies and interests have established an Adaptive Management Working Group that would oversee the management and archiving of the long-term monitoring program and data (see chapter in EIS). This group would evaluate the findings of the long-term monitoring program. This evaluation may lead to recommendations for changes in dam operations to ensure compliance with the objectives of the 1992 Grand Canyon Protection Act.

Although no specific institution has been selected for the actual management of the long-term monitoring program or archiving of monitoring information, an organizational structure needs to be set in place prior to initiation of any phase of long-term monitoring of the effects of Glen Canyon Dam operations. It would need to absorb the ongoing program of the Glen Canyon Environmental Studies which has managed data collection efforts to date and has embarked on an information management program as well (Scientific Information Management system - SIM).

GIS and Remote Sensing

The use of Geographic Information Systems (GIS) for data storage is an important component of the data management process; however, not all data can be put into GIS format. GIS can be an important analytical tool for integrating and comparing spatially based data, but the applicability of this technique would depend upon the particular objectives of each monitoring project. Each project would specify which GIS data layers are required.

The validity of the existing GIS reaches in the Canyon would be tested for representativeness or designation as critical reaches. Usefulness of these reaches for the long-term monitoring program would be evaluated once the objectives and priorities for long-term monitoring are established. The use of satellite and remote sensing (e.g., aerial video- and photography) data would also be evaluated relative to the level of detail needed for each monitoring project (satellite data would probably be too coarse for use in monitoring in the Canyon).