FINAL REPORT

OF THE

PROTOCOL EVALUATION PANEL

FOR THE

GRAND CANYON MONITORING AND RESEARCH CENTER

INTEGRATED WATER QUALITY PROGRAM (IWQP)

Prepared By

Jack Jones

Robert H. Kennedy

John Nestler

Dale Robertson

Richard J. Ruane

S. Geoffrey Schladow

FEBRUARY 23, 2001

IWQP PEP FINAL REPORT

TABLE OF CONTENTS

APPENDICES

FIGURES

EXECUTIVE SUMMARY

MAJOR FINDINGS AND RECOMMENDATIONS

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

- Employ water quality-ecosystem models in Lake Powell and the Colorado River to link Glen Canyon Dam (GCD) operations and physical/chemical/ecosystem responses in a timely manner using the best information available.

- Work with other programs in the Grand Canyon Monitoring and Research Center (GCMRC) Biological Resources Program in the integration of results to allow decision-making by the Technical Working Group (TWG) and the Adaptive Management Working Group (AMWG) by linking operations of GCD to various ecosystem responses.

- Develop a "proactive" long-range water quality monitoring strategy to evaluate current and future water management actions at Glen Canyon Dam.

- GCMRC should work with the TWG to improve the Management Objectives/ Information Needs (MO/INs) process.

- Lake Powell forebay station should be changed to the White Category.

- It is imperative that the GCMRC provide critical information in a timely manner to allow cost-effective and environmentally effective decisions for the Adaptive Management Program (AMP).

SPECIFIC TECHNICAL FINDINGS AND RECOMMENDATIONS

Data Collection

1. **<u>Inflows:</u>**

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

2. **In Lake:**

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

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

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

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

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

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

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

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

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

- A multi-parameter profiling station should be considered for the forebay. These data, together with data from the tailrace, would be telemetered to GCMRC and GCD in real time. These data will define the linkage between the lake and the river as well as provide the basis upon which a temperature control device (TCD) is operated. An "intelligent model" could be developed that would define tailwater water quality based on the water quality profile in the lake and operating conditions at GCD. The panel recommends that the inclusion of such a station be considered as part of the TCD project.

3. **Tailwater:**

- The current location of the tailrace Hydrolab probably does not provide representative data. A more representative location(s) is needed.

- This reach of river is very important for supplying organic matter and a food base for the Colorado River down to Lake Mead. Productivity in this reach needs to be monitored using Howard Odum's "upstream-downstream approach."

4. **Downstream:**

- The temperature data collected by continuous monitors at selected locations in the downstream reach are invaluable data for calibrating a water quality model.

- Additional sampling should be linked to the needs of the water quality-ecosystem model and fisheries biologists.

- If DO, conductivity, and pH data are needed for water quality modeling, water quality monitors can be deployed for short periods (7-10 days) and placed to monitor water quality lagged with time of water travel through the Colorado River. Automatic water samplers (e.g., ISCO samplers) can be used to track water quality through the downstream system. The time of travel can be determined using dye studies or estimated using a water quality model.

Water Sample Preservation And Analytical Procedures

Specific recommendations are offered on the following:

- Chemical Parameters
- Preservation Techniques
- Sample Analysis QA/QC
- Phosphorus Analyses

Data Management

The Panel recommended that IWQP use the USGS WRD data management systems.

Water Quality-Ecosystem Modeling

- A cursory review of the INs that have a ranking of medium or high priority indicates that all of them can best be addressed using reservoir and river models.

- Future management decisions will need to be made in the context of a very different set of operating conditions than what has prevailed in the past. Different lake levels, the possible use of a TCD, different flow regimes, different power demands may all make the value of past correlations questionable.

- It is strongly recommended that a model be developed for those variables that are readily predictable using current, deterministic engineering models (the time varying values of flow, stage, temperature). This model would then provide a vehicle upon which to attach a light model, a water quality model, an ecological model, etc. The present "conceptual model" could well provide many of these latter components.

- The Panel is concerned that there is a significant disconnect between the physical processes that are initiated at the dam and the present modeling of ecosystem effects downstream.

- Emphasis should be placed on applying the model to assist scientists and engineers in GCMRC, TWG, and AMWG in sufficiently making decisions, not on developing a model that represents all aspects of the real system.

- GCMRC should consider convening another panel to assist them in determining the best modeling approach for the river. Ideally, however, an experienced person responsible for the reservoir model might be suitably qualified to take the lead role in directing the river modeling activities.

- The order of accuracy for river water quality models is as follows:
  1. 1-D flow regime (flow and stage),
  2. temperature,
  3. other water quality parameters (e.g., DO, turbidity and light, carbon, phosphorus, nitrogen, photosynthesis),
  4. biological effects of water quality,
  5. biological effects of habitat, and
  6. biological effects of competitive fish species

- Many decisions on water resources management in the United States have been based on models that only include the first two or three types of models, with biological considerations being addressed either externally to the model or through water quality and ecological models that are attached to the physical model.

- A good model of flow and temperature can be applied years in advance of the more complex biological models, and it can assist the GCMRC, TWG, and AMWG significantly as soon as it is available.

- Based on a cursory review of "steady flow" decision for operating Glen Canyon Dam in the year 2000, an unsteady state model of flow and temperature for the Colorado River between Glen Canyon Dam and Lake Mead would have proven extremely useful and may have resulted in a more cost-effective decision for operations at Glen Canyon Dam without jeopardizing the biological objectives.

Priorities For Sampling

- Long-term monitoring is a major need due to the decadal nature of the hydrologic cycle for this system in addition to considering that this is a managed system that is still undergoing engineering and operational modifications.
- The Panel recommends that IWQP develop a long-term monitoring plan that can be maintained annually for about 20 years.
- The report provides guidance for developing a long-term monitoring plan.

Additional Findings And Recommendations

TCD Withdrawal Zone Considerations: Withdrawal zones for hydropower intakes often are higher in the water column than might be assumed and result in the discharge from the project being warmer than might otherwise be expected. The Panel recommends that the GCMRC inquire about the considerations that the BOR has given to the withdrawal zone for the TCD designs being considered.

The Panel recommends that GCMRC use an acoustic Doppler current profiler to measure the withdrawal zone for the current intakes.

SPECIFIC PROGRAMMATIC FINDINGS AND RECOMMENDATIONS

Adequacy of IWQP for MOs and INs

- IWQP appeared to be collecting data in response to the Ins.
- However, it is unclear how findings from individual studies will be integrated either within the subject program or how information will be integrated between the subject program and other programs within the larger GCMRC.
- Science-based water resources decision-making can be envisioned as an information pyramid.
- GCMRC program management should consider discussions with the TWG and AMWG to obtain feedback and guidance on how modeling and other integration approaches could best be structured to address their INs.

Five-Year Plan

The Panel recommends that program management consider a five-year program time frame formally starting in 2002 (the interval between program reviews), but actually getting underway during 2001. The primary goals would be the collection of a full model data set, the calibration and validation of a reservoir model, and the transition to a mode of operation in which model results can supplant much of the present upstream data collection. Emphasis would shift to the downstream after one or two years as the reservoir modeling was completed.

Contracting vs. In-House

- Senior staff within the program should shift their emphasis to higher levels of responsibility and to interaction with the TWG and AMWG so that the information provided by the program can be used directly and efficiently by decision-makers and stakeholders.

- As senior staff move to more of an integrating and interpreting function within the program, then their more routine tasks, such as collection of monitoring data, can be back-filled by contracts or by staff from sister agencies. However, the Panel would not want to see this approach implemented unless the current level of quality field word can be maintained.

Additional Findings And Recommendations

Observations Regarding the IWQP Personnel: The Panel made the following observations in the process of the review:

- The IWQP personnel are technically capable, conscientious, energetic, experienced, as well as professionally and personally interested in the Glen Canyon/Grand Canyon system.

- The IWQP has produced good products on the results of their monitoring and analyses. Their reports are professionally prepared using state-of-the-art data analyses.

- The staff desires to develop and/or apply tools (e.g., models) and collect data needed to assist AMP in making management decisions.

- The staff desires to determine linkage between Lake Powell inflows and effects on water quality in the forebay and downstream from Glen Canyon Dam.

The (Acting) Biological Resources Program Manager is seeking to improve management of the IWQP by providing leadership to do what is best for the program and for the AMP. Dr. Ralston spent much time with the Panel and challenged the Panel to provide a meaningful review for the IWQP.

Hire a Modeler and Convene a PEP to Assist The IWQP in Developing Management Principles for Modeling: The Panel recommends that the vacant Post-Doc position be filled by someone with an academic background in water quality modeling. This individual should be capable of providing direction on model selection criteria and approaches as well as providing a foundation of operating principles and philosophies for establishing a premier modeling organization within the GCMRC.

SPECIFIC INSTITUTIONAL FINDINGS AND RECOMMENDATIONS

Comments on INs and the Role of the GCMRC

- There is no indication that the cost, feasibility, cost-effectiveness, level of significance in decision-making, "critical path" considerations, and potential for success were taken into account in developing the individual INs and level of priority that should be given to them.

- The Panel believes the GCMRC should consider these factors in developing plans for addressing the MOs and the INs and provide feedback to the TWG and AMWG.

- ***The IWQP's position within the AMP calls for it to play a servant-leader role:*** the GCMRC plays the main role as the service provider for the AMP; they also are the organization with the most resources, most information on linkages between Glen Canyon Dam operations and environmental effects, and highest stake by putting their reputation on the line for planning and performing efficient and effective technical approaches to achieve the goal of the ROD. Hence, they need to play a major leadership role within the AMP.

- The Panel recommends that the GCMRC promote the concept of "cost of science" to agency partners and stakeholders. From a total "cost of science" standpoint, it is more defensible to understand water quality and ecosystem processes to the level that they can be simulated using models. It is less defensible to have a surface understanding of these processes and then use "operational experiments" to select optimum dam operations. The "cost of science" concept needs to be integrated across agency partners.

Forebay Monitoring Proposed for the White Category

- The forebay (Wahweap) station needs to be considered differently than the other lake stations. The forebay profile represents in many ways the best approximation to the upper boundary condition of the downstream river (from both data collection and modeling perspectives).

- Another main reason is that potential water quality problems for the downstream can be forecasted and therefore possibly avoided using data only from the forebay.

- Additionally, IN 5.4 is in the "white category" and calls for a very wide range of information on the lake that can only be addressed if data are collected on the lake.

- Finally, the Panel agrees with the NRC "Downstream" report that rigid definitions of geographic scope will hinder the accomplishment of AMP objectives.

Modeling Approach with BOR

- The GCMRC needs a model for Lake Powell, and it is only prudent that they use the model that the BOR is applying to Lake Powell. The Panel recommends that the two organizations use the CE-QUAL-W2 model, but that each organization apply the model based on their respective organizational objectives (some objectives are suggested for the IWQP).

- It is recommended that they exchange inputs, runs, findings, etc., to save time and money to meet their respective objectives as well as to review the basis for each other's findings. If each organization has CE-QUAL-W2 and commercially available software interfaces to use CE-QUAL-W2, then input and output files can be shared among the agencies through e-mail exchanges between distant locations.

INTRODUCTION

WATER QUALITY DYNAMICS IN RESERVOIR SYSTEMS

Reservoirs are complex aquatic systems strongly influenced by hydrologic and meteorological inputs that, in turn, influence the quality of river water downstream from the impounding dam. The timing, quantity and quality of water and material inputs dictate, in general, the water quality characteristics of receiving reservoirs. Such inputs or loads determine, for instance, potential nutrient availability and hydraulic flushing, both of which can directly influence primary production. However, it is the interaction of basin morphology, dam design and operations, and processes occurring within reservoirs that ultimately determine water quality characteristics in reservoirs. For example, advection and sedimentation markedly influence the fate of material inputs, often resulting in the establishment of pronounced longitudinal gradients in water quality. The establishment of thermal stratification, and seasonal density differences between inflowing water and reservoir water lead to the development of density currents, which can further influence the fate of material inputs.

The design of the impounding dam and its operation can further influence reservoir water quality. The size and location (depth and orientation) of structural features for water release, as well as the quantity and timing of releases, dictate the depths from which water is withdrawn. This has important implications for the quality of water discharged downstream as well as the limnological characteristics of the reservoir. In general, releases from surface waters result in the export of heat and the storage of material (such as nutrients), while release from bottom strata results in heat storage and the export of material. However, residence time of water in the reservoir significantly affects the interaction of water quality changes in lakes and the water quality in the releases from these projects. The effects are often pronounced, including changes in thermal structure and mixing regime. Such changes, in turn, progressively influence subsequent impacts on downstream water quality. All these interactions are site-specific and complex; hence, while there are general patterns that are common among various types of reservoirs, each reservoir/tailwater system has to be addressed individually to deal with site-specific issues.

Impoundment results in significant alterations to river reaches below the impounding dam. Normal seasonal fluctuations in flow, which determine, among other features, the stage and transport of material in freely flowing rivers, are replaced by engineered responses designed to reduce or otherwise modify these fluctuations. The results are marked changes to hydrology, chemistry and biology. The amplitude of changes in flow is reduced and the temporal distribution of flow events is often significantly modified. Based on thermal properties of the reservoir and the design of the outlet structure, downstream temperatures are often sub-optimal and/or seasonally inappropriate for native species. Sedimentation can markedly reduce material concentrations in released water, often with accompanying shifts in the chemical form (e.g., dissolved versus particulate). Recognition of interactions between reservoirs and downstream reaches of the rivers on which they are located has prompted efforts to identify management approaches that acknowledge societal needs for water control while ensuring that downstream environments are sustained. Recognizing that impoundments preclude natural responses in rivers, these strategies must involve thoughtful, science-based compromise, adaptation to changing requirements and expectations, and incorporation of new knowledge of the ecosystem to be managed.

ADAPTIVE MANAGEMENT PROGRAM FOR ADDRESSING ISSUES OF GLEN CANYON DAM AND THE COLORADO RIVER ECOSYSTEM

The adaptive management program for Glen Canyon Dam and the Colorado River ecosystem was recently reviewed by the National Research Council (NRC) in the report entitled, "DOWNSTREAM—Adaptive Management of Glen Canyon Dam and the Colorado River Ecosystem" (NRC, 1999).

The NRC report provides a history of the issues that have been addressed in this system over the last decade as well as how they have been addressed through Federal Legislative, Administrative, and Judicial processes. The establishment of the Adaptive Management Program (AMP) followed a lengthy process that started with the Grand Canyon Protection Act of 1992, the 1995 EIS on the Operation of Glen Canyon Dam, and the 1996 Record of Decision (ROD) on the EIS by the Secretary of Interior.

It is significant to note two key considerations for the Integrated Water Quality Program (IWQP) under the ROD regarding decisions under the AMP:

1. The Secretary of Interior decided to implement the Modified Low Flow Fluctuating Flow Alternative (see page 176 of the "Downstream" report for a description of this flow regime) as described in the final EIS on the Operation of the Glen Canyon Dam, with a minor change in the timing of beach/habitat building flows (see page 172 of the "Downstream" report). It further states, "If impacts differing from those described in the final EIS are identified through the AMP, a new ramp rate criterion will be considered (and/or the maximum flow restriction will be reviewed) by the Adaptive Management Working Group (AMWG) and a recommendation for action will be forwarded to the Secretary."

2. Under item VII. BASIS FOR DECISION of the ROD, the following is stated: "The goal of selecting a preferred alternative was not to maximize benefits for the most resources, but rather to find an alternative dam operating plan that would permit recovery and long-term sustainability of downstream resources while limiting hydropower capability and flexibility only to the extent necessary to achieve recovery and long-term sustainability." (See page 183 of the "Downstream" report.)

The AMP is the process by which operations as well as design modifications at Glen Canyon Dam are evaluated. Currently, the issues that are being addressed include the operational pattern selected in the ROD, flood flows such as the special operation used in 1996, and the temperature control device (TCD) that is currently being designed for Glen Canyon Dam by the Bureau of Reclamation (BOR).

The AMP is composed of the Secretary of the Interior's designee, the AMWG, the Technical Working Group (TWG), the Grand Canyon Monitoring and Research Center (GCMRC), and independent review panels.

In 2000, peaking power operations of Glen Canyon Dam were eliminated and the project was operated to maintain a continuous 24-hour flow for over 110 days during the hottest part of the summer when peaking power is most valuable. The cost impact of these restrictive operations was an additional $25 million in just one year over and beyond the estimated cost of $15 to $44 million loss of hydropower benefits for implementing the ROD (this information was provided during the Panel's tour of Glen Canyon Dam by the superintendent of operations; Barry Gold commented that the $25 million figure might be high). Considering the current energy shortage in the Western United States, the value of peaking power generated at Glen Canyon Dam will only increase.

Other issues facing the water and energy situation in the West are likely to alter the current water use regime for Lake Powell and result in revised operations of Glen Canyon Dam. This points to the additional need for the GCMRC to develop the critical tools needed for assisting water resource managers in cost-effective and environmentally-effective decision making.

It is readily apparent that environmental concerns associated with operations at Glen Canyon Dam should be addressed as rapidly as possible so that impacts to water resources management and power production are minimized. It is imperative that the GCMRC provide critical information in a timely manner to allow cost-effective and environmentally effective decisions for the AMP.

THE GRAND CANYON MONITORING AND RESEARCH CENTER

The Grand Canyon Monitoring and Research Center (GCMRC) was established by the Secretary of the Interior to provide high quality scientific information to the Secretary and the Glen Canyon Dam Adaptive Management Program (AMP).

GCMRC's Mission is:

> "To provide credible, objective scientific information to the AMP on the effects of operating Glen Canyon Dam on the downstream resources of the Colorado River ecosystem, as well as other information needs specified by the Adaptive Management Work Group, utilizing an ecosystem science approach."

Water quality, including the water movements through Lake Powell and the Colorado River, provides the key linkage between the effects of operations at Glen Canyon Dam and the Colorado River ecosystem as well as provides key information for water resource management implications. The GCMRC, through the Integrated Water Quality Program (IWQP), is charged with describing water quality of the reservoir and providing the water quality linkage between operations at Glen Canyon Dam and the Colorado River ecosystem.

Sound management of reservoirs and their tailwaters requires a comprehensive understanding of the complex linkages between water quality determinants in the reservoir, design and operation of the dam, and water quality and water routing in the downstream reach. The IWQP was designed as a means to meet requirements for water quality-related information as identified by the TWG based on the management objectives for the Colorado River, including Lake Powell and downstream reaches in the Grand Canyon to the headwaters of Lake Mead. These management objectives include aspects of both physical and biological resources, and were formalized within the scope of the Adaptive Management Program.

Based on a review of information needs, the TWG established priorities as a means to guide program implementation. Information needs related to management objectives for the downstream reach received highest priority, while those related to the influence of Lake Powell on downstream resources received medium priority and information needs related primarily to Lake Powell were assigned lower priorities.

The IWQP is a part of the GCMRC that is under the direction of the Biological Resources Program Manager, Barbara Ralston (Acting). Most of the work is performed by Susan Hueftle and Bill Vernieu, who are assisted by Nick Voichick.

THE IWQP PROTOCOL EVALUATION PANEL

To ensure the quality and objectivity of GCMRC monitoring and research activities, AMP uses independent external peer-review panels called Protocol Evaluation Panels (PEPs) to review its monitoring and research programs.

The IWQP PEP (hereinafter called the Panel) was requested to review the water quality activities organized under the Biological Resources Program. The IWQP does work in both Lake Powell and the Colorado River between Glen Canyon Dam and Lake Mead. This Panel was tasked to review and assess current and future plans for water quality studies designed to address the information needs developed by the TWG. Members of the Panel were provided with a set of objectives for the IWQP in both Lake Powell and the downstream Colorado River. The Panel was asked to review the current monitoring and research protocols being used by the IWQP to measure water quality and other parameters on Lake Powell and downstream in the mainstem Colorado River to see if they provide the needed data to meet those objectives. The Panel recommendations will be used to revise the monitoring and research protocols, as appropriate. The Panel also was provided the opportunity to comment on the appropriateness of the specific objectives in the context of the overall program.

The Panel was asked to address a series of questions that were put forth by the GCMRC (see Appendix A). The IWQP provided the Panel with water quality information about the Lake Powell and the downstream system, the program objectives, a written description of the monitoring and research program currently in place, an assessment of historical data from Lake Powell, and other written materials. This information was presented to the Panel in the form of reports, graphs, formal presentations, demonstrations of sampling and monitoring methods, and round-table discussions during the course of the five-day onsite tours and meetings. A list of the resources provided to the Panel is provided in Appendix B.

Bio-sketches of the Panel members are provided in Appendix C. The Panel hopes that its assessment and resulting recommendations will help the IWQP fully meet the expectations for the AMP and the AMWG, TWG and GCMRC.

The panel convened in Flagstaff, AZ, on November 26 and followed this schedule:

Day 1: Arrived in Flagstaff and was transported to Page, AZ.

Day 2-3: Toured lower end of Lake Powell (up to Oak Canyon) to observe the monitoring and research protocols and discuss the historical data collection with researchers.

Day 4: Toured Glen Canyon Dam and tailwater monitoring stations below the dam down to Lees Ferry. Returned to Flagstaff.

Day 5: Received presentations of monitoring and research protocols and scientific findings from staff at the GCMRC.

Day 6: Discussed Panel report and recommendations.

Day 7: Departed Flagstaff.

PANEL REPORT

This report addresses the following main issues: technical, programmatic, and institutional. The rest of this report is organized to address these issues directly. Most of the issues that are addressed were identified in the series of questions that were put forth by the GCMRC (see Appendix A). These issues are generally addressed first in the respective following sections of the report, and additional issues identified by the panel follow.

The Panel findings and recommendations are based primarily on the information presented to them during the visit to Flagstaff (see Appendix B.) The allotted time for the Panel did not allow for follow-up contacts with GCMRC staff to review additional materials. While some of the recommendations are very specific (e.g., inflow sampling, chemical analyses, data management), many of the recommendations provide general guidance on specific items. This report is a "program level" review, as opposed to a work plan for future of IWQP. It was developed under the assumption that IWQP staff would use the report as guidance for developing their future plans. The Panel did not receive any comments on the report from GCMRC; hence, they did not have the opportunity to respond to GCMRC questions or concerns about the contents of the report. Suffice it to say that the Panel did what they could within the time allotted for their participation in the review.

TECHNICAL FINDINGS AND RECOMMENDATIONS

This section is organized to address the major functional areas of work under the IWQP: data collection, water sample preservation and analytical procedures, data management, computer modeling, and priorities for future monitoring. Many of the issues addressed were identified in the series of questions that GCMRC put to the Panel, and the original questions are identified to help the reader link the panel responses to the GCMRC questions. The original list of questions is provided in Appendix A.

DATA COLLECTION—RESPONSES TO QUESTIONS I.C, II.A, II.B, II.C, II.D, IV, VII

Overriding Question: Is the existing sampling program adequate with respect to the location, number and frequency of sampling, as well as with respect to the parameters monitored? If not, what changes would you recommend and why?

Inflows: Inputs to Lake Powell from its major tributaries drive the physical and chemical dynamics in the lake as well as provide potential to change its water quality. Information describing the flow and water quality of its major tributaries is needed to model the lake and understand changes that occur over short-term and long-term scales.

Tributary inflows to the lake have been monitored at different intensities, historically. Up to 1999, the NASQAN program monitored the three main tributaries to the lake (Colorado River near Cisco, Utah; Green River at Green River, Utah; and San Juan River near Bluff, Utah). This monitoring included continuous (every 15 minutes) streamflow measurements and periodic sampling for water quality. This periodic sampling has changed in frequency over the past years, but the sites were sampled approximately 8 times per year in 1999. These data can be used to estimate daily loading of water, nutrients, and sediments to the lake. Water-quality sampling at these sites was discontinued in 2000, but streamflow measurements have continued. In addition to these sampling efforts, the IWQP has sampled the water quality of each of these three tributaries, as far upstream as possible, while sampling the lake on a quarterly basis.

The Panel recommends that IWQP reactivate the water-quality sampling of these three tributaries near where they are gaged. To minimize the costs associated with this sampling, it could be conducted in conjunction with streamflow monitoring that occurs on an approximately a six-week basis. These samples should be analyzed for total phosphorus, total nitrogen, TOC, TDS and suspended sediment. In addition, to continuous streamflow measurements, continuous measurements of water temperature and specific conductance should be collected and telemetered back to the office. These data can be used to estimate daily inputs to the lake and used in modeling efforts. Although, more intense sampling would provide more accurate daily inputs to be estimated, it is felt that this intensity, in conjunction with prior collected data, would enable daily loading to be estimated using a regression approach. (Note: the IWQP should also consider the other inputs that are used by the CE-QUAL-W2 model and decide whether they are warranted, possibly using sensitivity runs with the BOR model.)

It is suggested that tributary sampling by IWQP continue, but at sites as far upstream as can be consistently measured. Water quality at the gaged sites should then be compared with those collected by the IWQP to provide the best estimates of inputs to the model. Coordinated sampling of the gaged sites and the far upstream sites would improve this comparison.

In Lake: The present lake sampling comprises 8 long-term stations. Measurements include water column Hydrolab profiles (of temperature, conductivity, depth, DO, pH, ORP and turbidity) and Secchi depth, while vertical plankton tows and van Dorn bottle samples are collected for subsequent analysis. These analyses include chlorophyll (at 1-m only), alkalinity (performed on-board), nutrients, cations and anions, and phytoplankton and zooplankton speciation. Additionally, approximately 12 sites are sampled using Hydrolab profiles, only. The Wahweap station (hereafter referred to as the forebay station) is sampled monthly, whereas the remaining stations are sampled quarterly.

The existing program has produced a sound basis upon which a general understanding of the lake dynamics has been established. This pertains particularly to the tracking of water masses (via temperature and conductivity signatures) along the main stem, where the long-term record has been indispensable. The more recent measurements of biological parameters are necessary for future model calibration and validation, and appear to be yielding enhanced understanding of in-lake water-quality processes.

The Panel is of the view that the present effort is warranted and its continuation is necessary for the development of the lake model. However, it is recommended that the present effort be modified progressively. These modifications include changes in the manner in which sampling is performed, the inclusion of additional parameters, the separation of forebay sampling from up-reservoir sampling, and the phased reduction of the sampling frequency and spatial intensity. Current CE-QUAL-W2 modeling results by the BOR and possibly additional sensitivity analyses should be used to determine the primary data needs as soon as possible.

The Panel considers the absence of complete chlorophyll profiles and any TOC measurements to be a major shortcoming of the present sampling program. The absence of these data could result in the application of the lake water quality model being questionable, and precludes the possibility of understanding long-term changes in lake productivity and trophic status, as well as the role of the lake in controlling downstream productivity. Information on TOC content of the lake water is critical to the carbon budget of the tailwater reach. Oligotrophic lakes typically have a deep chlorophyll maximum layer, so the present surface values are of questionable value to indicate total biomass. The best manner in which such data can be obtained is through the use of a commercially available chlorophyll fluorometer. The present chlorophyll sampling should be maintained in order to provide calibration data, and even increased to include a sample from depth (say 10 m) to increase the dynamic range of the field measurements. Samples for TOC analysis should be collected as part of the present van Dorn bottle samples. Also, the Panel recommends that the IWQP review the adequacy of the number of samples that are currently collected at the Wahweap station to ensure they are sufficient to represent the quality of the water that is discharged downstream, especially during power operations.

While it may be possible to combine a fluorometer with the existing Hydrolab, the Panel feels that the use of the Hydrolab is inappropriate for a lake of this size. Up to 2 hours per station are taken in performing Hydrolab profiles. A better use of time will be afforded by changing to an autonomous, high frequency profiler, such as those manufactured by Seabird. This would provide data at a spatial resolution in the range of 10-100 cm, while at the same time reducing on-station time to less than 15 minutes. This may have the additional benefit of better identifying the signatures of intruding layers. The possibility of using the USGS, WRD Seabird SBE-19 profiler should be vigorously pursued. The Panel is uncertain whether this instrument has sufficient channels available for inclusion of a fluorometer. If not, consideration should be given to the purchase of a Seabird SBE-25 profiler. This instrument has a greater number of channels and a higher sampling rate.

Collection and enumeration of phytoplankton and zooplankton samples are a contribution to the knowledge base of Lake Powell. Basic information on the type and abundance of plankton contribute to understanding of lake structure and provide insight on the role of predation on structuring the community. Plankton enumeration also provides information on the abundance of undesired taxa, such as Cyanobacteria or presence of the exotic cladoceran Daphnia lumholtsi. However, at the present scale of sampling intensity, this information is not essential to evaluate the effects of dam operation on downstream resources. Our suggestion is that the scope of this effort be limited to quarterly collections at the Wahweap site, a mid-lake site in the main channel and at an up-lake site. These collections should continue until it is determined whether this information will be used to support in-lake modeling efforts. We suggest the savings be re-invested into efforts downstream. Sample storage should follow accepted practice—samples should be archived in amber glass bottles and preserved with lugols solution (bottles should be stored in a cool location with the lugols checked every six months).

The plankton information gathered to-date has been tabulated but largely remains without synthesis. Our suggestion is that this information be summarized (see question VIII.A) in a format suitable for peer-reviewed publication. The scope of this summary might include data on the fisheries and water clarity and include a consideration of whether the top down forces (Cascade Hypothesis) are apparent within this time series data set.

The absence of meteorological data is considered a major shortcoming of the existing data set. These data are a key part of any lake model. It is understood that wind data from Page Airport has been used in modeling efforts to date. The validity of this assumption can only be evaluated once on-lake data have been collected and a regression analysis performed. It is recommended that a full meteorological station (wind speed, wind direction, short wave radiation, long wave radiation, air temperature, relative humidity and precipitation) be established on a raft or buoy at the forebay station. In addition, wind speed and direction sensors be established at several locations along the lake. The suggestion made to the Panel that roofs of the waste pumpout stations located on the lake could be used to house wind stations is considered to be an excellent solution.

The Panel believes that a timescale of at least one, and possibly two year(s) will be required to collect sufficient inflow, meteorological, chlorophyll, and organic data to produce a useable lake data set for model calibration and application. During this time, the present level of monitoring together with the changes recommended herein should be continued. Increased profiling in the transition region using a Seabird profiler should also be considered during this period. Efforts should be made to coordinate with the Park Service and the USGS (WRD), so that costs and staff time commitments currently borne by GCMRC can be reduced. As progress is made on the CE-QUAL-W2 model that the BOR is building and that the GCMRC should start working with (see response to question VI.B), it is recommended that the model be used to help define the monitoring needed (i.e., parameters, locations, frequency, etc.) to ensure sound decisions can be made regarding the management objectives, information needs, and hypotheses that will be developed as the AMP progresses (see response to question VIII.B. and under the Sections on Programmatic and Institutional Findings and Recommendations).

The forebay (Wahweap) station needs to be considered differently than the other lake stations. Due to the difficulty of measuring some parameters in the tailwater (especially those parameters that cannot be continuously monitored with electronic instrumentation), the forebay profile represents in many instances the best approximation to the upper boundary condition of the river model. Another main reason is that potential water quality problems for the downstream can be forecasted and therefore avoided using data only from the forebay. For these reasons alone, the forebay station should be considered as belonging in the "White category".

It is recommended that in addition to the regular monthly sampling, consideration be given to installing either a permanent thermistor chain or a programmable, in-situ, multi-parameter profiling station at the forebay. The data from this installation, together with the data from the tailrace/tailwater and meteorological station(s), could be telemetered to a shore station, and then made available to both GCMRC and the operators at Glen Canyon dam in real time. The Panel believes that there is considerable merit in the display of such data in the control room of the Glen Canyon Dam powerhouse, particularly if a TCD is installed. These temperature data from the forebay and tailrace will define the linkage between the lake and the river as well as provide the basis upon which a TCD is operated. After sufficient data are collected with this system, a "smart model or intelligent model" could be developed that would define tailwater water quality based on the water quality profile in the lake and operating conditions at Glen Canyon Dam. This monitoring system in the forebay is particularly appealing at Lake Powell because water quality varies almost annually due to the combination of its volume and the variation in inflow hydrology. The changes can be related to temperature but also salinity and possible anoxic products after the water residence time increases in the bottom waters after the TCD becomes operational.

The panel recommends that the inclusion of such a station be considered as part of the TCD project.

Tailwater: The tailwater region below Glen Canyon Dam is a dynamic, heterogeneous environment posing significant logistical and sample design challenges. The GCMRC currently measures in-situ variables using a Hydrolab installed along the wing wall near the river outlet discharges and are experimenting with measurements at selected draft tube taps. In-situ monitors are deployed at Lee's Ferry and water samples are collected periodically. Central water quality questions for this reach of the system include changes in temperature and salinity regime, particularly as influenced by project operation, and the production and transport of reduced carbon.

The Panel agrees with GCMRC personnel that the current location of the afterbay Hydrolab, while logistically convenient, probably does not provide for the collection of representative data. Since water is released by one or more of three different withdrawal structures (powerhouse, river outlet and spillway) and the powerhouse has eight intakes, an effort should be made to assess heterogeneity in the river immediately below the dam and to select a representative site for relocation of the in-situ monitor. This site should also be sampled monthly for water quality. Such a site may require the installation of an in-channel fixture. (Experiences of the Corps of Engineers faced with similar challenges on the Columbia River may be useful; and Panel member R.J. Ruane has had such experience at the wide range of hydropower projects.)

The GCMRC may also wish to expand their current monitoring of selected penstocks to additional units in the powerhouse as a means to assess differences between penstocks due to their location and orientation. While providing only part of the answer to the question of release quality in the tailwater, the information gained would provide valuable information on withdrawal zone differences and provide an informational backdrop for future operational responses due to the proposed temperature control device. Another alternative is to use periodic short-term (2-3 days) monitoring across the units under a wide range of operational conditions. Tests should be conducted to see if penstock, scroll case, and draft tube data are representative of actual river flows downstream.

As emphasis shifts from descriptions of reservoir processes and in-reservoir phenomena, effort can be re-invested in downstream reaches by conducting special studies designed to address information needs identified by the TWG and in support of the development of a water quality-ecosystem model (see the section on Considerations For Modeling).

For instance, an understanding of the relationship between operational change and organic production will be essential for addressing management issues associated with downstream biological resources. Such a study would involve establishing material budgets based on collection of representative water quality data at upstream (afterbay) and downstream (Lee's Ferry) points. The objective would be to monitor the productivity and respiration of the system using the water quality model. After the model was calibrated, it could be applied to the current monitoring in the river reach down to Lee's Ferry. This reach of river is very important for supplying organic matter and a food base for the Colorado River down to Lake Mead. The study could be organized by defining "operational seasons" based on climatic season, conditions above the dam, mode of operation at the dam, and/or river stage, and would logically be integrated with the on-going studies of light regime. The study would establish linkages between operational impacts (e.g., flow and stage, nutrient supply, physical perturbation, light regime) and primary/secondary production. Other similar studies addressing knowledge requirements of the water quality-ecosystem model should be designed.

Downstream: Relatively little effort is currently targeted against the downstream reach, defined as that portion of the Colorado River from Lee's Ferry to the headwaters of Lake Mead, with regard to water quality. The primary issues are similar to those for the reach from Glen Canyon Dam to Lee's Ferry–temperature and salinity regimes, and the import of food sources from upstream reaches. The temperature data collected by continuous monitors at selected locations through out the downstream reach are invaluable data for calibrating a water quality model for the Colorado River.

While the logistics of sample collection are difficult (limited access and time investment), every effort should be made to increase the sampling efforts in this reach of the system, as needed to calibrate a water quality model or to address hypotheses posed by fisheries managers and investigators. Coordination with efforts conduced by the USGS and Northern Arizona University should be explored. The Panel recommends that such sampling be linked to operational seasons (see comments above) that reflect climatic changes, reservoir and release water quality, and operations-related changes in hydrology. Sampling approaches and the incorporation of special, focused studies should be linked to the needs of the water quality-ecosystem model.

Continuous DO, conductivity, and pH monitoring along with periodic sampling such as that used for the tailwater is not likely to be needed in the downstream reach, i.e., continuous through out the year. If DO, conductivity, and pH data are needed for water quality modeling, water quality monitors can be deployed for short periods (7-10 days) and placed to monitor water quality lagged with time of water travel through the Colorado River. Automatic water samplers (e.g., ISCO samplers) can be used to track water quality through the downstream system. The time of travel can be determined using dye studies or estimated using a water quality model.

WATER SAMPLE PRESERVATION AND ANALYTICAL PROCEDURES—RESPONSES TO QUESTIONS II.E, II.F, II.G, II.H

Chemical Parameters: Are chemical analysis parameters appropriate to meet objectives? For example, is TKN an appropriate method of measuring total nitrogen in an oligotrophic reservoir?

Answer: Levels of the nitrogen and phosphorus in Lake Powell are within the oligotrophic to mesotrophic range. These moderate concentrations are easily measured by contract chemistry labs prepared for low level analyses and rigorous QA/QC protocols. However, most contract labs dealing with sewage and other high nutrient waters do an unsatisfactory job precisely measuring nutrients in dilute lake samples. The wide variation in phosphorus values in Lake Powell over the recent past call to question some of the reported measurements from this lake. We suggest that total phosphorus be measured on all samples using persulfate oxidation and a spectrophotometer with a 5- to 10 cm path length. Likewise, the TKN method will likely result in variable results at these low levels of nitrogen. The recent limnological literature suggests low level measurements of total nitrogen are best accomplished with persulfate oxidation and second derivative detection.

Panel member J. Jones samples a lake in Nepal with total nitrogen and total phosphorus values virtually identical to those in Lake Powell. Sample storage and transport has been a challenge in this remote location. The solution has been to archive lake samples for total nitrogen and phosphorus in 15 mL silicate glass culture tubes (10 mL samples in 15 mL tubes, but the volumes of both the sample and tube could be increased when shipping is less of an issue). Caps are secured to the tube with Teflon tape around the glass threads and the plastic cap is secured to the tube with plastic lab tape to prevent volume loss during shipping. Laboratory analyses are done in this same tube. Persulfate is added to the tube and it is autoclaved before the color reagent is added. Once color is developed, the solution is taken directly from the tube into a cuvette in the spectrophotometer. Remarkable replication has been found when three tubes are prepared from each lake sample. No preservatives are added to the phosphorus samples because there is no gas phase and we are measuring the total amount and not fractions. For total nitrogen, sulfuric acid is added to reduce the pH to < 2; the sample is neutralized prior to persulfate digestion. Lake samples for total dissolved nitrogen and phosphorus are filtered and then treated using this same approach. The week long Lake Powell sampling program shares some of the logistic problems faced in Nepal. Perhaps the approach used in Nepal could be adapted to handle nutrient samples from Lake Powell. Reviewer J. Jones is willing to process a reasonable number of split samples at the University of Missouri Limnology Lab as a check on contract labs used to process samples from Lake Powell.

Preservation Techniques: Are preservation techniques adequate or necessary? For example, is H_2SO_4 an appropriate preservative for nutrient samples? Is it necessary to store all major ion samples on ice? Is heating of chlorophyll samples to dryness an acceptable method of preservation?

Answer: Some of these points have been addressed above. The panel feels that measurements of total phosphorus and total nitrogen are sufficient to characterize nutrients in the quarterly samples from Lake Powell sites. Reducing the scope of nutrient analyses to this level will free resources for use in the tailwater and specialized studies. We are concerned that SRP and ammonium values reported to date may not be reliable, and see no reason to continue collecting information that may not be trustworthy. One consideration is to measure dissolved forms of nitrogen and phosphorus in the inflow samples and the monthly samples collected at Wahweap. The handling and shipping time for these samples is greatly reduced relative to samples collected from up-lake site. Proximity to Page, AZ and other locations with express delivery may allow samples to be packed in 'blue ice' and shipped to a contract chemistry laboratory overnight, thereby avoiding the need for acidification of samples for nutrient fractions.

Chlorophyll samples should not be filtered in direct light, nor should the filters ever be exposed to direct sunlight. We suggest chlorophyll filters be folded onto themselves and stored in an envelope in silica gel (color indicating material). The gel dries the sample and there is little loss of pigment. If possible, samples should be kept in a cool, dark location but this is not essential. Reviewer J. Jones uses this approach in remote locations (Nepal, Alaska, and others).

Sample Analysis QA/QC: The IWQP program samples the lake on both quarterly and monthly monitoring trips. Concerns have been raised over the adequacy of replication represented by this monitoring program. Adequate replication of sampling is thought to be implemented spatially and temporally by that fact that this is a long-term monitoring program. Further, as a long-term monitoring program, the emphasis has been deriving long-term trends rather than on research-specific questions. Given available resources, are there areas where the IWQP should redistribute its efforts to ensure better data resolution and reliability? What do you see as the greatest sampling weaknesses in the program?

Answer: The panel suggests that monthly samples be collected at the Wahweap site and that quarterly samples be collected at the up-reservoir sites but that nutrient measurements be limited to total nitrogen and phosphorus and that plankton be collected at three sites (see II.D). The quarterly sampling trips should be scheduled to represent lake processes–maximum inflow, minimum temperatures, maximum summer temperatures, etc. We also suggest that a Seabird or similar instrument replace the Hydrolab as a time saving measure. Spatial resolution could be readily enhanced through the use of the Seabird profiler (or similar instrument) with little additional commitment of resources. This could be of particular importance in critical zones, such as the river/reservoir transition zones

We strongly encourage that no less than 15% of all samples be duplicates (two laboratory samples from a particular lake site), replicates (replicate laboratory samples from a particular lake sample), spikes (standard additions to lake samples) and blind samples (known concentrations sent to the lab as blind samples).

Phosphorus Analyses: Efforts at nutrient monitoring have been frustrating, nutrient values, particularly phosphorus and ammonia levels, frequently fall below our lab's detection limits. While we have recently seen an apparent reversal in this trend for phosphorus, as well as our lab's increasing detection levels from 0.005 mg-P/L to 0.001-0.003 mg-P/L, the issue of detection limits for nutrient monitoring will continue to be a concern. The nature of our quarterly sampling trips results in a lag time of one to two weeks before samples can be sent to the lab for analysis, for our monthly sampling trips the lag time is 2-5 days. What recommendations would you have on preservation vs. non-preservation; searches for labs with better detection limits, or other strategies that might alleviate some of these problems?

Answer: Many of these points have been addressed in answers to questions II.D-G. Phosphorus detection is < 3 ug/L in most limnology laboratories. It is unreasonable to accept less from a contract lab. We suggest evaluating contract labs that routinely process low level nutrient samples and are accustomed to shipping and receiving samples from distant locations. Air transport from Page may cut shipping time.

DATA MANAGEMENT—RESPONSE TO QUESTION V

Question: Are there any recommendations for data management guidelines and use of analytical tools?

Answer: The physical and chemical data collected by the IWQP are similar to data regularly collected by other programs in the USGS, such as lake programs conducted by the Water Resources Division. The Panel believes that rather than trying to develop their own databases, the IWQP should try to incorporate their data into existing databases. One possibility would be to incorporate the data into the USGS, Water Resources Division databases. Continuous data, such as thermistor string data and future meteorological data, could be stored in the NWIS, ADAPS database and non-continuous water-quality measurements be stored in the NWIS, QWDATA database. This would enable the data to be archived and retrieved as necessary. Guidelines and procedures have been developed for these databases.

The IWQP has displayed and interpreted their data primarily using SURFER and SAS. The graphical representations of the data have enabled much to be learned about the physical and water quality dynamics of Lake Powell. The Panel commends the IWQP in their work in this area and has no suggestions to improve these graphical representations. The statistical analyses of the data using SAS is justifiable. Care should be taken when examining time series with data that includes measurements below the detection limits. Procedures on how to evaluate these data are described in Statistical Methods in Water Resources (written by D. R. Helsel and R. M. Hirsh, 1993, published by Elsevier).

WATER QUALITY-ECOSYSTEM MODELING—RESPONSE TO QUESTION VI.B PLUS ADDITIONAL PANEL RECOMMENDATIONS

Question: What priority should be given to developing, calibrating and collecting background data for a numerical simulation model such as CE-QUAL-W2?

Answer: The Panel believes that the highest priority should be given to modeling activities, both in the lake and downstream. The BOR has invested time and resources into the calibration of CE-QUAL-W2. While it is not clear why this particular model was chosen over other modeling approaches, it is acknowledged that if a laterally averaged approach is justifiable, then CE-QUAL-W2 should work as well as other models in this class.

The Panel believes a modeling approach is so important to the questions and information needs, that future modeling be conducted directly by the GCMRC, through the hire of a post-doc or similarly qualified individual. It would be the responsibility of this individual to calibrate, validate and set up the model in such a way that it could eventually be used directly by a range of scientists at GCMRP. The model outputs should also be linked to inputs for any downstream model that is developed, either as part of this person's work, or as part of the existing "conceptual model". This recommendation should not be construed as criticism of BOR's modeling to date. Rather, it is clear to the Panel that the questions that GCMRC needs to be addressing with a model are fundamentally different from those that BOR addresses. In addition, the modeling effort and the data interpretation would be considerably enhanced by the continuous contact between a full-time modeler and other staff at GCMRC.

As addressed previously, there needs to be an adjustment to present practices in order to collect the types of data required by a modeling approach. This includes consideration of the installation of meteorological equipment on the lake, the collection of inflow parameters (including flow, temperature, conductivity), and the collection of more time-series data (such as thermistor chain data). These data are needed for improving calibration of the model.

Additional discussion about modeling is presented under Programmatic and Institutional Findings and Recommendations.

Additional Considerations for Modeling: A cursory review of the INs that have a ranking of medium or high priority indicates that all of them can best be addressed using reservoir and river models.

Model selection is best approached by establishing selection criteria for the model to use for the river. The panel was given a copy of "Ecosystem Modeling for Evaluation of Adaptive Management Policies in the Grand Canyon" by Walters, et al. (2000) which describes the "conceptual model," but time did not allow for its review (a presentation on this model was not made to the Panel). The model appears to focus primarily on the energetics and the ecological linkages between the communities that make up the river system, and used as a hypothesis-testing tool. While there were connections between river flow and stage (and regressions for temperature and turbidity) the hydrodynamic component of this model appeared to be well short of the full dynamic modeling that is now common used for decision analyses for managing river systems.

Future management decisions will need to be made in the context of a very different set of operating conditions than what has prevailed in the past. Different lake levels, the possible use of a TCD, different flow regimes, different power demands, changing climate etc., may all make the value of past regressions questionable. It is strongly recommended that a model be developed and used for those variables that are readily predictable using current, deterministic engineering models (the time varying values of flow, stage, temperature). There are several candidate models that could accomplish this. This model would then provide a vehicle upon which to attach a light model, a water quality model, an ecological model, etc. The present "conceptual model" could well provide many of these latter components.

As it presently stands, the Panel is concerned that there is a significant disconnect between the physical processes that are initiated at the dam and the present modeling of ecosystem effects downstream. GCMRC should consider convening another panel to assist them in determining the best modeling approach for the river. Ideally, however, an experienced person responsible for the reservoir model might be suitably qualified to take the lead role in directing the river modeling activities.

A model should be viewed as a tool for how it can help make decisions about managing Glen Canyon Dam; it should not be an end-in-and-of-itself objective, but viewed in the overall context of the adaptive management process itself. Also, emphasis should be placed on applying the model to assist scientists and engineers in GCMRC, TWG, and AMWG in sufficiently making decisions, not on developing a model that represents all aspects of the real system. It should be noted and considered as policy that the accuracy of a model will always depend on what part of the system is being simulated, i.e., flow regimes and temperature can be simulated and even predicted with more reliability than biological effects. The order of accuracy for river water quality models is as follows:

1. 1-D flow regime (flow and stage),
2. temperature,
3. other water quality parameters (e.g., DO, turbidity and light, carbon, phosphorus, nitrogen, photosynthesis),
4. biological effects of water quality,
5. biological effects of habitat, and
6. biological effects of competitive fish species.

Another key consideration for modeling is to give initial priority to the "drivers" for the system (e.g., flow, water levels, temperature) being modeled as well as the key "linking" factors between the causes and effects (e.g., Glen Canyon Dam operations and flows/stage at various points downstream) that are being modeled. Fortunately, the first two or three in the above list fall in these two categories. Many decisions on water resources management in the United States have been based on models that only include the first two or three types of models, with biological considerations being addressed either externally to the model or through water quality and ecological models that are attached to the physical model.

A good model of flow and temperature can be applied years in advance of the more complex biological models, and it can assist the GCMRC, TWG, and AMWG significantly as soon as it is available. It would appear based on a cursory review of "steady flow" decision for operating Glen Canyon Dam in the year 2000 that an unsteady state model of flow and temperature for the Colorado River between Glen Canyon Dam and Lake Mead would have proven extremely useful and may have resulted in a more cost-effective decision for operations at Glen Canyon Dam without jeopardizing the biological objectives.

Modeling has proven to be invaluable for addressing environmental issues on major water resource systems. Following is a partial list of major water resource systems where water quality modeling has played a significant role in decision-making:

- The reevaluation of priority water uses for operating the entire TVA system of over 50 reservoirs;
- the Savannah River for two major reservoirs;
- the White River in Arkansas (perhaps the premier trout fishery in the U.S.);
- 200 miles of the Snake River as it enters Hells Canyon;
- the Holston River below Kingsport, TN;
- the Chattahoochee River Basin;
- the Alabama River Watershed;
- the Ohio River;
- the San Joaquin River;
- the Trinity River;
- the Hudson River;
- the Delaware River;
- the Houston Ship Channel; and
- Chesapeake Bay.

Most all of these modeling applications have been used in situations that are consistent with adaptive management concepts even though many were not applied under an adaptive management "program." The "adaptive management" process in essence has been applied under the Clean Water Act since its beginning in many Regions of EPA, and models have normally been a key tool where such processes have been employed.

PRIORITIES FOR SAMPLING—RESPONSE TO QUESTION VI.A

Question: Long-term programs inevitably go through periods of scarce funding. Additionally, upcoming events; such as the potential TCD (temperature control device) can result in pressure to reprioritize existing activities. In the face of such potential resource limitations, how would you prioritize elements of the IWQP into two categories: (a) essential & untouchable, and (b) lower in priority? Consider both parameters sampled as well as temporal and spatial sampling resolution.

Answer: The Panel offers the following general observations. However, as alluded to in responses to several other questions, the Panel thinks that priorities for sampling ought to be driven either by: (1) hypotheses that are developed and that need to be tested, or (2) the requirements of models of the system to improve GCMRC's capability to offer decision-makers the tools they need.

Essential and Untouchable monitoring sites:

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

Parameters that are considered essential:

- TN
- TP
- Chlorophyll
- TOC/POC
- Temperature, salinity/conductivity, DO and pH, turbidity

Lower Priority monitoring sites:

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

Parameters of lower priority:

- Major ions (have sufficient information)
- Plankton data

In addition to these considerations, the Panel recommends that the IWQP consider the monitoring approaches that are being employed by water resources organizations (especially the Corps of Engineers) and that are described in a report by Thornton and Kennedy (1999). This report covers the results of a workshop dealing with how to monitor reservoirs. They present a five-tier approach that includes monitoring for the following reasons:

1. tracking the environmental conditions of the resource;
2. determining environmental trends in the resource;
3. conducting diagnostic studies to determine the cause(s) for any problems in the resource (i.e., to determine the linkages between operations at Glen Canyon Dam and water quality responses in the Colorado River);
4. determining how to improve the resource; and
5. tracking performance measures for evaluating management measures.

This report (number AM-10) can be downloaded at the following site:

http://www.wes.army.mil/el/elpubs/wqtncont.html

The first two tiers serve as the basis for long-term monitoring. The third tier is important to ensuring that IWQP has the necessary information to properly interpret the results of long-term monitoring. The fifth tier adds additional measures (power operations, operations of a TCD, etc.) that track operating conditions implemented to improve the environment.

In addition to these considerations, the Panel believes that long-term monitoring is a major need for a resource like the Lake Powell/Colorado River system due to the decadal nature of the hydrologic cycle for this system in addition to considering that it is a managed system that is still undergoing engineering and operational modifications.

The Panel recommends that IWQP develop a long-term monitoring plan that can be maintained every year for about 20 years. The Panel also recommends that IWQP: (1) develop the linkages between Glen Canyon Dam operations and water quality in the Colorado River to properly interpret the results of long-term monitoring, and (2) track operating conditions implemented at Glen Canyon Dam to improve the ecosystem in the Colorado River.

ADDITIONAL FINDINGS AND RECOMMENDATIONS

TCD Withdrawal Zone Considerations

The Panel does not recall any information being presented about the determination of the withdrawal zone for the TCDs being considered. Withdrawal zones for hydropower intakes often are higher in the water column than might be assumed based on the elevation of the penstock intakes. Depending on the design and configuration of the intake structure, the withdrawal zone can be substantially above the elevation of the intake and result in the discharge from the project being warmer than might otherwise be expected. The Panel recommends that the GCMRC inquire about the considerations that the BOR has given to the withdrawal zone for the TCD designs being considered.

The Panel recommends that GCMRC use an acoustic Doppler current profiler to measure the withdrawal zone at several locations in the fo rebay for the current intakes for:

- several representative operating conditions,
- several representative turbine units,
- the most important period of the year with respect to thermal stratification, and
- appropriate timing for the desired temperature increases for the downstream fisheries.

During the course of these studies, it would be important to collect appropriate water quality data in the forebay as well as for the discharges from the dam.

PROGRAMMATIC FINDINGS AND RECOMMENDATIONS

ADEQUACY OF IWQP FOR MOs AND INs—RESPONSE TO QUESTION I.A

Question: Does the IWQP monitoring and research program address the stated management objectives and information needs? Are there any deficiencies in the current program that will prevent it from providing information to address the stated management objectives and information needs?

Answer: Science-based water resources decision-making can be envisioned as an information pyramid (see Figure 1). At the base of the pyramid, professionals from various scientific disciplines, such as zoology, hydraulics, water quality and many others, collect data and use the data to test hypotheses, determine trends, or to describe important processes that define the health of the Grand Canyon ecosystem. However, information collected by different disciplines, cannot by itself, be used to support water resources decisions because of the specificity of the scientific data relative to the general nature of the information needs for defensible water resources decisions. Before scientific data can be used to support water resources decision-making, it must be passed up through several additional levels in the pyramid where the data are summarized within disciplines and integrated across disciplines so that broad trends and findings can be passed upward to stakeholders and decision-makers for their consideration.

As the Panel understands the issues, difficult water resources decisions loom on the horizon for regional decision-makers. The future operations that need to be considered can best be addressed in terms of hydraulic and water quality variables. A range of widely accepted engineering models have been used to address such issues in many other settings. Though the setup and use of such models is non-trivial, it is well within the capability of current engineering practice. Use of these models could considerably ease the burden of the next level within the pyramid, the stake holders, Use of standard, engineering approaches to describe different future operations would considerably enhance the ability of stakeholders to understand and quantify how they are affected by different operational plans and facilitate trade-off analyses and discussions among stakeholders. Ultimately, the use of these models will increase the acceptability, equitability, and defensibility of decisions rendered by the apex of the information pyramid, the decision-makers, who make decisions to allocate water resources for overall societal benefits.

The review Panel can identify a number of research and monitoring studies that occupy the lower levels of the information pyramid. We commend the researchers for their diligence and enthusiasm in their individual studies. However, it is unclear how findings from individual studies will be integrated either within the subject program or how information will be integrated between the subject program and other programs within the larger GCMRC. Therefore, it is unclear how the data collected within the program will be passed upward in the information pyramid in a manner that can be used by stakeholders. Additionally, it is unclear how engineering or ecological models are being employed to support decision-making. The availability of nearly-calibrated CE-QUAL-W2 model for some variables that could be used as a foundation for integrating across program elements and thereby support decision-making for the reservoir. The Panel also noted the availability of the "conceptual model." It is not clear how these models compliment each other or how they fit within the larger fabric of the GCMRC.

Program management should begin development of methods integrating information across program elements to support future trade-off analyses and decision-support. In addition, program management should clarify how modeling will be employed to describe and evaluate water resource alternatives and how the present collection of studies will tie into and support the modeling effort. In particular, efforts should be made to defragment the existing studies and increase linkages between present and future studies under the purview of the GCMRC. We understand that many of the studies that could potentially provide valuable information to the GCMRC fall under the purview of other agencies. Leadership should be exercised by the management of the GCMRC to have input to the activities of other agencies to better logistically and financially support the activities of the GCMRC, particularly since the ROD was signed at the level of Secretary of the Interior. We also recommend that program management consider discussions with the TWG and AMWG to obtain feedback and guidance on how modeling could best be structured to address their information needs. This feedback could occur through regular reporting or through presentations made at program meetings. In addition, program management should consider the preparation of documents to explain their program to the public.

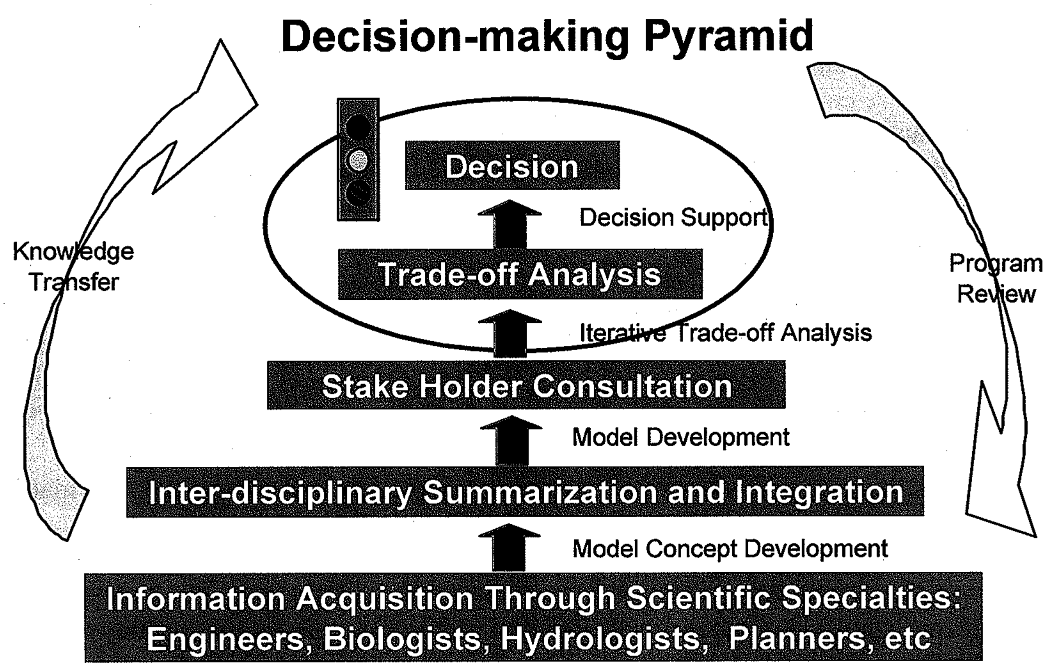

Figure 1. Science supports water resources decision-making by creating tools for selecting optimum alternative future conditions.

DOWNSTREAM DATA NEEDS—RESPONSE TO QUESTION I.B

Question: Can the data collected by the IWQP be used to evaluate effects of dam operation on downstream resources?

Answer: The present program structure is inadequate to evaluate effects of dam operation on downstream resources. Part of the reason for this conclusion by the panel may be associated with how the program was presented. It seems reasonable to expect the program structure to evolve so that as present information needs are met then old program elements will be replaced with new program elements. However, these new program elements were not presented other than for near-term plans.

The Panel considers that the evaluation of the effects of dam operations can best be understood and data needs best identified within a modeling framework. To the extent that a fully calibrated and validated reservoir model is not presently operational, and that a data set necessary to accomplish this has not been compiled to date, an evaluation of the effects of the dam cannot be made. The data collected by the IWQP is only part of the necessary data set.

The Panel recommends that program management consider a five-year program time frame formally starting in 2002 (the interval between program reviews), but actually getting underway during 2001. During this time frame the primary goals should be the collection of a full model data set, the calibration and validation of a reservoir model, and the transition to a mode of operation in which model results can supplant much of the present upstream data collection. Within this time frame, the program should be planned in a way that as existing information needs are met they are replaced by studies designed to meet new information needs (for example, greater attention on downstream effects) or by activities to integrate information. The following plan is an example of the type of phased approach the Panel would support.

```
P     Reservoir Research
H     |-----------------------------|
A                Calibrate W-2
S        |--------------------------------|
E                        Validate W-2
S                        |----------------|
            Increase Downstream Sampling/Calibrate Water Quality Model
                      |--------------------------------------------------------------------------|
                                                Develop & Use Tradeoff Framework
                                      |----------------------------------------------------------|
                                                                         Decision-Support
                                      |----------------------------------------------------------|

         FY01          FY02          FY03          FY04          FY05          FY06
YEARS →
```

It seems reasonable to the Panel that the program should progress from a reservoir data collection/summarization phase, to a reservoir simulation phase, to a downstream data collection/summarization phase, and finally to a downstream simulative/assessment/predictive phase.

IMPORTANCE OF RESERVOIR ECOSYSTEM—RESPONSE TO QUESTION I.D

Question: In your view, how important is understanding the reservoir ecosystem to the overall goal of the adaptive management program: "determining the effects of dam operations on downstream resources"?

Answer: The Panel considers an understanding of the reservoir ecosystem to be important to the overall goal of the AMWG. However, the Panel recognizes the need to refocus on downstream resources as understanding of reservoir processes evolves. The Panel's review of the documents and the presentations provided by the IWQP describing the present and recently completed work found that considerable progress has been made in understanding the upstream system so that studies in the reservoir can be de-emphasized in the future and those resources reprogrammed to the downstream resources.

The Panel recommends that the program focus on consolidating their understanding of reservoir processes and that the program work with BOR scientists to use the CE-QUAL-W2 model as the vehicle to consolidate their information needs. Therefore, the program could then use the model to describe reservoir processes of importance to the downstream reaches and reduce their reservoir program to the minimum necessary to obtain boundary conditions and validation information.

DOWNSTREAM SAMPLING—RESPONSE TO QUESTION I.E

Question: The bulk of the IWQP is focused on monitoring activities in the reservoir, forebay and tailwaters immediately below the dam. Downstream sampling has consisted mostly of mainstem and side-channel thermal monitoring, light penetration, suspended sediments and turbidity, with sporadic chemical sampling. Do you believe this is adequate to meet IWQP goals or should there be greater sampling of the downstream chemical and/or biologic environment?

Answer: We do not believe that the present sampling program for the downstream reaches are adequate.

The present research paradigm of collecting assorted water quality variables at a few scattered points within the GC cannot meet the INs of the AMG. The Panel recommends that the IWQP consider developing an overarching concept based on an expansion of the methods used by Marzolf in the Colorado River upstream from Lee's Ferry.

Data collection should be divided between two types. First, there is a need to collect the type of data needed to support a model (a linked hydrodynamic/water quality/ecological model) of the river downstream of Glen Canyon Dam. This would include time series of stage, flow, temperature, turbidity, dissolved oxygen, etc. These parameters are similar to what is already being collected; however, greater attention needs to be given to the locations necessary to provide sufficient calibration and validation data. Similarly, the duration of instrument deployments needs to be more fully considered. For example, dissolved oxygen, light and turbidity sensors (which require frequent cleaning and calibration) may only need to be deployed for short periods to characterize different flow conditions or seasons. On the other hand, temperature and stage instruments could be permanently installed at several locations.

The second data type required relates to specific experiments that are targeted at addressing specific knowledge gaps. These must be filled in order to allow construction of an appropriate model. For example, the energy that drives the ecosystem can be imported, fixed within the ecosystem or some combination of the two. Changes in how energy is fixed within the system can have a substantial effect on the natural resources within the system. Presently, it appears that the base of the food web in the system may be provided by the periphyton growing on aquatic macrophytes that grow in the reach down to about the Paria River inflow. It is clear that the macrophytes and the periphyton and Gammarus that depend upon them are sensitive to discharge patterns at the dam. In addition, the community has been going through succession and cause is unknown but could be important. Productivity in this reach can be monitored using continuous DO, pH, and temperature data collected in the tailrace and at Lee's Ferry. This approach was developed by Howard T. Odum in the 1950s and has been used for a large number of river systems by applying DO models that incorporate photosynthesis and respiration caused by aquatic plants. This particular issue is of such fundamental importance that we suggest that the IWQP devise a sampling program that addresses the specific issue of the biological functioning of the system between Glen Canyon Dam and Lee's Ferry. See our response to question VIII.B for additional details.

CONTRACTING VS. IN-HOUSE—RESPONSE TO QUESTION III.A

Question: Is this program most efficiently conducted in-house or should it be contracted out?

Answer: Program management should consider their program as evolving over a five-year time frame as data needs are met and new sources of uncertainty are identified. Senior staff within the program should shift their focus to higher levels of the pyramid shown in Figure 1 and to interaction with the TWG and AMWG so that the information provided by the program can be used directly and efficiently by decision-makers and stakeholders.

As senior staff move to more of an integrating and interpreting function within the program, then their more routine tasks, such as collection of monitoring data, can be back-filled by contracts or by staff from sister agencies. However, the Panel would not want to see this approach implemented unless the current level of quality field word can be maintained.

PROGRAM MANAGEMENT—RESPONSE TO QUESTION III.B

Question: Is there adequate scientific direction and program management to ensure the most efficient and scientifically credible program.

Answer: The Panel feels that scientific direction and program management could be improved for efficient and scientific execution of the program.

Program management should demonstrate the leadership necessary to emphasize program linkage/integration, formulation of hypotheses consistent with AMWG and TWG management objectives and information needs, information integration and technology transfer within the overall GCMRC.

Also, the Panel understands that the GCMRC hires contractors that are not always required to release all the data that they collect. The Panel recommends that this practice be avoided and that, if needed, the GCMRC hire their own contract employees to collect such data. Continuation of this practice can jeopardize the credibility of the GCMRC as well as its cost-effective performance in the event such data become crucial to decision-making for operations at Glen Canyon Dam. All data collected by the GCMRC should be available for anyone to evaluate on their own.

INTEGRATION OF INTERAGENCY DATA AND PEER-REVIEWED PUBLICATIONS—RESPONSES TO QUESTIONS VI.B, VIII.A

Question: What priority should be given to the integration of interagency data and the production of peer-reviewed publications?

Answer: The nature of the GCMRC's responsibility deals with a reservoir and river system that requires an emphasis on integration of most of the information that is collected and generated through models and other data analysis approaches such as presently employed. Also, most of the information generated is related to cause-effect relationships between operations at Glen Canyon Dam and the ecosystem of Lake Powell and the downstream Colorado River. Hence, integration of information and interagency data must be among the highest of priorities. As discussed in previous questions, modeling and the development of testable hypotheses provides a focus for integration efforts.

Also, by its nature the IWQP has to generate more reports than most organizations since the results of its work are used by other organizations. In essence, the GCMRC is a high-level service provider to the AMP which deals with high-value issues. It is assumed that other review panels or the Science Advisory Board will have a broader scope of responsibilities that will address the question regarding peer-reviewed publications. However, certainly the GCMRC would incorporate some approach to peer reviewing their results as part of a QA/QC procedure for their end products.

PRIORITIZATION OF FUTURE EFFORTS—RESPONSE TO QUESTION VIII.B

Question: Based on what you have learned over the course of the PEP, where do you feel our efforts should best be directed and prioritized to best address the MOs and INs provided by the AMWG?

Answer: Sufficient data and information has been collected to develop hypotheses about the system and the expected impacts of operational changes at Glen Canyon Dam. Much of the information needed to begin modeling the reservoir and the river is available, although the information required to address some of the issues in the INs is not yet available. The establishment of hypotheses and the application of models to the water resource issues of the AMP is critical to the efficiency and timely effectiveness of the GCMRC in meeting its mission.

ADDITIONAL FINDINGS AND RECOMMENDATIONS

Observations Regarding the IWQP Personnel

. The Panel made the following observations in the process of the review:

- The IWQP personnel are technically capable, conscientious, energetic, experienced, as well as professionally and personally interested in the Glen Canyon/Grand Canyon system.
- The IWQP has produced good products on the results of their monitoring and analyses. Their reports are professionally prepared using state-of-the-art data analyses.
- The staff desires to develop and/or apply tools (e.g., models) and collect data needed to assist AMP in making management decisions.
- The staff desires to determine linkage between Lake Powell inflows and effects on water quality in the forebay and downstream from Glen Canyon Dam.

The (Acting) Biological Resources Program Manager is seeking to improve management of the IWQP by providing leadership to do what is best for the program and for the AMP. Dr. Ralston spent much time with the Panel and challenged the Panel to provide a meaningful review for the IWQP.

Hire A Modeler And Convene A PEP To Assist The IWQP In Developing Management Principles For Modeling

The Panel recommends that the vacant Post-Doc (as shown in the Biological Resources Manager on the proposed organization chart dated 10/5/00) be filled by someone with an academic background in water quality modeling. This individual should be capable of providing direction on model selection criteria and approaches as well as providing a foundation of operating principles and philosophies for establishing a premier modeling organization within the

GCMRC. This PEP could also provide insights to the GCMRC on how models have been used for decision-making on water resource issues and in conjunction with adaptive management processes (or similar processes) and how they might be used by the GCMRC.

Agreement with the NRC Downstream Report

The NRC report presents several findings that are particularly pertinent to the IWQP that the Panel agrees with and thinks are worthy of noting in this report (note that the bold font in the following items is bold in the original report):

1. ***The Core Adaptive Management Experiment.*** "Clear articulation of this core experiment (i.e., as presented in the ROD linking dam operations to responses in the Colorado River ecosystem) is needed to guide science and monitoring and to focus discussions among stakeholders (including the TWG, AMWG, and the GCMRC). **The GCMRC should clearly articulate the core adaptive management experiment in the Grand Canyon and, in particular, the hypothesized relations between dam operations, ecosystem responses…"**

2. ***Scientific Basis For Trade-Off Analysis And Decision Support Systems.*** **"It should be recognized that adaptive management for the Grand Canyon ecosystem will require trade-offs among management objectives favored by different stakeholder groups. It is recommended that the…Center begin to develop decision support systems and methods. The Center's revised Strategic Plan should include a strategy for scientific evaluation of management alternatives, both in terms of ecological outcomes and satisfaction of stakeholder groups…"**

3. ***Ecosystem Science and Monitoring.*** "…Although central to the Center's mission, a well-defined monitoring program has not yet been articulated. **Development and implementation of a detailed, long-term monitoring program should be a high priority for the Center…"**

INSTITUTIONAL FINDINGS AND RECOMMENDATIONS

COMMENTS ON INs AND THE ROLE OF THE GCMRC

There is no indication that the cost, feasibility, cost-effectiveness, level of significance in decision-making, "critical path" considerations, and potential for success were taken into account in developing the individual INs and level of priority that should be given to them. The Panel believes the GCMRC should consider these factors in developing plans for addressing the INs and provide feedback to the TWG and AMWG on the implications of implementing the INs. The GCMRC should consider giving higher priority to the MOs, and as technical experts on Lake Powell and the downstream Colorado River provide their best plan for addressing the MOs while giving significant consideration to the INs. As recommended in the NRC report, "Downstream…" the GCMRC should develop testable hypotheses that relate to Glen Canyon Dam operations and related environmental effects. Where the GCMRC determines that the IN priorities are inconsistent with original rankings, they should work with the TWG and AMWG and provide their reasoning for the GCMRC's reevaluations.

The Panel believes that all planning by the GCMRC needs to give major consideration to the original goal identified in the ROD for selecting a preferred alternative: the "preferred alternative was not to maximize benefits for the most resources, but rather to find an alternative dam operating plan that would permit recovery and long-term sustainability of downstream resources while limiting hydropower capability and flexibility only to the extent necessary to achieve recovery and long-term sustainability." It would appear that this goal provides the key foundation and guiding principle for planning the GCMRC's plans through the adaptive management process for the AMP. This goal is consistent with trends across the United States for the management of hydropower projects.

***The IWQP's position within the AMP calls for it to play a servant-leader role as well as a broader role*:** the GCMRC plays the only role as the service provider for the AMP; but, they also are the organization with the most resources, most information on linkages between Glen Canyon Dam operations and environmental effects, and highest stake by putting their reputation on the line for planning/performing efficient and effective technical approaches to achieve the goal of the ROD. Hence, they need to play a major leadership role within the AMP.

IWQP needs to consider the traditional role of water quality management in addition to their technical sampling and data analyses. Water quality programs often include the role of developing water quality management strategies to improve the environmental aspects of water resources for the benefit of various water uses. They play role of linking reservoir operations and environmental resources. In this role they not only collect and analyze data but also get involved in the management aspects of the system. As discussed in several areas of the preceding sections, the IWQP would need to broaden the scope of their present activities so that the are in better position to offer assistance to the AMWG and TWG to improve their processes of decision-making.

We recommend that the GCMRC promote the concept of "cost of science" to agency partners and stakeholders. For example, the cost in benefits foregone to test a particular scenario can be measured in tens of millions of dollars. The cost of developing a modeling capability to allow many scenarios to be simulated is considerably less. From a total "cost of science" standpoint, it is more defensible to understand upstream limnological processes and downstream riverine processes to the level that they can be described mathematically or statistically. It is less defensible to have a surface understanding of these processes and then utilize "operational experiments" to select optimum dam operations. The total "cost of science"–or perhaps the benefits foregone if science is not conducted in an efficient and timely fashion–is not presently given the priority it deserves within the AMP. The "cost of science" concept needs to be integrated across agency partners.

FOREBAY MONITORING—PROPOSED FOR THE WHITE CATEGORY

As discussed in the answer to question II.C, the forebay (Wahweap) station needs to be considered differently than the other lake stations. The forebay profile represents in many instances the best approximation to the upper boundary condition of the downstream river. Another main reason is that potential water quality problems for the downstream can be forecasted and therefore avoided using data only from the forebay. Additionally, IN 5.4 is in the "white category" and calls for a very wide range of information on the lake that can only be addressed if data are collected on the lake. Finally, the Panel agrees with the NRC "Downstream" report that rigid definitions of geographic scope will hinder the accomplishment of AMP objectives (see the quote from the "Downstream…" report in item 2 of the following section entitled, "Agreement with the NRC Downstream Report"). For these reasons, <u>the forebay station should be considered as belonging in the "White category".</u>

MODELING APPROACH WITH BOR

The BOR has invested considerable time and funding in applying the CE-QUAL-W2 model to Lake Powell. While they are still in the process of improving the model, the efforts required for this endeavor would be required for any model that was used to accomplish the same purposes. The CE-QUAL-W2 model is considered by many to be the "work horse of the industry" and can be used to address the INs identified by the TWG. The GCMRC needs a model for Lake Powell, and it is only prudent that they use the model that the BOR is applying to Lake Powell. The Panel recommends that the two organizations use the CE-QUAL-W2 model, but that each organization apply the model based on their respective organizational objectives. It is recommended that they exchange inputs, runs, findings, etc., to save time and money to meet their respective objectives as well as to review the basis for each other's findings. If each organization has CE-QUAL-W2 and commercially available software interfaces to use CE-QUAL-W2, then input and output files can be shared among the agencies through e-mail exchanges between distant locations.

The following is a list of reasons the GCMRC needs to use the model:

1. to develop monitoring plans;
2. analyze results of monitoring efforts;
3. to adjust monitoring plans as needed;
4. to establish and test hypotheses;
5. to develop cause/effect linkages between operations of Glen Canyon Dam and environmental effects in Lake Powell; and
6. to provide the information that the AMWG and TWG needs for making decisions about operations and design considerations for Glen Canyon Dam;
7. to examine the effects of major changes in operations, climate change and other conditions for which prior experience does not exist.

AGREEMENT WITH THE NRC DOWNSTREAM REPORT

The NRC report presents several findings that are particularly pertinent to the IWQP that the Panel agrees with and thinks are worthy of noting in this report (note that the bold font in the following items is bold in the original report):

1. ***Management Objectives and Information Needs.*** "The 1998 Strategic Plan listed 36 management objectives and 176 information needs. Some are hard to understand, redundant, or not measurable; and some information needed for ecosystem...analysis is not included. There are few cases of cross-program linkages. The lack of a clear and coherent set of management objectives and information needs makes it difficult to design or test adaptive management experiments. **The Center...should work with the TWG to develop a revised set of management objectives and information needs. These should be linked with testable hypotheses and situated within an internally consistent understanding of the ecosystem, for consideration by the AMWG."**

2. ***Geographic Scope of Center Programs.*** **Rigid definitions of geographic scope will not serve the AMP well. After clearly defining the Program's geographic focus, decisions about geographic linkages with adjacent areas and larger scales should be made on a case-by-case basis, considering ecosystem processes, management alternatives, funding sources, and stakeholder interests.**

Appendix A

Questions/Issues for The Integrated Water Quality Program (IWQP) Protocol Evaluation Panel

I. Program Focus and Scope

A. Does the IWQP monitoring and research program address the stated management objectives and information needs? Are there any deficiencies in the current program that will prevent it from providing information to address the stated management objectives and information needs?

B. Can the data collected by the IWQP be used to evaluate effects of dam operation on downstream resources?

C. Given political constraints with the AMP (i.e. focus on effects of dam operations on downstream resources), is the monitoring program adequate to address processes within the reservoir?

D. In your view, how important is understanding the reservoir ecosystem to the overall goal of the adaptive management program: "determining the effects of dam operations on downstream resources."

E. The bulk of the IWQP is focused on monitoring activities in the reservoir, forebay and tailwaters immediately below the dam. Downstream sampling has consisted mostly of mainstem and side-channel thermal monitoring, light penetration, suspended sediments and turbidity, with sporadic chemical sampling. Do you believe this is adequate to meet AMP goals or should there be greater sampling of the downstream chemical and/or biologic environment?

II. Sampling

A. Repeated sampling of "historic" stations has been a guiding principle within the IWQP rather than random sampling, with additional sampling where conditions are most dynamic (i.e., transitional zones). Balancing the history of a station with the need to adequately represent sites by significance based on volume or effect presents a challenge to the sampling program. How would you rate the adequacy of the sampling resolution?

B. There are a number of potentially important parameters that the IWQP monitors inconsistently or not at all. These include:

- light penetration
- trace metal concentrations

- sediment accumulation and makeup
- BOD
- diurnal plankton migration
- primary production over depth
- sidebay dynamics and main channel interactions

Alternately, there may be parameters currently monitored that are under-used or of lesser Importance (e.g., major salt ion analyses). How would you prioritize the key parameters that should be monitored by the IWQP in light of the existing management objectives and information needs?

C. Is the existing sampling program adequate with respect to the location, number and frequency of sampling, as well as with respect to the parameters monitored? If not, what changes would you recommend and why?

D. Is the sample design and level of identification of plankton samples appropriate? Are the proper analyses being performed on these data? Is it necessary to archive all plankton samples? If so, what techniques should be employed to ensure future utility of the samples?

E. Are chemical analysis parameters appropriate to meet objectives? For example, is TKN an appropriate method of measuring total nitrogen in an oligotrophic reservoir?

F. Are preservation techniques adequate or necessary? For example, is H_2SO_4 an appropriate preservative for nutrient samples? Is it necessary to store all major ion samples on ice? Is heating of chlorophyll samples to dryness an acceptable method of preservation?

G. The IWQP program samples the lake on both quarterly and monthly monitoring trips. Concerns have been raised over the adequacy of replication represented by this monitoring program. Adequate replication of sampling is thought to be implemented spatially and temporally by that fact that this is a long-term monitoring program. Further, as a long-term monitoring program, the emphasis has been deriving long-term trends rather than on research-specific questions. Given available resources, are there areas where the IWQP should redistribute its efforts to ensure better data resolution and reliability? What do you see as the greatest sampling weaknesses in the program?

H. Efforts at nutrient monitoring have been frustrating, nutrient values, particularly phosphorus and ammonia levels, frequently fall below our lab's detection limits. While we have recently seen an apparent reversal in this trend for phosphorus, as well as our lab's increasing detection levels from 0.005 mg-P/L to 0.001-0.003 mg-P/L, the issue of detection limits for nutrient monitoring will continue to be a concern. The nature of our quarterly sampling trips results in a lag time of one to two weeks before samples can be sent to the lab for analysis, for our monthly sampling trips the lag time is 2-5 days. What recommendations would you have on preservation vs. non-

Appendix B

Resources Used

"Assessment of Impacts of Glen Canyon Dam Operations on Water Quality Resources in Lake Powell and the Colorado River in Grand Canyon (Draft)," Susan Hueftle and Bill Vernieu, March 5, 1998

Downstream—Adaptive Management of Glen Canyon Dam and the Colorado River Ecosystem, Committee on Grand Canyon Monitoring and Research, NRC, 1999

"Experimental Flood Effects on the Limnology of Lake Powell Reservoir, Southwestern USA," Susan Hueftle and Lawrence Stevens, 2000 (accepted for publication in Ecological Applications)

"GCMRC Integrated Water Quality Program," Bill Vernieu and Susan Hueftle, June 24, 1999

Presentations by the following individuals on November 30, 2000: Barry Gold, Nancy Hornewer, Barbara Ralston, Jerry Miller, and Mike Yard.

"The IWQP Annual Report for Water Year 2000," Susan Hueftle, September 2000

"Water Quality below Glen Canyon Dam—Water Year 2000 (Draft)," Bill Vernieu, October 25, 2000

Appendix C

The Panel

Jack Jones, Professor of Limnology and Chair, Department of Fisheries and Wildlife Sciences, School of Natural Resources, University of Missouri, Columbia. He received M.S. and Ph.D. in Limnology and Water Resources from Iowa State University, Ames and has been on the faculty at the University of Missouri for 25 years. He teaches Limnology and Water Quality Management courses. His research interests focus on quantifying factors that control algal biomass in freshwaters. He has worked on algal biomass in streams and reservoirs in the Midwest and has worked on nutrient-algal biomass relations in Alaska and Costa Rica. In Asia (Nepal, Thailand and Korea) he has described the role of the seasonal monsoon on lake trophic state and processes.

Robert H. Kennedy is a Research Limnologist and the Leader, Limnology and Water Quality Research Team, Environmental Laboratory (EL), Engineer Research and Development Center (ERDC), Vicksburg, Mississippi; he also serves as the Acting Chief, Environmental Processes Branch, EL, ERDC, Corps of Engineers. He received a Ph.D. degree in Biological Sciences from Kent State University in 1978. His current research interests include reservoir limnology, water quality management for reservoirs and lakes, modeling, and methods for assessing spatial aspects of limnological processes.

John Nestler is a Research Ecologist and Leader of the Fisheries Engineering Team within the Water Quality and Contaminant Modeling Branch, Ecosystem Processes and Effects Division, Environmental Laboratory, Corps of Engineers, Vicksburg, Mississippi. He received a B.S. degree in Biology from Valdosta State College in 1972, M.S. degree in Zoology from the University of Georgia in 1976, and Ph.D. in Zoology from Clemson University. His work includes describing, predicting, assessing, and reducing the effects of reservoir operation on inpool and downstream natural resources. He has authored or coauthored over one hundred professional publications and hold seven patents with another three patents pending. He is a Certified Senior Ecologist; an Adjunct Professor at the Institute of Ecology, University of Georgia; Adjunct Professor at the Iowa Institute of Hydraulic Research, University of Iowa; and an Associate Editor of Regulated Rivers.

Dale M. Robertson, Research Hydrologist, U.S. Geological Survey, Water Resources Division, Middleton, Wisconsin (1991). He received M.S. and Ph.D. in Limnology and Oceanography from the University of Wisconsin-Madison. His research interests and activities focus on physical limnology; water-quality modeling; influence of environmental factors, watershed management strategies, and in-lake management alternatives on the water quality of rivers and lakes; ice as climatic indicators; effects of artificial destratification; and regional loading estimates. He is presently leading interdisciplinary studies on several lakes in the Midwest, involved in modeling the effects of aeration in a proposed deep reservoir for Chicago, and involved in determining more effective ways to spatially and temporally sample streams and rivers.

Richard J. Ruane, President, Reservoir Environmental Management, Inc. (1995). He was with TVA 28 years and last served as Senior Environmental Engineer for Water Resources and Principal Technical Advisor for the Reservoir Releases Improvement Program. He received BS and MS degrees in Civil and Environmental Engineering from The University of Texas at Austin. He has been involved in all aspects of water quality management for water resources systems, primarily in relation to large reservoir projects. His main experience has been in monitoring, assessments, modeling, and management of reservoirs to address various water uses and a wide range of water quality and biological issues. He's participated in managing or improving the water quality of over 50 reservoirs across the United States, Spain, and South Africa/Lesotho.

S. Geoffrey Schladow, Professor of Water Resources and Environmental Engineering, University of California, Davis. His research interests are on exploring the linkages between fluid mechanics, water quality and ecological system management. His work has focused on both field and modeling studies in lakes, reservoirs, rivers and estuaries. These projects are typically interdisciplinary in nature, and are directed at the watershed or system scale. He teaches classes in Water Quality Modeling; Mixing Processes in Lakes and Reservoirs; and Engineering Hydraulics. He has been involved in modeling lakes and reservoirs in the US, Canada, Australia, Spain, Israel, Malaysia, Taiwan, Japan and Cameroon.