Grand Canyon Monitoring and Research Center

Integrated Water Quality Program

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GRAND CANYON MONITORING AND RESEARCH CENTER INTEGRATED WATER QUALITY PROGRAM

LIST OF FIGURES

LIST OF TABLES

Abstract.

The Grand Canyon Monitoring and Research Center Integrated Water Quality Program (IWQP) addresses information needs of the Glen Canyon Dam Adaptive Management Program (AMP). The primary goal of the IWQP is to describe and understand the influence of dam operations on water quality in Lake Powell and Glen Canyon Dam releases and its effect on downstream resources. This goal will be met by maintaining a long-term program of basic water quality data monitoring, defined as the periodic measurement of a consistent, repeatable set of common water quality parameters from an integrated network of sites from Lake Powell through the Grand Canyon. The four monitoring components are quaterly reservoir sampling, monthly and continuous forebay and tailwater sampling and downstream sampling. The data will be collected according to standardized monitoring protocols and maintained in a common database. Necessary research will be also be conducted based on specific hypotheses to fully address specific INs, form linkages with other resource components, and to evaluate protocols and methodologies. The four basic long-term monitoring elements of the GCMRC IWQP will be carried through Fiscal Year 2000 and beyond, as the need for this information continues. The research component will be based on prioritized INs and integrated with other resource areas (e.g., aquatic food base, native fish, and trout). This report provides a description of the four proposed monitoring and supporting research activities

In addition to the monitoring and research activities outlined, several areas of work that either require additional focus or that are associated with the AMP are identified (e.g., database management, BHBF's, Temperature Control Device). The components are either proposed for FY 2000 and 2001, or simply indicate that some activities will require additional data collection efforts beyond those currently proposed. It is anticipated that progress in these additional focus areas will result in refinements to the existing monitoring program, that will result in more cost-effective execution of the program, better definition of informational requirements, increased data availability and utility, and better feedback to management objectives.

The IWQP can be divided into a physical/chemical and biological component. Common physical and chemical parameters of water quality will be routinely collected during the measurement of a reservoir profile, continuously in the tailwater below Glen Canyon Dam, and in conjunction with the collection of all chemical samples. These measurements will include temperature (^{o}C), specific conductance (μS), pH, dissolved oxygen (mg/L), and turbidity (NTU). All of these parameters are identified as important for understanding linkages between reservoir, operations and downstream water quality. The biological component characterizes, in both the lake and the tailwaters, long-term, seasonal, and spatial trends in abundance, community structure, and primary and secondary productivity. It is designed to accomplish the following: quantify primary productivity in the reservoir and tailwaters; use biological indicators to evaluate water quality trends; and quantify secondary productivity of the reservoir and tailwaters. Collectively, this program will provide further understanding of linkages between dam operations, water quality, and the aquatic ecosystem of the Colorado River.

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Chapter 1 INTRODUCTION AND BACKGROUND

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

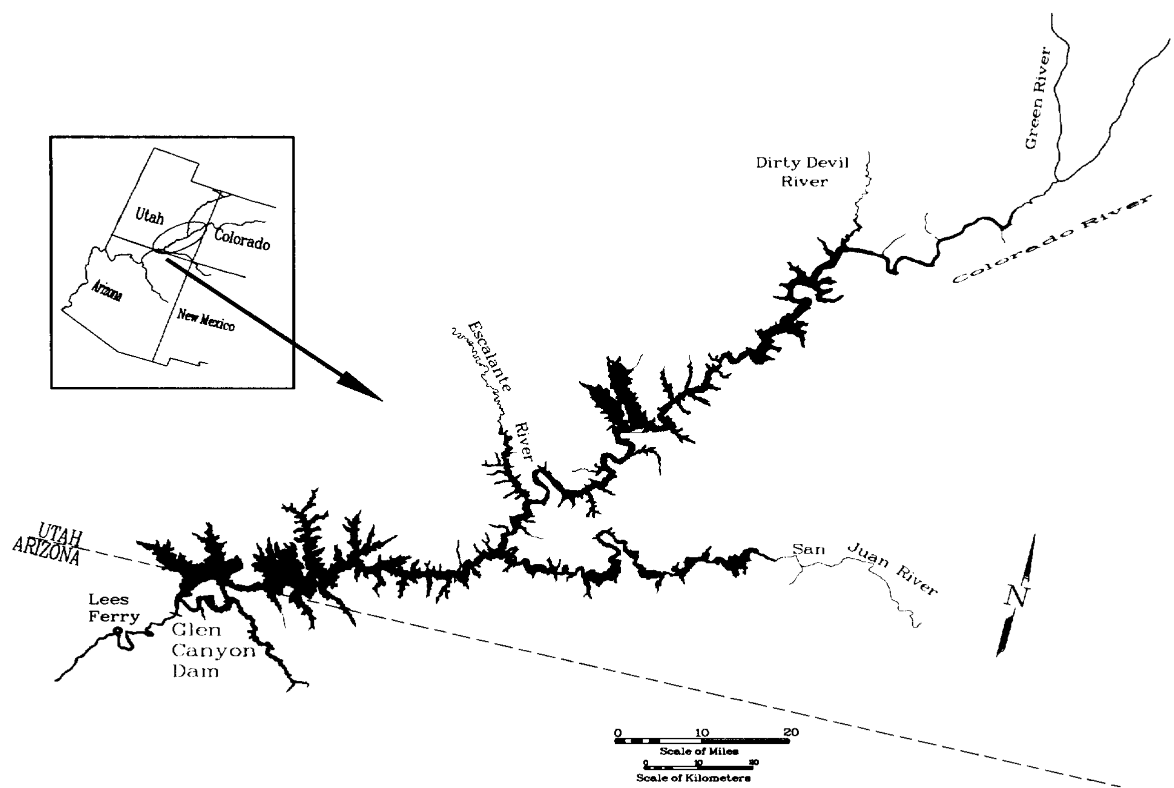

Figure 1. Lake Powell geographic setting and major tributaries

Purpose and Scope

The purpose of this report is to present an integrated water quality monitoring and research program that addresses information needs of the Glen Canyon Dam Adaptive Management Program (AMP). Information collected from this program will provide further understanding of linkages between dam operations, water quality, and the aquatic ecosystem of the Colorado River.

This report provides a description of proposed monitoring and research activities and areas of focus for FY 2000 and 2001. The report contains a brief discussion of the role of the Grand Canyon Monitoring and Research Center (GCMRC) Integrated Water Quality Program (IWQP) within the context of the AMP. The report also describes, in detail, the methodology of the proposed long-term program (Appendix B).

Water Quality Monitoring and Adaptive Management Information Needs

The purpose of the IWQP is to address the various water quality-related Information Needs (INs) developed by the Technical Work Group (TWG) to meet the Management Objectives (MOs) of the Adaptive Management Work Group (AMWG) for adaptive management of the Colorado River ecosystem.

MOs and INs were developed by the TWG and recommended for approval by the AMWG on July 21, 1998. MOs are defined as desired future resource conditions obtainable within the Modified Low Fluctuating Flow alternative prescribed by the Secretary of Interior's Record of Decision (ROD) (October, 1996) on the Operation of Glen Canyon Dam Final Environmental Impact Statement (GCDEIS) (USBR, 1995). INs describe monitoring, research, or information management requirements to evaluate the effects of the Secretary's actions on downstream resources and refine management approaches.

Several INs currently exist that relate to water quality for Lake Powell and downstream resources. Some of these INs relate solely to downstream resources and are met by monitoring activities conducted below Glen Canyon Dam (White Category). Others relate to downstream resources but are addressed by activities conducted upstream of Glen Canyon Dam (Gray Category). Still others relate primarily to resources upstream of Glen Canyon Dam and can be met by monitoring and research conducted upstream of the dam (Black Category). These categories are discussed in further detail in Appendix A. The grouping of INs into these categories was an attempt to separate activities that address downstream resources based on where these activities were conducted so that appropriate funding sources could be identified.

The following summary of water quality-related INs lists the text of the specific Information Needs in the White, Gray, and Black categories, by resource area, along with a description (in italics) of how the IWQP addresses the IN. These are also presented in Table 1.

The INs listed below represent a subset of the entire collection that has direct links between water quality and the given resource of concern. The IWQP has been designed to provide data in support of these INs as described below. In some cases, the IWQP provides all of the data required to address an IN and we describe these as water quality-related INs that are directly addressed by the IWQP. In other cases, the IWQP provides baseline data in support of a water-quality IN with the full understanding that additional data may be required. This additional data will be developed within the context of a specific research project addressing that IN and we describe these as water quality-related INs that are indirectly supported by the IWQP. We also acknowledge that some INs can only be fully met through research projects that collect their own water quality data in a manner that is linked spatially and temporally to project specific research activities. Finally, some INs are not addressed, such as in cases where the IN is deemed to be outside the scope of the IWQP, where other studies already address the IN, or the IN has received very low priority by the TWG. The IWQP is intended to provide basic, consistent long-term water quality monitoring and associated research activities to address the INs described below within the financial limits of the program.

The IWQP was developed by starting with the INs. We next evaluated the data required to meet a given IN and determined whether this IN could be met through a monitoring or research activity. Following this step, we compared the data needs with ongoing water quality activities and developed the plan presented here. As discussed above, within the specified budget limitations, we have designed a plan that directly or indirectly addresses the specified INs. Finally, as described in Chapter 2, this program will undergo a protocol evaluation panel (PEP) review in FY2001.

Overall priorities, as determined by the TWG on 4/28/98, are listed for each IN. These were arbitrarily divided into three categories based on the number of votes received out of a total of fourteen: High (9-14), Medium (5-8), or Low (0-4). Based on a memo from the GCMRC Chief to the TWG dated 5/5/98, "...those information needs ranking highest, between 8 and 14, were the information needs that this group of stakeholders felt needed to have monitoring and research activity started immediately, that is, within 2000 and 2001. Those information needs having a ranking of 0 to 4 are information needs that this 14 member stakeholder group generally felt could be delayed to 2002 or 2003 and still provide value to the Adaptive Management Process."

White Category

The following INs relate to downstream chemical and biological water quality resources and are addressed by activities conducted downstream of Glen Canyon Dam.

Biological Resources

A1 - Aquatic Food Base

IN 1.1 Determine status and trends in aquatic food base species composition and population structure, density and distribution and the influence of ecologically significant processes (High Priority-10)

IN 1.2 Determine the effects of past, present, and potential dam operations under the approved operations criteria on the aquatic food base species composition, population structure, density, and distribution in the Colorado River ecosystem (High Priority-10)

Assessment of the aquatic food base in the Grand Canyon ecosystem is a complicated task requiring the integration of information across several resources areas. The IWQP will support these information needs by providing a record of status and trends of water quality components in Glen Canyon Dam releases and changes occurring downstream. These components that directly affect the aquatic food base include temperature, nutrient concentration, water clarity, and biological composition. Monitoring these components in Lake Powell provides information on the quality of current and future releases as well as that available from the operation of alternative release structures.

A2 – Trout

IN 2.6 Define criteria (e.g., temperatures, flow regimes, contaminants, metals, nutrients) for sustaining a healthy rainbow trout population in Glen Canyon. (Low Priority-4)

Definition of criteria for trout requires, in part, an analysis of past and current water quality conditions under which the trout population in Glen Canyon exists. The water quality components of these criteria support life, affect behavior, and determine recruitment success for trout and other fish populations. The IWQP supports this information need by ensuring the appropriate water quality data is available to downstream fishery programs. Information on metals and contaminants is not currently provided by the IWQP program but is addressed by USGS NASQAN monitoring at Lees Ferry.

A3 - Native Fish- Humpback Chub

IN 3/4.3 Develop and implement a program to evaluate effects of factors limiting overwintering survival of young-of-the-year HBC in the Grand Canyon (fall 97, RPM 1) (High Priority-10)

Survival of young-of-the-year HBC depends in large part on temperature regimes available in habitat used by these fish. The IWQP will provide basic data describing expected temperatures at a given location and time and expected patterns and trends under various operational scenarios.

IN 3/4.7 Determine origins of fish food resources, energy pathways, and nutrient sources important to their production, and the effects of Glen Canyon Dam operations on these resources. Evaluate linkages between the aquatic food base and the health and sustainability of HBC populations. (Medium Priority-7)

The IWQP does not directly address this information need but provides information on food resources and nutrient sources from water quality monitoring below Glen Canyon Dam and in Lake Powell. Plankton and nutrient concentrations in the Colorado River that form energy pathways for native fish are dependent on their starting concentrations in Glen Canyon Dam releases. These concentrations, in turn, depend on the concentrations of these parameters in the Lake Powell reservoir at levels affected by dam operations.

IN 5.1 Determine a set of possible temperature changes in the mainstem Colorado River resulting from implementing selective withdrawal. (Medium Priority-6)

Research and monitoring specific to a Temperature Control Device (TCD) experiment will be developed separately from the IWQP. However, the basic long-term monitoring specified in this plan provides information to establish baseline patterns on which the operation of a TCD could be evaluated, as well as addressing INs not directly related to the TCD. Downstream thermal monitoring will provide needed information on warming patterns related to discharge levels and geomorphic reach. Tailwater monitoring will describe current annual variations on long-term trends in temperature patterns of Glen Canyon Dam releases. Monitoring of temperature throughout Lake Powell is required to quantify the heat content of the reservoir on a quarterly basis so that effects of periodic and long-term warm water withdrawal can be evaluated. All of the above information will be integrated into hydrodynamic and conceptual models to predict the effects of varying amounts or frequencies of TCD operation.

IN 5.2 Determine the anticipated effects on HBC and other native populations which may result from installing a selective withdrawal structure for thermal modification in the mainstem of the Colorado River downstream of Glen Canyon Dam. Determine the range of temperatures for successful larval fish development and recruitment and the relationship between larval/juvenile growth and temperature. (High Priority-10)

Studies on behavior and life history requirements of HBC and other native fish will determine effects of a TCD on native fish populations. Temperature of larval/juvenile habitat is important in determining growth and survival of these life stages. The IWQP will provide long-term main-channel temperature information related to current status, trends, and potential effects of a TCD.

IN 5.3 Determine the effects of dam operations, including installing a selective withdrawal structure for thermal modification in the mainstem of the Colorado River downstream of Glen Canyon Dam, on: (High Priority-14)

a) Reproductive success, growth, and survivorship of Grand Canyon fishes;

b) Parasites and disease organisms of endangered and native fishes in the Colorado River ecosystem;

c) Temperature induced interactions between native and non-native fish competitors and predators; and

d) The effects of temperature, including seasonality and degree, on Cladophora and associated diatoms, Gammarus, and aquatic insects.

Observed temperature patterns through Grand Canyon and in dam releases will be required, in addition to other information, to evaluate effects of a TCD on HBC and other native fish populations. This temperature data will also be required to determine effects on fish recruitment, parasites, native/non-native interactions, and benthic organisms. While these INs will be primarily addressed by other research specific to these areas, the IWQP will provide the temperature data needed to evaluate these INs in a consistent high-quality format from an integrated database.

IN 5.4 Evaluate effects of withdrawing water on the heat budget of Lake Powell, effects of potentially warmer inflow into Lake Mead, and the concomitant effects on the biota within both reservoirs. Evaluate the temperature profiles along with heat budget for both reservoirs. Evaluate effects of reservoir withdrawal level on fine particulate organic matter and important plant nutrients to understand the relationship between withdrawal level and reservoir and downstream resources. (Medium Priority-7)

The proposed IWQP plan includes temperature measurements in Lake Powell that could be used to determine heat content and help identify heat budget components. However, the focus is on characterizing the chemical and biological composition of water in Lake Powell that would be available for withdrawal under a TCD scenario and normal operating conditions. Operation of a TCD could affect changes in the water quality of the reservoir, which could result in significant longer-term changes to the water quality of downstream releases, by altering the reservoir's heat budget, chemistry, or biological composition. The IWQP will provide the baseline data describing status and trends of these components. Future monitoring and research specific to the TCD will evaluate these effects of TCD operation.

The effects of TCD operations will certainly change the characteristics and fate of water entering Lake Mead, possibly affecting biological processes in Lake Mead significantly. However, study of effects to Lake Mead is not proposed as part of the IWQP and will be left to other parties to accomplish.

IN 5.5 Evaluate when to release warmer temperature water, what seasonal pattern of releases to use to avoid establishment of permanent backwater areas, and how best to use floods, to limit expansion or invasion of non-native fish species. (High Priority-9)

This IN primarily relates to native fish studies. The IWQP will provide information on the availability of warm water in the reservoir, seasonal temperature variations in dam releases, and warming patterns associated with time of year, discharge levels, and geomorphic reach.

A3 - Native Fish- Flannel Mouth Sucker and other native fish

IN 8.4 Determine historic and current ecosystem requirements (habitat, spacing, food source, interdependencies, etc.) of native fish species. (Medium Priority-5)

The IWQP will provide necessary water quality information to support native fish and related food base and behavioral studies.

Physical Resources - Water Resources

IN 2.1 Monitor water quality, composition and temperature and compare to applicable standards. (High Priority-9 not differentiated between 2.1a and 2.1b)

IN 2.1a Quantify current selenium levels in water discharged from Glen Canyon Dam. Determine how selenium concentrations are affected by dam operations.

The IWQP does not currently provide specific focus on selenium levels in Glen Canyon Dam discharge. The Bureau of Reclamation is currently undertaking an Upper Colorado River basin-wide selenium study to address sources of loading and effects to biological resources (Jerry Miller, personal comm.) Field support on quarterly reservoir surveys will be provided for Lake Powell sample collection. Selenium concentrations are also monitored by the USGS at the Lees Ferry and Diamond Creek NASQAN gauging station. No further work in this area is planned unless unacceptable levels of selenium are found and a direct linkage exists relating selenium concentrations to dam operations.

IN 2.1b Determine/quantify the dynamics of major cations, anions and nitrate/phosphate ratios resulting from dam operations.

The chemical characteristics (major ions and nutrients) of water released from Glen Canyon Dam are affected by different aspects of Glen Canyon Dam operation as well as by hydrological and climatological factors and internal reservoir processes, such a seiche effects. Dam operations, including the use of alternate release structures, high sustained release volumes, and daily fluctuations can significantly affect reservoir and downstream release water quality (Hueftle and Vernieu, in review). Changes in reservoir water quality near the dam have an immediate effect on downstream releases; changes in upstream portions of the reservoir have a longer-term effect on release water quality. The IWQP is designed to measure changes in the reservoir and downstream releases under current and future dam operations to meet this information need. Continued analysis and application of hydrodynamic and conceptual models is planned to further understand the effects of dam operations on downstream water quality.

IN 2.2 Evaluate feasibility of short term or long term changes of water temperature through selective withdrawal. (Medium Priority-6)

The feasibility of changing water temperature at a given point in Grand Canyon through the use of a TCD is dependent on availability and quantity of warm water in Lake Powell, depth of withdrawal from the reservoir, time of withdrawal, and warming patterns dependent on discharge level and geomorphic reach. The Bureau of Reclamation is evaluating feasibility of a TCD from an engineering standpoint. While research and monitoring specific to a Temperature Control Device (TCD) experiment will be developed separately from the IWQP, the basic long term monitoring specified in this plan provides valuable information to establish baseline patterns on which the operation of a TCD could be evaluated.

Recreation Resources

IN 1.5 Determine potential impacts of increased heavy metals on sport fishing (Low Priority-0)

This information need is not being met by the proposed IWQP. While related to water quality issues (concentration of heavy metals in water, it also has implications to fisheries, public health, and toxicology issues. Metals concentrations are currently measured by the USGS at the Lees Ferry and Diamond Creek NASQAN gauging station. If unacceptable metals concentrations are identified and determined to be related to dam operations, involvement of other agencies such as the EPA or Arizona Dept. of Environmental Quality and other further research could be pursued. This information need received very low priority by the TWG.

Gray Category

These INs while characteristic of the Lake Powell reservoir, also relate to downstream resources. Operations of Glen Canyon Dam can affect both the quality of water released from the dam, having immediate effects on the downstream ecosystem, and the quality of water within the reservoir, having longer-term effects downstream. Monitoring activities focus on characterizing reservoir conditions and eventual release water quality and are conducted upstream of Glen Canyon Dam. They meet the INs specified in this category as well as those specified in the white category.

Lake Powell Water Quality (Physical/Chemical)

IN 1.1 Determine the effect of current dam operations on reservoir water quality, including but not limited to the following: (High Priority-10)

a) Determine near-dam hydrogen sulfide levels (and other hazardous chemical constituents) within the hypolimnion occurring under current dam operating criteria.

The generation of hydrogen sulfide can occur with the depletion of dissolved oxygen, or anoxia. Hydrogen sulfide is both toxic to aquatic organisms and corrosive to powerplant machinery. Dissolved oxygen levels below 1 mg/L have not been recorded during this historical monitoring program. However, the potential exists, under extended periods of meromixis, for anoxia to occur in the forebay with the formation of hydrogen sulfide and potential release downstream. Anoxic conditions are observed with some regularity in Navajo Canyon and the Escalante Arm of Lake Powell and can be used to model main channel anoxia.

Dissolved oxygen measurements collected during a reservoir water quality profile will be used to determine when there is a potential for the presence of hydrogen sulfide. When dissolved oxygen levels of less than 1 mg/L are observed, hydrogen sulfide determinations will be made using a portable test kit.

b) Determine the dynamics of lake stratification and advective flows and their effects on chemical constituents

Lake stratification, convective mixing, and the influence of advective currents in Lake Powell are determined by quarterly reservoir monitoring surveys and monthly forebay monitoring. Forebay monitoring provides information on stratification patterns in the deepest portion of the reservoir on a monthly basis. Quarterly reservoir-wide surveys describe the behavior of advective currents and longitudinal variations in the reservoir, on a seasonal basis, providing a longer-term view of future release water quality and describing how internal mixing processes in the reservoir affect water quality patterns near the dam and in downstream releases. By determining the influence of internal dynamics and other hydrologic and climatological factors the effects of various aspect of dam operations can be determined more clearly.

c) Determine/quantify the dynamics of major cations, anions, and nitrate/phosphate ratios resulting from dam operations

Chemical sampling for nutrient compounds and major ions is used to determine and quantify the dynamics of these constituents. These chemical samples are collected from various depths at selected stations during quarterly reservoir surveys, monthly forebay surveys, and on a monthly basis below the dam and at Lees Ferry. Actual hydrodynamics of significant strata related to dam operations are determined by more resolute measurements of temperature and specific conductance during a reservoir water quality profile. These samples characterize the chemical makeup and nutrient concentration of significant strata within the reservoir and in releases downstream and can be used to determine the origin or history of a particular body of water in the reservoir.

d) Determine the effects of dam operations (under approved operating criteria) on the physical/chemical dynamics of Lake Powell side channels and embayments

The major focus of the IWQP reservoir monitoring program is on the main channel of the Colorado River and other major tributary arms of the reservoir (San Juan and Escalante). The main channel is dominated by advective flow patterns and thus, more directly affected by dam operations. It has been recognized, however, that side channels and embayments are important to biological processes and fishery habitat in the reservoir due to relatively longer retention times of water in these areas. These areas may also exhibit water quality problems related to dissolved oxygen and other contaminants. Direct effects of dam operations in these areas are limited to fluctuations in reservoir elevation and influence of main channel processes. IWQP monitoring activities in these areas are limited to occasional observations of conditions in selected areas for problem identification and to model main channel processes on a smaller scale.

e) Quantify/model the heat budget for Lake Powell to determine near-term and long-term (monthly/weekly and annual summaries respectively) effects of a selective withdrawal system

The feasibility of changing water temperature released from Glen Canyon Dam through the use of a TCD is dependent on availability and quantity of warm water in Lake Powell, depth of withdrawal from the reservoir, time of withdrawal, and downstream warming patterns. The Bureau of Reclamation is evaluating feasibility of a TCD from an engineering standpoint. While research and monitoring specific to a Temperature Control Device (TCD) experiment will be developed separately from the IWQP, the basic long term monitoring specified in this plan provides valuable information to establish baseline patterns on which the operation of a Temperature Control Device could be evaluated.

f) Determine the effect of current dam operations on reservoir levels of selenium.

The IWQP does not currently provide specific focus on selenium levels in Lake Powell. The Bureau of Reclamation is currently undertaking an Upper Colorado River basin-wide selenium study to address sources of loading and effects to biological resources (Jerry Miller, personal comm.) Field support on quarterly reservoir surveys is provided for Lake Powell sample collection. Selenium concentrations are being monitored by the USGS at the Lees Ferry and Diamond Creek NASQAN gauging station. No further work in this area is planned unless unacceptable levels of selenium are found and a direct linkage exists relating selenium concentrations to dam operations.

Lake Powell Water Quality (Biological)

IN 1.1 Determine the impacts of dam operations and resulting water quality on primary and secondary productivity of Lake Powell, including: (Medium Priority-5)

a) Algae (phytoplankton component)

c) Zooplankton

The IWQP monitors the basic indicators of primary and secondary productivity in Lake Powell and downstream releases to the Colorado River. Quarterly reservoir sampling characterizes chlorophyll concentration, and the abundance and community structure of phytoplankton and zooplankton populations. These sestonic components of the primary and secondary productivity in Lake Powell are those that are part of the water in the reservoir and could be affected by dam operations and incorporated into down stream releases. The biological components normally attached to the substrate of the reservoir are part of the black category described below and are not addressed by the IWQP.

Black Category

These INs relate mostly to the Lake Powell aquatic ecosystem with little or no connection to downstream resources. They are not part of the Adaptive Management Program but are retained in a non-program information-desired category. No support is provided by the IWQP in this area and no activities are proposed in this plan to address these information needs.

Lake Powell Water Quality (Biological)

IN 1.1 Determine the impacts of dam operations and resulting water quality on primary and secondary productivity of Lake Powell, including: (Medium Priority-5)

a) Algae (periphyton component)

b) Macrophytes

d) Macroinvertebrates

IN 1.2 Quantify levels of selenium and describe effects of these levels on primary and secondary productivity, fish and waterfowl, and human consumption. (Low Priority -1)

Lake Powell Aquatic Ecosystem

IN 2.1 Determine the effects of water temperature caused by dam operations. (Low Priority-1)

IN 2.2 Determine the effects of fluctuations in the reservoir surface elevations caused by dam operations (under approved operating criteria) (Low Priority-0)

IN 2.3 Determine the effects of elevated selenium levels caused by dam operations (under approved operating criteria) (Low Priority-0)

IN 2.4 Determine the effects of advective flow patterns on the Lake Powell aquatic ecosystem caused by dam operations (under approved operating criteria) (Low Priority-0)

IN 2.5 Determine the effects of predator/prey relationships caused by dam operations (under approved operating criteria) (Low Priority-1)

IN 2.6 Determine the effects of fish movements caused by dam operations (Low Priority-1)

Table 1. Comparison of Information Needs with Monitoring Plan Content

Category	Information Need	Priority	Support Level	Supporting Data	Locations
White Category - Activities below dam addressing downstream resources					
Bio Res A1-Aq Food IN 1.1	Determine status and trends in aquatic food base species composition and population structure, density and distribution and the influence of ecologically significant processes	High - 10	Indirect	▪ Temperature ▪ Nutrients ▪ Biological composition	▪ Lake Powell ▪ Forebay ▪ Tailwater ▪ Grand Canyon (temperature)
Bio Res A1-Aq Food IN 1.2	Determine the effects of past, present and potential dam operations under the approved operations criteria on the aquatic food base species composition, population structure, density and distribution in the Colorado River ecosystem	High - 10	Indirect	▪ Temperature ▪ Nutrients ▪ Biological composition	▪ Lake Powell ▪ Forebay ▪ Tailwater ▪ Grand Canyon (temperature)
Bio Res A2-Trout IN 2.6	Define criteria (e.g., temperatures, flow regimes, contaminants, metals, nutrients) for sustaining a healthy rainbow trout population in Glen Canyon	Low - 4	Indirect	▪ Temperature ▪ Nutrients ▪ Biological composition	▪ Tailwater ▪ Grand Canyon (temperature)

Category	Information Need	Priority	Support Level	Supporting Data	Locations
Bio Res A3-HBC IN 3/4.3	Develop and implement a program to evaluate effects of factors limiting overwintering survival of young-of-the-year HBC in the Grand Canyon (Fall 97, RPM 1)	High - 10	Indirect	▪ Temperature	▪ Tailwater ▪ Grand Canyon
Bio Res A3-HBC IN 3/4.7	Humpback Chub (HBC) - Determine the origins of fish food resources, energy pathways and nutrient sources important to their production, and the effects of GCD operations on these resources. Evaluate linkages between the aquatic food base and the health and sustainability of HBC populations	Medium - 7	Indirect	▪ Temperature ▪ Nutrients ▪ Biological composition	▪ Lake Powell ▪ Forebay ▪ Tailwater ▪ Grand Canyon (temperature)
Bio Res A3-HBC IN 5.1	Determine a set of possible temperature changes in the mainstem Colorado River resulting from implementing selective withdrawal	Medium - 6	Direct	▪ Temperature	▪ Lake Powell ▪ Forebay ▪ Tailwater ▪ Grand Canyon
Bio Res A3-HBC IN 5.2	Determine the anticipated effects on HBC and other native populations, which may result from installing a selective withdrawal structure for thermal modification in the mainstem of the Colorado River downstream of GCD. Determine the range of temperatures for successful larval fish development and recruitment and the relationship between larval, juvenile growth and temperature.	High - 10	Indirect	▪ Temperature	▪ Tailwater ▪ Grand Canyon

Category	Information Need	Priority	Support Level	Supporting Data	Locations
Bio Res A3-HBC IN 5.3	Determine the effects of dam operations, including installing a selective withdrawal structure for thermal modification in the mainstem of the Colorado River downstream of GCD on: • Reproductive success, growth and survivorship of GC fishes • Parasites and disease organisms of endangered and native fishes in the CR ecosystem • Temperature induced interactions between native and non-native fish competitors and predators and the effects of temperature, including seasonality and degree, on Cladophora and associated diatoms, Gammarus and aquatic insects	High - 14	Indirect	▪ Temperature	▪ Tailwater ▪ Grand Canyon
Bio Res A3-HBC IN 5.4	Evaluate the effects of withdrawing water on the heat budget of Lake Powell, effects of potentially warmer inflow into Lake Mead, and the concomitant effects on the biota within both reservoirs. Evaluate the temperature profiles along with heat budget for both reservoirs. Evaluate the effects of reservoir withdrawal level on fine particulate organic matter and important plant nutrients to understand the relationship between withdrawal level and reservoir downstream resources.	Medium - 7	Indirect	▪ Temperature ▪ Specific conductance ▪ Dissolved oxygen ▪ pH ▪ Turbidity ▪ Major Ions ▪ Nutrients ▪ Biological composition	▪ Lake Powell ▪ Forebay ▪ Tailwater ▪ Grand Canyon (temperature)

Category	Information Need	Priority	Support Level	Supporting Data	Locations
Bio Res A3-HBC IN 5.5	Evaluate when to release warmer temperature water, what seasonal pattern of releases to use to avoid establishment of permanent backwater areas, and how best to use floods to limit expansion or invasion of non-native fish species	High - 9	Indirect	▪ Temperature	▪ Lake Powell ▪ Forebay ▪ Tailwater ▪ Grand Canyon
Bio Res A3-FMS et al IN 8.4	Determine historic and current ecosystem requirements (habitat, spacing, food source, interdependencies, etc.) of native fish species.	Medium - 5	Indirect	▪ Temperature ▪ Nutrients ▪ Biological composition	▪ Lake Powell ▪ Forebay ▪ Tailwater ▪ Grand Canyon (temperature)
Phys Res IN 2.1	Monitor water quality, composition and temperature and compare to applicable standards.	High - 9			

Category	Information Need	Priority	Support Level	Supporting Data	Locations
	IN2.1a Quantify current selenium levels in water discharged from GCD. Determine how selenium concentrations are affected by dam operations.		None	▪ Selenium concentrations from UC-BOR program ▪ Selenium concentrations from USGS NASQAN program	▪ Lake Powell ▪ Lees Ferry (NASQAN)
	IN2.1b Determine/quantify the dynamics of major cations, anions and nitrate/phosphate ratios resulting from dam operations		Direct	▪ Temperature ▪ Specific conductance ▪ Dissolved oxygen ▪ pH ▪ Turbidity ▪ Major Ions ▪ Nutrients ▪ Biological composition	▪ Lake Powell ▪ Forebay ▪ Tailwater ▪ Grand Canyon (temperature)

Category	Information Need	Priority	Support Level	Supporting Data	Locations
Phys Res IN 2.2	Evaluate feasibility of short term or long term changes of water temperature through selective withdrawal	Medium - 6	Indirect	▪ Temperature	▪ Lake Powell ▪ Forebay ▪ Tailwater ▪ Grand Canyon
Rec Res IN 1.5	Determine potential impacts of increased heavy metals on sport fishing	Low - 0	None	▪ Selenium concentrations from USGS NASQAN program	▪ Lees Ferry (NASQAN)

Category	Information Need	Priority	Support Level	Supporting Data	Locations
Gray Category - Activities above dam addressing downstream resources					
Lake Powell Water Quality (Phys/Chem) IN 1.1	Determine effect of current dam operations on reservoir water quality including but not limited to the following:	High - 10			
	IN 1.1a Determine near-dam hydrogen sulfide (…) within the hypolimnion under current dam ...criteria.		Direct	▪ Temperature ▪ Specific conductance ▪ Dissolved oxygen ▪ pH ▪ Hydrogen sulfide (if indicated)	▪ Lake Powell ▪ Forebay ▪ Tailwater

	IN 1.1b Determine the dynamics of lake stratification and advective flows and their effects on chemical constituents		Direct	▪ Temperature ▪ Specific conductance ▪ Dissolved oxygen ▪ pH ▪ Turbidity ▪ Major Ions ▪ Nutrients	▪ Lake Powell ▪ Forebay ▪ Tailwater
	IN 1.1c Determine/quantify Dynamics of major cations, anions, and nitrate/phosphate ratios from dam operations		Direct	▪ Temperature ▪ Specific conductance ▪ Dissolved oxygen ▪ pH ▪ Turbidity ▪ Major Ions ▪ Nutrients ▪ Biological composition	▪ Lake Powell ▪ Forebay ▪ Tailwater

	IN 1.1d Determine effects of dam operations (…) on the phys./chem. Dynamics of Lake Powell side channels and embayments.		Indirect	▪ Temperature ▪ Specific conductance ▪ Dissolved oxygen ▪ pH ▪ Turbidity ▪ Major Ions ▪ Nutrients ▪ Biological composition	▪ Lake Powell ▪ Forebay
	IN 1.1e Quantify/model the heat budget for Lake Powell to determine near-term and long-term (...) effects of a selective withdrawal system		Direct	▪ Temperature ▪ Specific conductance ▪ Biological composition	▪ Lake Powell ▪ Forebay ▪ Tailwater ▪ Grand Canyon (temperature)
	IN 1.1f Determine the effect of current dam operations on reservoir levels of selenium		None	▪ Selenium concentrations from UC-BOR program ▪ Selenium concentrations from USGS NASQAN program	▪ Lake Powell ▪ Lees Ferry (NASQAN)

Lake Powell Water Quality (Biological) IN 1.1	Determine the impacts of dam operations and resulting water quality on primary and secondary productivity of Lake Powell including phytoplankton and zooplankton	Medium - 5	Direct	▪ Temperature ▪ Specific conductance ▪ Dissolved oxygen ▪ pH ▪ Turbidity ▪ Nutrients ▪ Biological composition	▪ Lake Powell ▪ Forebay ▪ Tailwater

Category	Information Need	Priority	Support Level	Supporting Data	Locations
Black Category - Activities above dam addressing upstream resources					
Lake Powell Water Quality (Biological) IN 1.1	Determine the impacts of dam operations and resulting water quality on primary and secondary productivity of Lake Powell including: periphyton, macrophytes and macroinvertebrates	Medium - 5	None	None	▪ No support
Lake Powell Water Quality (Biological) IN 1.2	Quantify levels of selenium and describe effects of these levels on primary and secondary productivity, fish and waterfowl and human consumption	Low - 1	None	▪ Selenium concentrations from UC-BOR program ▪ Selenium tissue concentrations from USFWS sampling	▪ Upper Colorado Basin ▪ Lake Powell
Lake Powell Aq. Ecosystem IN 2.1	Determine effects of water temperature caused by dam operations on the Lake Powell aquatic ecosystem	Low - 1	None	▪ Temperature ▪ Biological composition	▪ Lake Powell

Lake Powell Aq. Ecosystem IN 2.2	Determine the effects of fluctuations in the reservoir surface elevation on the Lake Powell aquatic ecosystem caused by dam operations (under approved operating criteria)	Low - 0	None	▪ Temperature ▪ Biological composition	▪ Lake Powell
Lake Powell Aq. Ecosystem IN 2.3	Determine the effects of elevated selenium levels on Lake Powell aquatic ecosystem caused by dam operations (under approved operating criteria)	Low - 0	None	▪ Selenium concentrations from UC-BOR program ▪ Selenium tissue concentrations from USFWS sampling ▪ Biological composition	▪ Upper Colorado Basin ▪ Lake Powell
Lake Powell Aq. Ecosystem IN 2.4	Determine the effects of advective flow patterns on the Lake Powell aquatic ecosystem caused by dam operations (under approved operating criteria)	Low - 0	None	▪ Temperature ▪ Specific conductance ▪ Dissolved oxygen ▪ pH ▪ Turbidity ▪ Nutrients ▪ Biological composition	▪ Lake Powell

Lake Powell Aq. Ecosystem IN 2.5	Determine the effects of predator/prey relationships on the Lake Powell aquatic ecosystem caused by dam operations (under approved operating criteria)	Low - 1	None	▪ Biological composition	▪ Lake Powell
Lake Powell Aq. Ecosystem IN 2.6	Determine the effects of fish movements caused by dam operations	Low - 1	None	▪ None	▪ None

Chapter 2 WATER QUALITY MONITORING PLAN

Introduction

The monitoring program described in this report is designed to meet the Information Needs (INs) of the Glen Canyon Dam Adaptive Management Program identified in Chapter 1. The primary goal of the Integrated Water Quality Program (IWQP) is to describe and understand the influence of dam operations on water quality in Lake Powell and Glen Canyon Dam releases and its effect on downstream resources.

This goal will be met by maintaining a long-term program of basic water quality data monitoring, defined as the periodic measurement of a consistent, repeatable set of common water quality parameters from an integrated network of sites from Lake Powell through the Grand Canyon. The information will be collected according to standardized monitoring protocols and maintained in a common database. Necessary research will be also be conducted based on specific hypotheses to fully address specific INs, form linkages with other resource components, and to evaluate protocols and methodologies.

The IWQP consists of four components of basic long-term monitoring and a research component to meet specific INs. The overall objectives of the program are to evaluate trends in water quality, determine the effects of dam operations and other factors on water quality, and provide information to form linkages between water quality and other components of the aquatic ecosystem. Specific objectives guide monitoring activities under each program component and are listed separately under the description of each component.

Under a proposal agreed to by the Technical Work Group (TWG), funding for activities under the "Gray Area" of the IWQP, those conducted upstream of Glen Canyon Dam, will come from the Bureau of Reclamation O&M program (Appendix A). The proposal specifies that GCMRC develop the scope of work in coordination with Reclamation and that GCMRC and/or its contractors will accomplish this work.

This plan has been developed in coordination with Reclamation personnel and has undergone technical review by independent experts and the TWG. We provide an overview of the plan components and proposed scientific activities that would be conducted in addition to the monitoring plan. It is now presented to the Adaptive AMWG for recommended adoption.

A. Proposed Monitoring and Research Activities

The proposed GCRMC IWQP consists of four monitoring components and a research component:

Monitoring Activities

1. Quarterly reservoir water quality surveys.
2. Monthly Forebay water quality surveys above Glen Canyon Dam.
3. Monthly Tailwater sampling immediately below the dam and at Lees Ferry.
4. Downstream water quality monitoring.

Each of the four monitoring components is designed to meet specific objectives and INs.

Research Activities

1. Necessary and Complementary Research.

The four basic long-term monitoring elements of the GCMRC IWQP will be carried through Fiscal Year 2000 and beyond, as the need for this information continues. The research component will be based on prioritized information needs and integrated with other resource areas (e.g., aquatic food base, native fish, and trout). A brief discussion of the activities and objectives of the monitoring and research areas follows.

Quarterly reservoir surveys

The objective of quarterly reservoir surveys will be to characterize the chemical, physical, and biological conditions in the major strata of the reservoir, and describe seasonal and longitudinal variations in stratification patterns, mixing processes, effect of inflows, trophic status, planktonic community structure and abundance, and quality of water released downstream. Information from reservoir surveys provides a prediction of future release water quality or potential water quality problems and forms a baseline from which the long-term effects of management actions related to dam operations can be evaluated.

Reservoir surveys will be conducted four times per year, coinciding with seasonal patterns observed on the reservoir. Primary focus will be given to the main channel of the Colorado River and its major tributaries in Lake Powell. When appropriate, additional efforts will be made to characterize conditions in smaller tributaries and embayments where conditions differ significantly from the main channel.

A thirty-four-year period of record exists for reservoir-wide surveys, varying in frequency from monthly to yearly (Figure 2). Quarterly sampling has been shown to sufficiently describe major seasonal patterns in the reservoir. Sampling at less frequent intervals does not show these seasonal patterns, nor can it give context to observed conditions at the forebay.

Profiling of common physical and chemical parameters will be performed at 20-25 stations on the reservoir. At a smaller number of selected long-term station locations, chemical sampling (nutrients and major ions) and biological sampling (chlorophyll, phytoplankton, and zooplankton) will be performed. The objective of this sampling will be to describe chemical and biological conditions of the major strata of the reservoir, significant inflow patterns, or other unusual conditions. General field observations of existing weather conditions, water depth, and water clarity will also be made.

Monthly Forebay Surveys

The objective of monthly forebay surveys will be to characterize the physical, chemical, and biological conditions of the Glen Canyon Dam forebay and describe monthly variations in stratification patterns, mixing processes, planktonic community structure and abundance, and quality of water released downstream. Information from forebay monitoring forms a baseline from which the immediate effects of management actions at Glen Canyon Dam can be evaluated.

Sampling will focus on characterizing conditions within the major strata of the reservoir and at potential release depths. The monthly sampling frequency provides increased temporal resolution of conditions existing upstream of the dam. Conditions in the forebay have an immediate effect downstream and follow operational patterns at Glen Canyon Dam more closely than those monitored on a less frequent basis. A thirty-four-year period of record exists for forebay surveys on an approximately monthly basis, with the exception of the period 1982-1990 (Figure 2).

Monthly forebay monitoring will consist of a profile of physical parameters through the water column; chemical sampling for nutrients and major ions specified depths, and biological sampling for chlorophyll, phytoplankton, and zooplankton. General field observations of existing weather conditions, water depth, and water clarity will also be made. These data have utility to researchers involved in both the reservoir and downstream (USBR/TCD, aquatic foodbase, trout, and native fish).

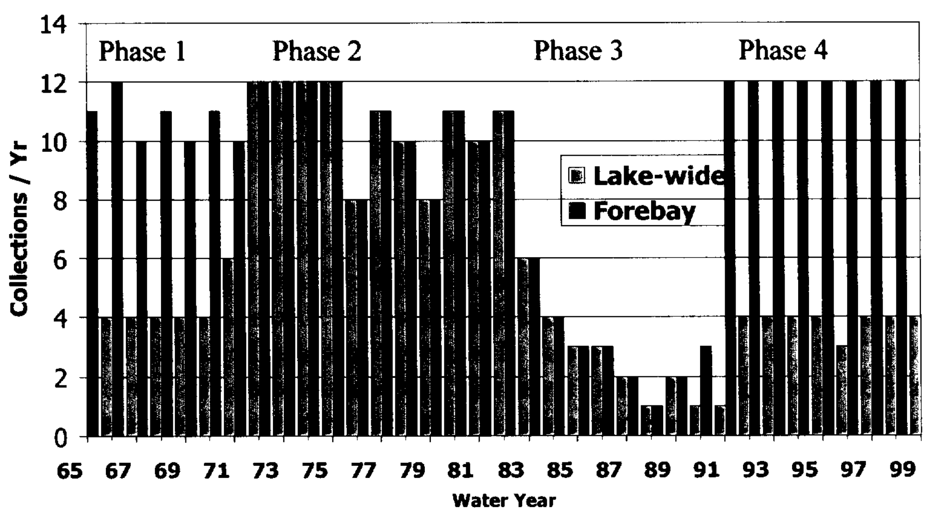

Figure 2. 35-year period of Lake Powell monitoring

Continuous Tailwater Monitoring

The objective of the tailwater monitoring program will be to characterize the quality of water released from Glen Canyon Dam and measure changes occurring in the tailwater below Glen Canyon Dam. These characteristics are the result of long-term climatological and hydrological processes in the Colorado River basin, advective and convective mixing processes within Lake Powell, and the operation of Glen Canyon Dam. The water quality of Glen Canyon Dam releases forms a baseline from which changes occur downstream and directly affect the aquatic ecosystem. A ten-year period of record exists for these data.

Continuous monitoring of tailwater quality will be performed below Glen Canyon Dam and at Lees Ferry. Monitors will be maintained inside Glen Canyon Dam, in the tailwater immediately below the dam, and at Lees Ferry, 25 km (15.5 mi.) downstream of the dam. Measurements of temperature, specific conductance, dissolved oxygen, and pH will be made at 20-minute intervals and logged within the monitor. Monitors will be downloaded, serviced, and recalibrated on a monthly basis. On a monthly basis, chemical sampling for nutrients and major ions, and biological sampling for chlorophyll, phytoplankton, and zooplankton will be performed inside Glen Canyon Dam and at Lees Ferry. Researchers working in other resource areas within the Colorado River ecosystem (e.g., primary productivity, trout, and native fish) can utilize these data.

Downstream Monitoring

The purpose of this monitoring will be to describe downstream water quality conditions in the Colorado River and its tributaries and evaluate warming patterns that vary with geomorphic reach and release patterns from Glen Canyon Dam. Thermal conditions are of significant importance to fish, aquatic invertebrates, aquatic vegetation, and other components of the ecosystem. Evaluation of warming patterns is needed to describe baseline levels and the potential for instream warming of dam releases. As the water quality of Glen Canyon Dam releases forms a baseline from which changes occur downstream, the continued monitoring of some of these parameters provides more clarity regarding the direct affect of water quality on the downstream aquatic ecosystem.

Thermal monitoring will be performed at several sites on the Colorado River in Grand Canyon and at major tributary mouths. Submersible monitors will be placed unobtrusively at 8 main-channel locations on the Colorado River spaced approximately 50 km apart, and 9 tributary sites in Grand Canyon (Table 2). An isolated group of warm springs near Fence Fault (RM 30) that have been identified as potential spawning areas will also be monitored. Instruments will be downloaded and serviced on a quarterly basis, in conjunction with other scheduled research trips.

Monitoring of parameters other than temperature, will take place at gauging stations in Grand Canyon that are either supported by GCMRC through a contract with the U.S. Geological Survey

(USGS), or are data that are available from the USGS. The GCMRC directly supports data collection efforts at the Lees Ferry, above the Little Colorado River and at the Grand Canyon Gages. These gages collect temperature, specific conductance and turbidity data. The Lees Ferry Gage and Diamond Creek Gage are also national water quality monitoring sites (NASQAN). These sites collect dissolved organic carbon, dissolved oxygen, bacteria counts, nitrogen and phosphorous data. While these latter efforts will not be supported by the integrated water quality plan, these data are available to downstream researchers. Sampling for these latter constituents occurs six times per year, rather then on a continuous basis.

Table 2. Grand Canyon thermal monitoring locations

Mainstem Monitoring Sites	Tributary Monitoring Sites
Colorado R. above Little Colorado R.	Paria R. above Lees Ferry
Colorado R. near Grand Canyon	Nankoweap Creek
Colorado R. at RM 127	Little Colorado R. above Mouth
Colorado R. above National Canyon	Bright Angel Creek
Colorado R. at RM194	Shinumo Creek
Colorado R. above Diamond Ck.	Tapeats Creek
Colorado R. at RM230	Kanab Creek
Colorado R. above Spencer Canyon	Havasu Creek
	Spencer Creek

Necessary and Complimentary Research

Several information needs associated with water quality are research oriented. Additionally, monitoring programs require regular analysis and assessment in order to provide quality information. A research program will be a component of the IWQP. We are proposing that a three-phase approach to research that include historical assessment, protocol review and integrated water quality research. The later component will stress forming linkages between water quality parameters with trophic level processes. The feedback loop between monitoring and research ensures that adequate baseline data for water quality are collected in support of other downstream resources.

Possible management strategies and technological advances may exist in the future that the long-term IWQP cannot address or that requires revisions to the program. These new developments or information from the monitoring program may lead to small-scale research projects to test new technologies or approaches that can advance the management objectives and information needs, as well as to respond to emergency actions or unusual events within Lake Powell or the tailwater. Examples of such research could include quantification of seiche effects on dam releases (winddriven internal oscillations), sidebay trophic status and interactions, sediment movements, and advances in food web linkage technology (stable isotope research). These projects would be of short duration and limited expenditure, with possible integration into the monitoring program if appropriate.

Downstream Linkages

The quality of downstream releases of reservoir water has direct effect on the downstream aquatic food base. Stratification and hydrodynamic flow patterns in the reservoir influence the chemical, physical and biological features of the discharge. Linkages are being found relating lake water chemistry and temperature discharges to light attenuation patterns (M. Yard, pers. comm.) and phyto-benthic communities and productivity in the tailwaters (Blinn et al. 1998, P. Benenati et al., 1997). GCMRC is collaborating with other researchers to link these factors. This primarily includes collaboration with tailwater food-base and fisheries scientists, but also links to research performed throughout the Colorado River ecosystem. Water quality changes (e.g., DO, pH, nutrients, temperature, and selenium) can indirectly affect higher trophic level resources (fish, amphibians, and avifauna) through food chain linkages. The IWQP seeks to serve and collaborate with downstream research by providing the relevant water chemistry and physical analysis, and appropriate biologic sampling.

The proposed monitoring and research program addresses many of these issues. Gaps in the information will be addressed through specific research or collaboration with other agencies. High-resolution trace metal sampling is not currently included in this program, though Reclamation performs some selenium analysis. Further research with stable isotopes may be needed to establish food-web connections. Other techniques may become available that assist in linking reservoir sidebay interactions with the mainstem and consequently downstream discharges. Other linkages may evolve as information is evaluated.

B. Proposed Activities for FY2000

In addition to the monitoring and research activities outlined above, several areas of work requiring additional focus are proposed for FY2000. It is anticipated that progress in these areas will result in refinements to the existing monitoring program, that will result in more cost-effective execution of the program, better definition of informational requirements, increased data availability and utility, and better feedback to management objectives.

Hydrodynamic Modeling

Reclamation is currently working on applying and refining various hydrodynamic computer simulation models for Lake Powell. The primary purpose for this modeling effort has been to predict immediate effects of temperature control modifications at Glen Canyon Dam. Having a well-calibrated model to simulate historical conditions and predict future conditions could benefit the management of Lake Powell and Glen Canyon Dam and could potentially reduce of some of the current monitoring effort. Cooperation between Reclamation and GCMRC in the setup, calibration, validation and application of a hydrodynamic model for Lake Powell is crucial to ensure its effectiveness for multiple purposes.

Several objectives of applying a hydrodynamic model for Lake Powell are proposed. The model could evaluate the long-term data collection program and recommend refinements to the current scheme of sample location and monitoring frequency. The relative effects of climate and hydrology could be more accurately separated from those of dam operations. The model could be used to fill in previous gaps in the historical data set. Scenarios for different aspects of dam operation and predicted downstream effects could be evaluated. Future predictions could be coupled with the downstream conceptual model to anticipate downstream ecosystem effects. Conditions that may result in sustained periods of meromixis and potential water quality impacts could be evaluated.

Applying and calibrating a hydrodynamic model requires several types of information in order for the model to function properly (Cole and Buchak, 1995). Inflow water quality and meteorological data is needed to meet these basic requirements. Reclamation will be working with other federal agencies to establish additional weather stations on Lake Powell. GCMRC and/or other agencies can participate with field collection, maintenance of remote monitoring equipment, and data management to facilitate data input to the modeling effort.

During FY2000, GCMRC will evaluate water quality data collected at existing upstream gages. If a need for additional monitoring is required in the inflow areas of Lake Powell, GCMRC will deploy and maintain this instrumentation on quarterly reservoir surveys. GCMRC will collaborate with Reclamation in the development, application, and calibration of the hydrodynamic model.

Data Management

Effective management of water quality data is crucial for gathering large amounts of historical monitoring information together for analysis. The establishment of a comprehensive data management system for water quality is proposed for FY 2000. Details of this plan are presented in Chapter 4. This plan describes the proposed design, implementation, and integration of the database within the GCMRC Information Technology program. It also describes the various tools and methodologies for analyzing and presenting these data.

In order to provide effective and timely feedback on current conditions and the effects of management actions, further work needs to be done making these data, summary products, and other analyses readily available to the AMWG, other researchers and the general public. Several means are currently in place and will be enhanced. Information will be developed for availability on the World Wide Web, GCMRC technical reports, and in peer-reviewed journal articles.

Proposed activities for FY 2000 include conversion of existing data files to Microsoft Access, maintaining the relational structure proposed in 0. As the GCMRC Oracle database development proceeds, this database will be migrated in modular form to that system. A primary goal of this project is to evaluate all existing data within a common system, provide error checking and validation, make it easily available to interested parties. The EPA STORET Version 1.1 will be evaluated for providing this function.

C. Proposed Activities for FY2001

As in FY2000 the monitoring and research activities outlined above would continue, but the emphasis of additional work will change. The focus in FY2001 will be protocol evaluation and further evaluation of the downstream water quality program. The timing of this protocol evaluation is linked to the aquatic food base evaluation scheduled to take place in FY2001.

Protocol Evaluation

New developments or information from the monitoring program may lead to small-scale research projects to test new technologies or approaches that can advance the management objectives and information needs of the proposed program. In addition, the program will undergo protocol evaluation in conjunction with the established review of the Biological Resources Program.

Examples of such research could include use of a fluorimeter to provide in situ chlorophyll analysis, acoustic Doppler for defining current velocities, alternate chemical analysis methods, sampling methodology or locations. Some elements may be integrated into the monitoring program, if appropriate, under approval of TWG.

Downstream Water Quality Program

The IWQP recognizes that the information collected in the downstream reach may not be adequate to a number of management objectives and information needs identified by AMWG. It is proposed that a 3-phase program be considered to fill this gap. This program would be contracted out via the RFP process.

1. Assessment:
   - Literature would be reviewed to develop a synthesis of past collections of water quality data since the construction of the dam.
   - Existing data collections would be evaluated.
   - An evaluation of downstream researchers' water quality data needs (parameters, collection frequency, and data quality requirements) for addressing AMWG information needs would be conducted.
2. Research will be designed to ascertain the best methodologies for describing water quality trends and will integrate with existing programs. It will address long-term versus short-term data needs and may include a testing phase.
3. The research will be used to design an efficient water quality monitoring program.

D. Related Activities

There are activities associated with the adaptive management program that will require additional data collection efforts. While these activities are not developed in this document, the IWQP recognizes that the level of monitoring and research covered in this plan may not adequately cover the needs of these planned actions.

Temperature Control Modifications

Modifications at Glen Canyon Dam for the installation of a temperature control device have been proposed. This device would withdraw warmer water from the epilimnion of the reservoir at a higher level than that normally used for powerplant operations. This has the potential for creating significant changes both in the downstream environment and the reservoir within Lake Powell as the surface has much higher biological productivity and different chemistry than penstock depths. This experiment will require modification to the existing water quality program to include more detailed baseline data, document changes under operation of the device, and evaluate its effect to longer-term reservoir and downstream water quality patterns.

The biological monitoring program in particular would need revision as it currently does not have the spatial and temporal resolution to reflect short-term effects. The distribution and abundance of plankton is of a patchier nature than chemicals in solution; it is regulated by dynamics within the fisheries community, penetration of light, temperature and location of the thermocline, wind patterns, nutrient availability, and many other factors (Horne & Goldman 1994, Wetzel 1975, and others).

A monitoring plan specific to the temperature control device experiment will be developed by GCMRC. At this point, the monitoring plan described in this document does not include specific activities related to the temperature control device. Maintenance of the current program, however, ensures that minimal baseline data is being gathered.

Beach Habitat Building Flows

In January 1998, the AMWG approved hydrologic triggering criteria that must be met before a Beach Habitat Building Flow (BHBF) is conducted. The ROD specifies that the objectives of the BHBF were to be accomplished in high reservoir storage years using releases in excess of powerplant capacity required for dam safety purposes. When appropriate hydrologic triggering criteria are met, releases above powerplant capacity will occur, which will involve the withdrawal of water from alternate release structures on Glen Canyon Dam. A similar release in 1996 resulted in significant changes to the water quality in Lake Powell and Glen Canyon Dam releases (Hueftle & Stevens, in review). A research plan is included in the BHBF contingency plan, but it may also need to incorporate special water quality monitoring requirements beyond those proposed or those elements specified in this plan.

Conceptual Modeling

Further work is proposed to the existing Grand Canyon Conceptual Model to allow for better linkage with Glen Canyon Dam release water quality. Currently, water quality inputs to the model are limited to historical temperature patterns. Further work needs to be done to allow better linkage to the model from Glen Canyon Dam release water quality. While providing a needed linkage between reservoir release water quality and the downstream ecosystem, this project will be part of the development of the Grand Canyon Conceptual Model and will not be funded from O & M funds.

Proposed objectives of this effort are:

1. Identify critical parameters in Lake Powell that have direct effects on downstream resources
2. Quantify the effects of dam operations and long-term hydrology on these parameters
3. Determine the usefulness of linking a reservoir simulation model with the downstream conceptual model and modification to the food base component of the downstream conceptual model. Detailed conceptual modeling of the broader Lake Powell ecosystem is not proposed at this time.

E. Resource Requirements

In order to accomplish this program, certain resources are required in several areas. Equipment and instrumentation must be in safe and reliable condition and meet technological requirements of precision and accuracy. Staffing needs must be met to provide program direction, contract support, technical analysis and interpretation, data management, field support, maintenance of instrumentation and equipment and clerical support. An adequate budget must be established and maintained to ensure the continuation of the long-term monitoring program.

Equipment

Equipment is currently in place at GCMRC to effectively execute this water quality monitoring program. One of the most important tools for accomplishing reservoir work is the 32-foot Uniflite limnology vessel and its associated equipment. This boat has been in service on Lake Powell since 1970 and much of the limnological equipment and field methodology has been customized around it. Auxiliary equipment includes a sonar depth finder, radio, motorized reel for deployment of the Hydrolab Surveyor 3/H20 profiling instrument, motorized winch for sample collection, and a sample filtration station.

The boat is currently in need of mechanical and exterior work to ensure its safety and reliability into the future. This work will be performed in FY 1999 and includes replacement of the engines and power train, replacement of the generator, refinishing of the exterior, and some remodeling of the interior of the boat.

Water quality instrumentation consists of a Hydrolab Surveyor3/H20 with a 160-m cable, four Hydrolab Recorder multi-parameter dataloggers, and a collection of thermal dataloggers for Grand Canyon thermal monitoring use. The purchase of additional Hydrolab Recorders is proposed to initiate Lake Powell inflow water quality monitoring and to provide backup units for tailwater monitoring. Other sampling equipment consists of plankton nets, secchi disks, filtration apparatus, and other associated equipment.

Staffing

Presently, the GCMRC IWQP is being conducted with two permanent staff positions. Ancillary help is received from an Interagency Acquisition from the National Park Service, part time term appointees, and volunteers as available. Reclamation's Upper Colorado Regional Office has provided assistance for quarterly reservoir surveys for the past several years.

Staffing requirements include field activities for sampling and instrument deployment and retrieval. These activities require trip planning and preparation, ensuring adequate supplies and needed equipment, and scheduling of personnel. Instrument downloading, maintenance, calibration and servicing are performed in the field or in a laboratory setting. Sample processing and shipment and equipment maintenance is required following a field survey. Data management, statistical summarization, and graphical analysis of the data are required prior to interpretation and subsequent reporting.

Budget

The budget presented below allocates the costs of the program by program element as well as source of funding. Currently, $162,000 of program funds is allocated through a competitive contracting process. These include the costs for sample processing and for downstream water quality data collected at the USGS gages. In addition, about 10 to 20 percent of the time of the limnologist and aquatic biologist are allocated to GCMRC activities outside of the IWQP. Research funds, are estimated at $50,000 per year and will be used to support necessary research activities. Consistent with GCMRC policies, it is anticipated that the monitoring funds are allocated for the long-term whereas the research funds are expected to role over from year to year and become available to support a subsequent research activity, once the prior research activity is completed. Finally, in FY 2001 approximately $25,000 will be spent on a protocol evaluation panel.

Table 4. Proposed budget for IWQP for FY2000

Program Elements	Source of Funds O&M	AMP	Total
1. Personnel[1]			
-- Limnologist	$54,000	$23,000	$77,0002
-- Aquatic Biologist	$54,000	$23,000	$77,000
-- Environmental Studies Asst.	$25,000	$10,000	$35,000
-- Other	$22,000	$10,000	$32,000
Sub-total	$155,000	$66,000	$221,000
2. Sample Processing[3]	$ 85,000	$ 7,000	$ 92,000
3. Downstream Water Quality (USGS)[4]	$ - 0 -	$70,000	$ 70,000
4. Research	$ 30,000	$ 20,000	$ 50,000
5. Logistics[5]	$ 20,000	$ 8,000	$ 28,000
6. Travel	$ 8,000	$ 2,000	$ 10,000
7. Data Analysis & Report Preparation[6]	$ 2,000	$ 1,000	$ 3,000
TOTAL	$300,000	$174,000	$474,000

1 These costs cover personnel for Lake Powell data collection, data analysis, and reporting, as well as tailwater and downstream activities, including thermal monitoring. Also included are trips required to maintain the sensors that are in the field.

2 Includes base salary, benefits, and leave assessment.

3 Sample analysis is contracted out through a competitive process to a qualified water quality lab.

4 USGS currently has a contract, obtained through the competitive RFP process to collect water quality data at gages in the Grand Canyon.

5 Includes boat operating and O&M expenses, foodpacks, equipment maintenance and reagents.

6 This covers the cost of additional sample analysis that may be required, and the cost of report preparation, including color copies, as well as the cost of preparing slides and posters for scientific and public meetings.

Chapter 3 SAMPLING LOCATIONS AND FREQUENCY

Introduction

The primary goal of the GCMRC Integrated Water Quality Program (IWQP) is to describe and understand the influence of dam operations, in the context of climatological and hydrological factors, on water quality in the reservoir and downstream releases and anticipate the effects of future operational scenarios.

Monitored Parameters

Physical and Chemical

Common physical and chemical parameters of water quality will be routinely collected during the measurement of a reservoir profile, continuously in the tailwater below Glen Canyon Dam, and in conjunction with the collection of all chemical samples. These measurements will be taken using a multi-probe instrument, such as a Hydrolab Surveyor3/H20 or Hydrolab Recorder. These measurements will include temperature (^{o}C), specific conductance (μS), pH, dissolved oxygen (mg/L), and turbidity (NTU).

Temperature and specific conductance are important in reservoir surveys because they primarily define the density of the water and determine the fate of an inflow and degree of stratification. Specific conductance is also an indirect measure of salinity and is one indicator of the chemical composition of water. DO and pH indicate layers of biological respiration that can influence concentrations of nutrients. Temperature is important to downstream chemical and biological processes. Specific conductance is also used in a river system to quantify additional chemical inputs from non-gauged tributaries by mass balance.

Dissolved oxygen is important to downstream biological processes. Aquatic organisms have specific requirements for dissolved oxygen. In the reservoir, dissolved oxygen levels indicate the relative age of inflow currents, suitability for release to downstream organisms, and the degree of decomposition of organic matter in a particular stratum. pH is affected by biological and chemical processes such as respiration and oxidation-reduction potential and reflects changes in dissolved oxygen, indicates amounts of carbon dioxide and degree of buffering in the water from biological or atmospheric processes. Turbidity is used to track inflow currents, indicating the concentration of organic or inorganic particles and the amount of light available underwater.

Chemical samples for major ion analysis will be collected to characterize the overall chemical makeup of the water being sampled. Laboratory analysis will include specific conductance, pH, total dissolved solids and total suspended solids, which describe the physical aspects of the water. Chemical concentrations will also be determined for the major cations and anions (sodium, calcium, magnesium, potassium, sulfate, chloride, carbonate, and bicarbonate), in addition to alkalinity, total dissolved solids, iron and dissolved organic carbon. Alkalinity determinations are also performed in the field concurrently with the collection of a chemical sample.

Samples will be collected to determine the concentration of nutrient compounds (total phosphorus, soluble reactive phosphorus, dissolved ammonia nitrogen, total Kjeldahl nitrogen, and dissolved nitrate-nitrite nitrogen). These nutrient compounds support primary productivity in the reservoir and downstream aquatic ecosystem. Phosphorus levels in the reservoir and tailwater are low; most concentrations are below detectable limits by currently used analytical procedures. Further exploration of techniques to achieve lower detection levels will be pursued (Table 4).

Table 4. Detection limit and EPA Methodology of chemicals analyzed for the IWQP.

Analyte	Symbol	Sample Units	Detection Limit	EPA Method
Physical (Hydrolab profiles)				
Temperature	T	°C	0.1	
Specific Conductance	EC	µS/cm	1	
PH	pH	pH	0.01	
Dissolved Oxygen	DO	mg/L	0.01	
Oxidation-Reduction	ORP	mV	1	
Turbidity		ntu	0.1	
Major Ions				
Specific Conductance	Lab EC	µS/cm	2	120.1
pH	pH	pH	N/A	150.1
Total Suspended Solids	TSS	mg/L	4	160.2
Total Dissolved Solids	TDS	mg/L	10	160
Calcium	Ca	mg/L	0.03	200.7
Magnesium	Mg	mg/L	0.03	200.7
Sodium	Na	mg/L	0.03	200.7
Potassium	K	mg/L	1.0	200.7
Carbonate	$CO^{3=}$	mg/L	1.0	310.1
Bicarbonate	HCO^{3-}	mg/L	1.0	310.1
Chloride	Cl^-	mg/L	1.0	300
Sulfate	$SO_{4=}$	mg/L	1.0	300
Silica	SiO_2	mg/L	0.02	200.7
Alkalinity	$CaCO_3$	mg/L		Calc.
Nutrients				
Total Phosphorus	TP-P	mg/L	0.005	365.1
Soluble Reactive Phosphorous	OP-P	mg/L	0.005	365.1
Ammonia	NH_3-N	mg/L	0.01	350.1
Nitrate + Nitrite	$NO_3 + NO_2$-N	mg/L	0.03	353.2
Total Kjeldahl Nitrogen	TKN-N	mg/L	0.05	351.4
Biological				
Chlorophyll-a		mg/m^3	0.01	
Chlorophyll-b			0.1	
Chlorophyll-c			0.1	
Pheophytin-a			0.01	
Phytoplankton		Mostly spp.		
Density		#/L &%		
Biovolume		mm^3/L &%		
Zooplankton		Mostly spp.		
Density		#/L & %		
Biovolume		mm^3/L & %		
Fecundity		egg ratios		

06/24/99

Biological

The objective of the biological program is to characterize, both in the lake and tailwaters, long-term, seasonal, and spatial trends in abundance, community structure, and primary and secondary productivity. This is a long-term program focussing on broader trends. Separate research programs must address quantification of shorter-term effects. Specific goals of the program include the following:

Quantify primary productivity in the reservoir and tailwaters. We can determine trophic status with long-term, seasonal and reach trends in chlorophyll and phytoplankton. Using statistical correlation, limiting and determinative factors of the food-base (physical, chemical, and biotic) can be indicated.

Use biological indicators to evaluate water quality trends. Zooplankton and especially phytoplankton have been used to indicate trophic status, presence of pollutants and other chemical concentrations relevant to plankton growth. The IWQP can both benefit from previous research (Hutchinson 1967) and be instrumental in developing an index for arid reservoirs and regulated rivers.

Quantify secondary productivity of the reservoir and tailwaters. Zooplankton are integral both as predators upon themselves and algae and as prey for fisheries, particularly during the periodic crash of forage fish. The ability to track fisheries lies in part on tracking zooplankton dynamics, both spatially and temporarily.

Frequency and Timing of Sampling

Lake wide surveys will be conducted on a quarterly basis to correspond to significant seasonal processes occurring in the reservoir. These surveys will be timed to coincide with the timing of these processes, rather than being based on strict calendar intervals.

Late Winter

Late winter sampling will be conducted within the period from late January to early March. The objective of sampling during this period is to describe conditions when maximal winter mixing of the reservoir surface has occurred, inflows are of high density and levels of discharge are low, and biological processes are at a minimum.

The epilimnion, or surface layer, of the reservoir (Figure 3) has received the maximum amount of mixing from convective and wind processes, cooling the reservoir surface during the previous winter months. In the deep lower to mid-lake regions of the reservoir, mixing has occurred to its greatest depth; however, temperature and chemical stratification persists, with the underlying hypolimnion, or bottom layer, containing colder and more saline water. In the upstream areas of the reservoir, where depths are less than the maximum depth of winter mixing, turnover, or complete mixing occurs.

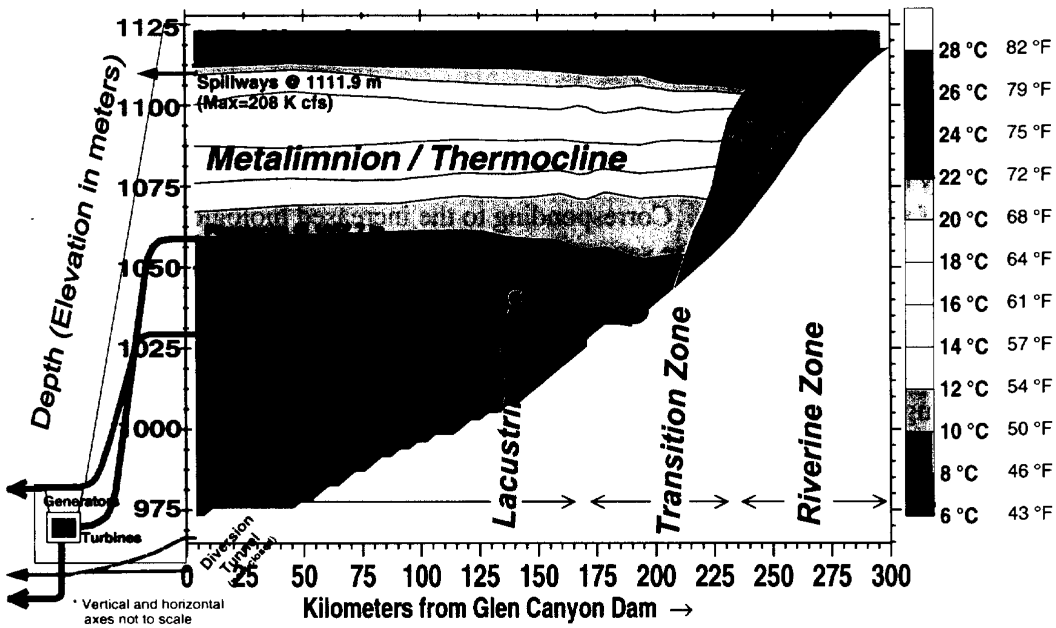

Figure 3. Cross-section isopleth of reservoir temperature showing vertical and longitudinal zones

Inflows to the reservoir are cold and saline, resulting in densities greater than that of the reservoir water. Therefore, a plunging current flows along the bottom of the lake until it 1) dissipates and mixes with water of equal density, 2) moves through the reservoir as a inter-flow, or 3) continues along the bottom of the reservoir, displacing water of lesser density. The fate of this winter inflow current appears to be a function of the volume of inflow and relative density difference between the inflow current and the existing water in the reservoir (Hueftle & Vernieu, in review).

Late Spring

Late spring sampling in May and early June will be performed to describe conditions which have developed during the spring months. Sampling during this period describes the transition between winter mixing and summer stratification. By this time, the lake begins to experience significant thermal stratification from spring warming, biological processes are peaking and the inflows to the reservoir have increased.

As sunlight angle, day length, and ambient air temperature increases, the surface of the lake begins to warm. In areas unaffected by the inflow current, a thermal density gradient is created between the surface and the underlying colder water and a barrier to mixing develops at the thermocline, or depth of maximum temperature change. As the surface waters continue to warm, the depth of the thermocline deepens and the thickness of the new epilimnion increases.

The increased inflows are the result of snowmelt runoff from the high mountains in the upper portions of the basin, which have flowed through the warmer lower elevation agricultural areas and canyon lands. These inflows tend to be warm and dilute, resulting in waters of lower density than the reservoir and a current that overflows the surface of the reservoir.

Biological processes in these areas of the reservoir increase, resulting from warmer conditions, increased sunlight, and higher nutrient availability from winter mixing. The biological processes are limited mainly by nutrient levels and, in the inflow areas, by available light from the increased turbidity of the runoff inflows. Corresponding to the increased biological productivity dissolved oxygen concentrations above the saturation level and high chlorophyll levels are frequently seen in the epilimnion.

Late Summer

Late summer sampling, to be performed during the period of early August to late September, will represent conditions when the reservoir is at its maximum degree of thermal stratification and surface warming. Biological processes are declining and inflows have tapered off, becoming denser and migrating to intermediate depths of the reservoir.

The high flows of the spring snowmelt runoff have subsided; the large inflow volume of this water has extended to downstream regions of the reservoir's epilimnion. Reservoir surface temperatures have reached a maximum. These factors combine to increase the volume and thickness of the epilimnion and maximize the density gradient between the epilimnion and hypolimnion, which defines the degree of stratification.

Inflow temperatures are usually less than reservoir surface temperatures and salinity levels have increased with the return to base flows. This results in an inflow slightly denser than of the epilimnion which usually plunges to intermediate depths in the reservoir.

Biological processes, which have developed throughout the summer, typically become limited by temperature (Blinn 1983, Blinn et al. 1976, Stewart & Blinn, 1976) and nutrient concentrations in the late summer. The resulting decomposition of biomass from the biological activity, combined with organic and inorganic matter contained in the runoff volume begins to depress oxygen concentrations in the reservoir. This decomposition results in significant oxygen deficits at the lower boundary of the epilimnion. These metalimnetic oxygen deficits typically reach a maximum in early autumn.

Late Autumn

Late autumn sampling will be performed within the months of November to December. During this period the lake is in a transition state between the strongly stratified conditions of the previous summer and the maximally mixed conditions of late winter. Biological processes are reduced and inflows migrate to deeper portions of the reservoir.

Cooler conditions result in the onset of convective winter mixing. As warm water at the reservoir surface cools, it becomes denser, and mixes with water of equal temperature at lower depths. As this process continues, this mixed surface layer thickens as it mixes with underlying cooler water. As this new epilimnion cools, its increased density reduces the strong stratification gradient that developed in the summer. It then becomes susceptible to further mixing by winds on the lake's surface. This winter mixing process will eventually cause the breakdown of the strongly stratified epilimnion that developed during the previous summer.

Inflow currents are generally low and have cooled considerably. The low inflow volumes are more sensitive to increases in dissolved minerals from natural and man-made sources become more saline. Decreased temperatures and increased solute concentrations cause inflow currents to plunge to deeper depths in the reservoir due to their increased density.

Biological processes are still active, but on the decline due to lower water temperatures, decreased sunlight and lower nutrient levels. The metalimnetic dissolved oxygen deficits seen during the late summer may still be present at this time but will begin to disappear as winter mixing processes incorporate the metalimnetic waters into the mixed epilimnion. Dissolved oxygen throughout the reservoir is at a minimum as bacterial respiration outpaces algal productivity.

Monitoring Locations

Determination of Sample Locations

Based on the Lake Powell assessment, the evaluation of the data required to support the INs identified above, the sample locations identified below were developed. In the future, new stations will be selected based on the following considerations. First, is whether the general location will provide the required additional information considering trip logistics and expense of data processing and sample analysis. Secondly, is whether or not the proposed station is located at a narrow point or constriction of the lake surface. This is to avoid anomalies which may be present in open bays due to wind effects or other phenomena which may not be representative of main channel conditions. Furthermore, advective density currents, which may be present in upstream reaches, can be better defined in a constricted zone rather than thinned and dissipated in an open bay. Lastly, because the station is selected to represent the entire water column of the reservoir, the station should be located in the deepest portion of the lake or the original river channel. Other considerations may be incorporated to adjust the sampling location, such as direction of prevailing winds to aid in maintaining position for the duration of sampling and availability of landmarks or other features to aid in repositioning.

Table 5. Lake Powell monitoring locations (LT – long-term station since 1965, NEW – station added since 1990, PRO – profile only, no samples, INF – inflow station)

Station Code	RCD (km)	Station Name	Type
Colorado River Main Channel (river channel distance from Glen Canyon Dam)			
LPCR0024	2.4	Wahweap	LT
LPCR0453	45.3	Crossing of the Fathers	LT
LPCR0905	90.5	Oak	LT
LPCR1169	116.9	Escalante	LT
LPCR1400	140.0	Iceberg	PRO
LPCR1589	158.9	Lake	PRO
LPCR1692	169.2	Bullfrog	LT
LPCR1772	177.2	Moki	PRO
LPCR1932	193.2	Knowles	PRO
LPCR2085	208.5	Lower Good Hope Bay	NEW
LPCR2255	225.5	Scorup	PRO
LPCR2387	238.7	Hite Basin	LT
LPCR2483	248.3	Colorado River above North Wash	PRO
LPCR****		Colorado River Inflow	INF
Escalante Main Channel (river channel distance from confluence)			
LPESC072	7.2	Escalante above Clear Creek	PRO
LPESC119	11.9	Escalante at Davis Gulch	NEW
LPESC200	20.0	Escalante at Willow Creek	PRO
LPESC276	27.6	Escalante above Garces Island	PRO
LPESC***		Escalante Inflow	INF

San Juan River (river channel distance from confluence)			
LPSJR193	19.3	Cha (SJR)	LT
LPSJR329	32.9	Lower Piute Bay (SJR)	PRO
LPSJR431	43.1	Upper Piute Bay (SJR)	PRO
LPSJR625	62.5	Lower Zahn Bay (SJR)	PRO
LPSJR***		San Juan River Inflow	INF
<u>Other Tributary Stations</u>			
LPNVC124	12.4	Mid Navajo	NEW

Chapter 4 DATA MANAGEMENT AND ANALYSIS

Introduction and Background

Before computerized database management systems were used to store and manage data from Lake Powell and other reservoirs, information was stored on field sheets and hard copy reports in the Upper Colorado Regional Office in Salt Lake City. As the amount of information gathered from this program and from other projects increased, the need for a computerized tool for data management and analysis became apparent.

During the 1980's, information from the Lake Powell monitoring program was stored in a relational database, residing in Reclamation's Upper Colorado Regional Office in Salt Lake City, Utah. Applications were developed to provide random access to data collected at selected locations and times, tabular reporting and graphical representation of profile information. Concurrent with the development of the Lake Powell data management system were similar relational databases for other limnological and water quality projects in the Upper Colorado region. As each new database developed, it incorporated new characteristics and enhancements reflective of the specific monitoring program and current state of database management techniques.

In 1995, the databases for the various Upper Colorado basin projects were consolidated, integrated, and converted to a standardized database residing on a server in Salt Lake City, Utah (Wheeler, 1995). This database received limited usage due to difficulties with data transfer and the availability of other PC-based software applications for processing data locally. Data now reside in several applications, depending mostly on the type of data, its point of origination, and the primary analysis application.

A consolidation of all water quality information collected by GCMRC is planned to begin in 1999 and is proposed to carry over into FY 2000. The advantage of this system is to facilitate integration of different types of water quality data in a common system for access by the TWG and AMWG, GCMRC analysts, downstream research efforts, and other interested parties. Linkage to other databases such as Glen Canyon Dam releases, USGS gauging stations and other GCRMC monitoring and research projects will also be incorporated. Information from this system will be made available as part of the State of the Canyon Resources Report, developed by GCMRC for the TWG, via the Internet from web-based query engines, or directly from the GCMRC database. Once consolidated, the data will go through a verification and quality assurance process and be transmitted to the EPA STORET system for wide availability to the general public.

Plans for consolidation of the water quality information include the use of Microsoft Access as the primary database for development and population. It will be based on the features described below using a relational database model. The relational structure will facilitate modular development and migration of the data to other systems. Once the GCMRC Oracle database becomes operational, data from this system will be migrated to that database as a permanent repository.

Features

The design structure of the water quality database allows for the incorporation of similar information from other components of the IWQP and is flexible to allow for adaptation of other types of data. This database will be directly accessible by authorized users from within and outside of GCMRC. Preliminary design of the database has used preexisting standards and protocols for station and sample identification, parameter coding and other design factors from the EPA STORET system whenever possible.

Continued progress has occurred with the development and refinement of analytical tools to retrieve selected data from the database, perform statistical and other types of numerical analyses, and display these data in tabular and graphical format.

Currently, the majority of below-dam data analysis is being performed with the use of SAS software (SAS Institute, 1990), which provides comprehensive data management, statistical, and graphical analysis capabilities for data served from the water quality database. In addition to its analytical capabilities, the SAS system stores and maintains hydrologic, water quality and climatic databases for the Grand Canyon maintained by the GCMRC office. Capabilities existing with the SAS system include providing tabular reports, data manipulation, statistical summaries, multi-parameter color graphs of individual profiles (Figure 4), and graphical analysis

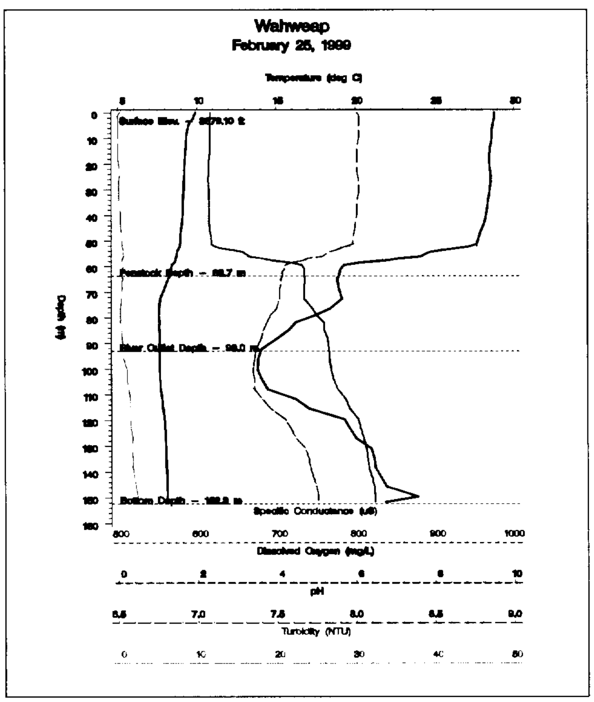

Figure 4. Reservoir water quality profile.

of time series information (Figure 5).

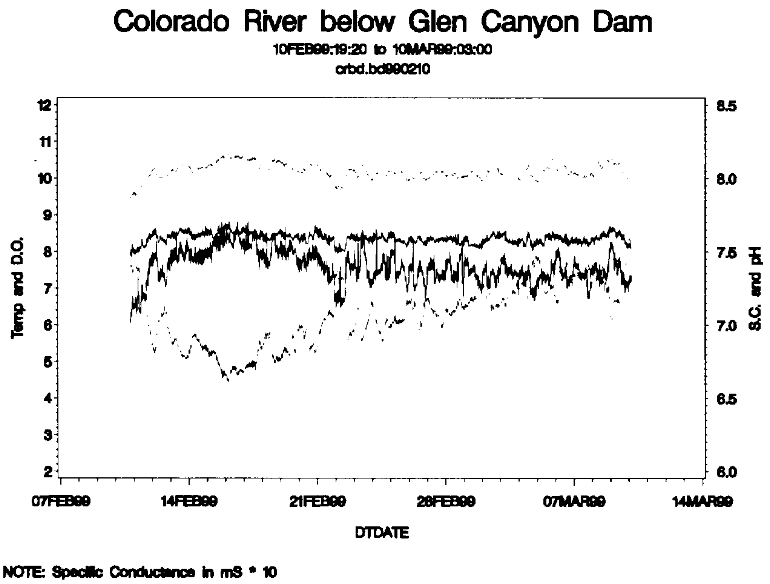

Figure 5. Time series of water quality.

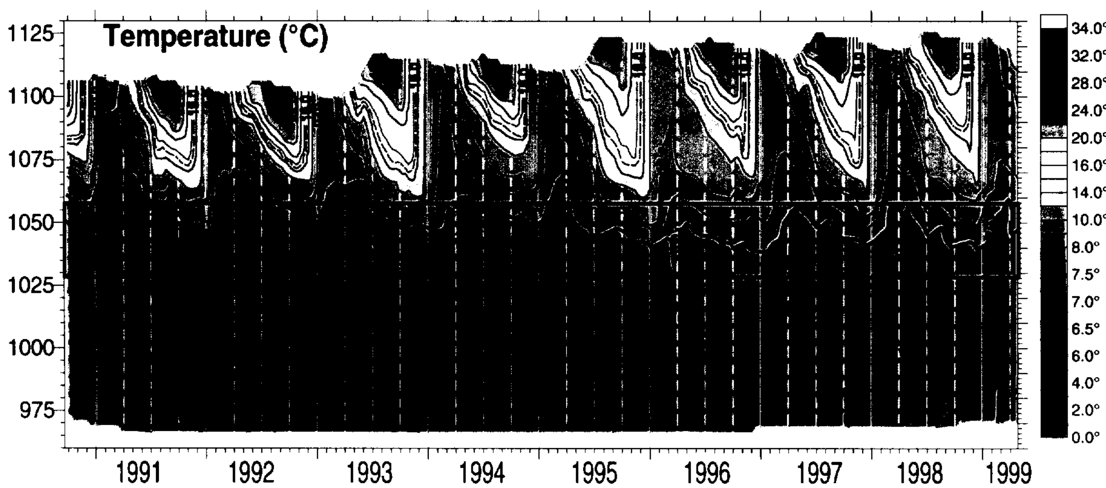

Figure 6. Time series temperature isopleth of Wahweap forebay station, with penstock intakes and river outlet works intakes indicated at 1058m and 1028 m, respectively.

Much of the Lake Powell reservoir data is analyzed using SURFER (Golden Software, Inc.), a three-dimensional analysis program used to develop isopleths of various parameters of the Lake

Powell monitoring program. This provides a valuable tool for depicting information which changes with time at a given station (Figure 6), or which changes across the reservoir at a specific time (Figure 7). The isopleths allow increased understanding of advective and convective processes in the reservoir on a spatial and temporal basis. Timing and frequency of sampling efforts and as well as selection of sampling locations are important considerations when using this tool to represent three dimensional data sets.

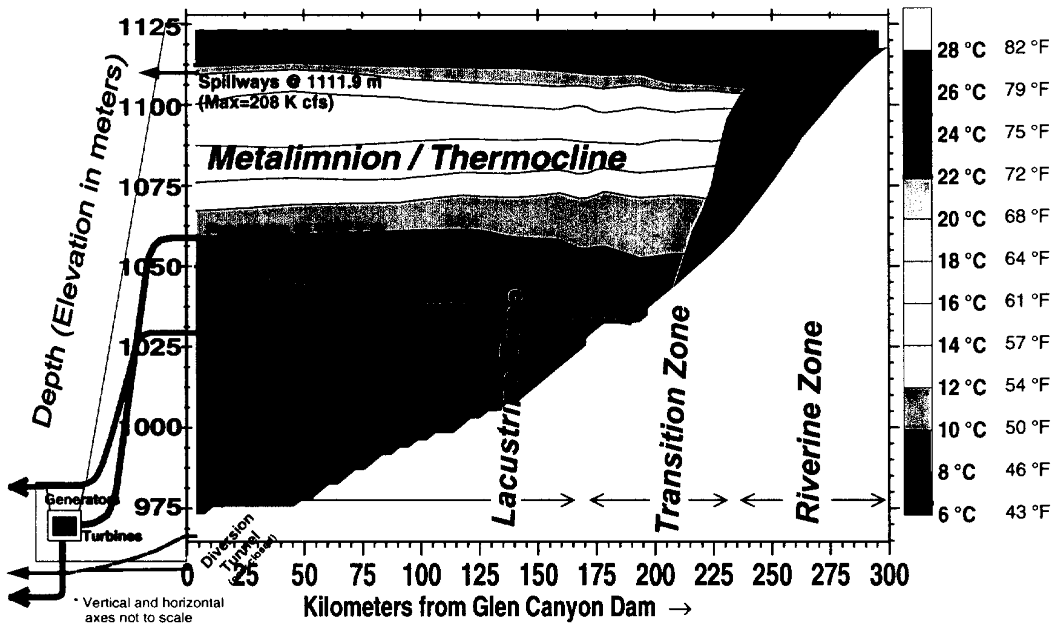

Figure 7. A cross-section of an isopleth of main-channel reservoir temperature.

Recently, a revised station identification scheme has been developed to allow for a standardized system of identifying reservoir sites and incorporating this information as spatial data into the GCMRC geographical information system. As a result, a digitized map of the reservoir has been developed using GIS. Stations can be located and river channel distances from a given reference point can be determined. A record of visual and verbal documentation, geographical coordinates, and river channel distance is maintained for each main channel station.

Database Design

Design Considerations

The design of the IWQP database will determine from the consideration of several factors. First and foremost, it should be a repository for all significant information collected by the monitoring program and be easily retrievable for a variety of purposes. It should follow established standards of relational database management principles such as normalization, optimization, and security. It should have a structure compatible with other existing water quality databases such as the EPA STORET system and the USGS WATSTORE system. In some cases, these goals may be conflicting and choices have to be made to achieve an effective compromise. This compromise is usually made in favor of ease of use and data accessibility.

Furthermore, it is not anticipated that the current design and structure of this database will remain static in the future, as different types of data are stored and further optimization of the existing design occurs. Therefore, a final goal of the database design is that the data exist in a modular format for ease of portability and the table structure and data definitions remain flexible while ensuring the information's overall integrity. A schematic of the proposed structure of the IWQP database is shown in Figure 8.

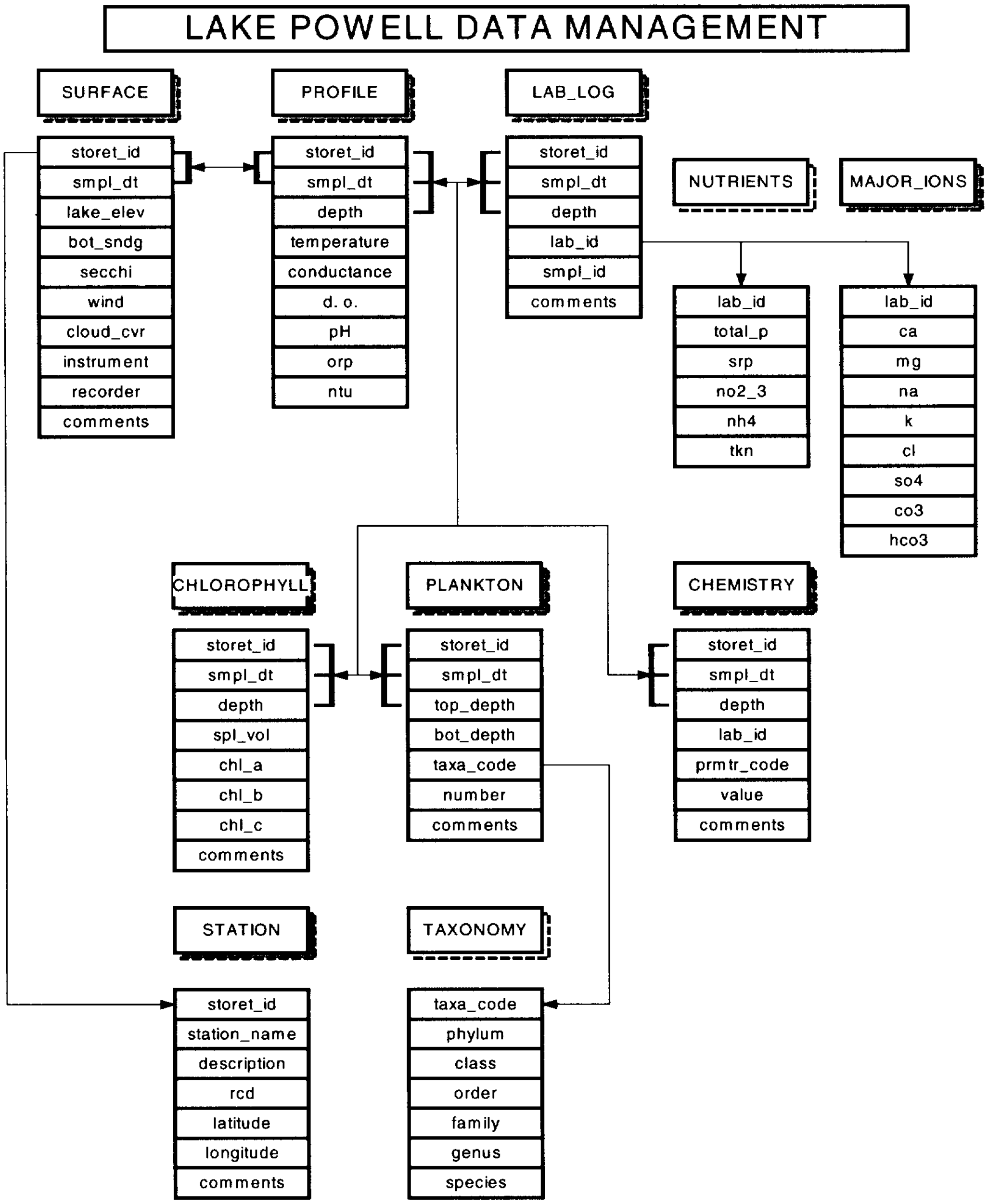

Figure 8. Water quality relational database structure.

Reporting

A number of reports are expected to result from the IWQP. These include quarterly and yearly technical reports, and a five-year review and assessment of the program. In addition, regular research articles are expected to be produced based on the data collected as a part of the IWQP monitoring and research activities, as well as from collaborations with other researchers supported by GCMRC.

References

American Public Health Association. 1992. Standard methods for the examination of water and wastewater. 18th edition. APHA, Washington, D.C. ISBN 0-87553-131-8.

Angradi, T.R., Clarkson, R.W., Kinsolving, D.A., Kubly, D.M., & Morgensen, S.A. 1992. Glen Canyon Dam and the Colorado River: Responses of the Aquatic Biota to Dam Operations. Prepared for Bureau of Reclamation Glen Canyon Environmental Studies. Flagstaff, AZ. Cooperative agreement # 9-FC-40-07940. 155 pp.

Ayers, A.D., & McKinney, T. 1996. Water chemistry and zooplankton in the Lake Powell Forebay, Glen Canyon Dam discharge and tailwater. Arizona Game and Fish Department. Phoenix, AZ.

Benenati, P.L., Shannon, J.P., Blinn, D. W., & Wilson, K.P. 1997. Temporal Changes of Phytobenthos in the tailwaters of Glen Canyon Dam in the Colorado River. Bull North Am. Benthol. Soc. 14:61.

Blinn, D. W. 1993. Diatom community structure along physiochemical gradients in saline lakes. Ecology. 74: 1246-1263.

Blinn, D. W., Shannon, J.P., Benenati, P.L., & Wilson, K.P. 1998. Algal Ecology in Tailwater Stream Communties: The Colorado River below Glen Canyon Dam, Arizona. J. Phycology. 34: 734-740.

Blinn, D. W., Tompkins, T., & Stewart, A. J. 1976. Seasonal Light characteristics for a newly formed reservoir in southwestern USA. Hydrobiologia. 51: 77-84.

Cole, T.M. and E.M. Buchak. 1995. CEQUAL-W2: A two-dimensional, laterally averaged, hydrodynamic and water quality model, version 2.0. Instructional report EL-95-1. Army Corps of Engineers, Washington, DC.

Eckhardt, D.W. 1995. Mapping Water Quality on Lake Powell using Landsat Thematic Mapper Imagery (Remote Sensing). Applied Sciences Referral Memorandum No. 94-4-1. Unpublished results.

EPA - Methods for chemical analysis of water and wastes, EPA-600/4-79-020, (Environmental Monitoring and Support Laboratory, Cincinnati, OH, March 1983).

Ferrari, R.L. 1988. 1986 Lake Powell survey. U.S. Bureau of Reclamation Rep. REC-ERC-88-6. NTIS, Springfield, VA.

Gloss, S.P.. R.C. Reynolds, Jr., L.M. Mayer and D.E. Kidd. 1981. Reservoir influences on salinity and nutrient fluxes in the arid Colorado River basin. In: H.G. Stefan (ed.) Symposium on Surface Water Impoundments ASCE. June 2-5, 1980. Minneapolis, MN. Pages 1618-1629.

Haury, L.R. 1983-1987. Summary Report of Zooplankton Collections from Lake Powell. Unpublished results to Glen Canyon National Recreation Area. Page, AZ.

Horne, A.J., & Goldman, C.R. 1994. Limnology. 2nd edition. McGraw-Hill, Inc. New York. 576 pp.

Horn, M. & G. Mueller. Hydro-Acoustic measurement of zooplankton and fisheries dynamics in Lake Powell Bureau of Reclamation, Denver CO. (in draft).

Hutchinson, G.E., 1967. A Treatise on Limnology. II. Introduction to Lake Biology and the Limno-plankton. New York, John Wiley & Sons, Inc., 1115 pp.

Hueftle, S. J. and L.E. Stevens. 1999. Experimental Flood Effects on the Limnology of Lake Powell Reservoir, Southwestern USA. Ecological Applications. (In review).

Hueftle, S. J. and W. S. Vernieu. Assessment of Impacts of Glen Canyon Dam Operations on Water Quality Resources in Lake Powell and the Colorado River in Grand Canyon. Grand Canyon Monitoring and Research Center, Department of Interior. Flagstaff, AZ. (In review).

Miller, Jerry, Personal communications, (801)524-5454.

Millipore Corporation 1994. Bedford MA.

SAS Institute, Inc. 1990. SAS Language: Reference, Version 6, First Edition, Cary, NC.

Sollberger, P., Vaux, P.D., & Paulson, L.J. 1988. Investigation of Vertical and seasonal distribution, abundance and size structure of zooplankton in Lake Powell. Lake Mead Limnological Research Center, University of Nevada, Las Vegas. 263 pp.

Stanford, J.A. and J.V. Ward. 1991. Limnology of Lake Powell and the chemistry of the Colorado River. In: Colorado River Ecology and Dam Management. WSTB. May 24-25, 1990. Santa Fe, NM. Pages 75-101.

Stewart, A. J., and Blinn, D. W., 1976. Studies on Lake Powell, USA: Environmental factors influencing phytoplankton success in a high desert warm monomictic lake. Arch. Hydrobiology. 78, 2, 139-164.

Thornton, K.W., B. L. Kimmel, F. E. Payne, ed. 1990. Reservoir Limnology: Ecological Perspectives. John Wiley and Sons, Inc. New York, NY.246 pp.

US Bureau of Reclamation. 1995. Operation of Glen Canyon Dam final environmental impact statement. Salt Lake City, UT.

US Geological Survey, National handbook of recommended methods for water data acquisition, Office of Water Data Coordination, 1977.

Vernieu, W. S., Effects of reservoir drawdown on resuspension of deltaic sediments in Lake Powell. Lake and Reservoir Management, in print, 1995.

Wheeler, G. 1995. Water quality water management: user's guide. Bureau of Reclamation, Information Resources Division, Salt Lake City, UT.

Wetzel, R. G. 1975. Limnology. W. B. Saunders Co., Philadelphia, PA. 767 pp.

Wildco. 1998. 301 Cass St. Saginaw, MI.

Appendix A RELATIONSHIP OF WATER QUALITY MONITORING TO GLEN CANYON DAM ADAPTIVE MANAGEMENT PROGRAM

Historical Background

The Lake Powell water quality monitoring program was revised and enhanced in 1990 under the direction of the Glen Canyon Environmental Studies (GCES) Program Manager to provide information on physical, chemical, and biological processes in the reservoir and how these processes affected the quality of releases to the downstream ecosystem. Funding was accomplished under the GCES overall program budget.

Since the establishment of the Glen Canyon Dam Adaptive Management Work Group (AMWG) on February 4, 1997, several of the Adaptive Management Program (AMP) stakeholders raised questions about whether monitoring activities in Lake Powell were appropriate within the scope of the Adaptive Management Program. A primary concern related to whether changes in dam operations, as specified under the Record of Decision, affected the water quality of Lake Powell and Glen Canyon Dam releases.

Lake Powell Assessment

To address this question, GCMRC agreed to undertake a one-year assessment of existing water quality information to determine whether historical operations of Glen Canyon Dam had significant effects on the water quality of the Lake Powell and the Colorado River downstream of Glen Canyon Dam (Hueftle & Vernieu, in review). Three professional limnologists from outside the federal government reviewed the preliminary findings of this assessment and comments were received from several water quality specialists within the federal government. A final draft of this document was issued March 6, 1998 to the AMWG and its Technical Work Group (TWG).

This assessment concluded that, while major water quality changes in Lake Powell and downstream releases are primarily governed by hydrological and climatological factors, several aspects of dam operations have significant effects on the water quality of the reservoir and downstream releases to the Colorado River. Changes to water quality have been identified from the operation of alternate release structures, high-sustained releases during several historical periods, and from daily powerplant fluctuations. Some of the historical release scenarios have had significant effects on the reduction of meromictic conditions in Lake Powell. Meromixis is characterized by a buildup of dense water in the deepest portions of the reservoir, which stagnates and loses dissolved oxygen over time, causing the potential for detrimental impacts to aquatic ecosystems and power generation facilities.

Based on the findings of significant effects to Lake Powell and Colorado River water quality from Glen Canyon Dam operations, the AMWG requested GCMRC to develop a five-year monitoring and research plan for future water quality monitoring. This plan was presented to the AMWG on July 22, 1998, along with the GCMRC FY 2000 budget request. The plan, at that time, focussed primarily on addressing the information needs developed to meet management objectives specific to Lake Powell. Several elements of downstream water quality monitoring were incorporated. The plan also specified the development of a conceptual model for the Lake Powell reservoir ecosystem as well as other studies confined to Lake Powell.

Additional concern was raised at this meeting as to whether water quality monitoring activities in Lake Powell related to effects to downstream resources. Expansion of the geographical scope of the AMP monitoring and research program and GCMRC funding levels were also concerns. Report language of the Grand Canyon Protection Act specifies that the Glen Canyon Dam Adaptive Management Program focuses on effects primarily to downstream resources. From this discussion, the Technical Work Group was charged to determine which water quality monitoring activities in the five-year plan related to effects to downstream resources and which had relationship solely to resources upstream of Glen Canyon Dam.

Separation of Monitoring Activities

Three categories were described to facilitate separation of activities, White, Black, and Grey. The White category was defined to represent those activities conducted below Glen Canyon Dam that address effects to downstream resources. As an example, monitoring of Glen Canyon Dam release water quality would fall under this category. The Black category was defined to represent those activities conducted upstream of Glen Canyon Dam that are not directly related to downstream effects. An example of an activity in this category might be evaluating water quality impacts to recreation or shoreline vegetation in Lake Powell. The Grey category included those activities conducted upstream of Glen Canyon Dam which relate to effects to resources downstream of Glen Canyon Dam. An example of this category would be monitoring of the water column in the forebay immediately above Glen Canyon Dam. It was felt that responsibility for activities in the White and Grey areas would remain under the AMP, while those in the Black area were beyond the scope of the AMP and would not be funded.

It is recognized that there may be a great deal of overlap between activities in the Grey and Black areas. Monitoring performed in Lake Powell characterizes both conditions within the Lake Powell reservoir and the water that will be discharged from Glen Canyon Dam to the downstream environment. The chemical, physical, and biological conditions of all water within Lake Powell is affected by advective and convective mixing processes and influenced by the operation of Glen Canyon Dam. These conditions and the processes that act on them directly influence the quality of releases to the aquatic ecosystem downstream of Glen Canyon Dam (Hueftle & Stevens 1999, Hueftle & Vernieu 1998, in review, Gloss et al. 1981).

Reclamation Funding Proposal for Lake Powell Monitoring

In an effort to resolve the difficult questions of authority and responsibility for the various components of the proposed five-year plan for Lake Powell monitoring and research, an ad hoc committee of the TWG was formed. A proposal was developed by this committee, with approval of various stakeholder groups, to fund all water quality monitoring activities conducted upstream of Glen Canyon Dam though the Reclamation O&M budget from CRSP power revenues or other sources, as appropriate. Doing so would place less budgetary obligation on the AMP and would maintain a definite geographic boundary (Glen Canyon Dam) for AMP monitoring and research activities. GCMRC would develop the scope of work, in coordination with Reclamation, and would accomplish the work with internal staff and/or contractors. Activities within the White category would remain under AMP responsibility and funding authority and those within the Black category would not be part of the AMP, but would be accomplished and funded by Reclamation, members of an interagency group of entities with interest in Lake Powell, or other sources.

This committee further defined the White, Black, and Grey categories as follows:

1. White Areas

Those AMWG MO/INs that relate to downstream (below GCD) effects and conducted downstream of the dam:

-- Funded by the AMP budget

-- Scope of work reviewed and approved by AMWG/TWG

-- Includes all appropriate approved MOs and INs

-- GCMRC protocols apply (peer review, etc.)

-- Accomplished by GCMRC and/or its contractors

-- GCMRC will determine its capabilities to accomplish the work within funding personnel and other constraints

2. Gray Areas

Those AMWG MO/INs that relate to downstream effects, but conducted upstream of the dam:

-- Funded by the Reclamation O&M budget for Glen Canyon Dam or other sources, as appropriate

-- Scope of work developed by GCMRC with Reclamation and the Lake Powell Group to respond to all appropriate AMWG MOs and INs and those of Reclamation and the Lake Powell Group, as appropriate

– GCMRC protocols apply with PEP review before submission to AMWG/TWG

-- Submitted to AMWG/TWG for review and recommended adoption

-- Accomplished by GCMRC and/or its contractors

3. Black Areas

Those AMWG MO/INs not directly related to downstream effects and conducted upstream of the dam

-- Funded by Reclamation, Lake Powell Group, or other sources

-- MO's and IN's are retained until next revision.

-- GCMRC protocols may not apply, but data collection should be consistent for sharing of results

-- Accomplished by Reclamation or participants in the Lake Powell Group

-- Results will be shared with GCMRC and AMWG

GCMRC Integrated Water Quality Program

Since the establishment of the Grand Canyon Monitoring and Research Center (GCMRC), water quality activities have formerly been spread across different program areas. Water quality monitoring at mainstem gages in Grand Canyon, as well as some forebay monitoring and tailwater research, were administered by the GCMRC Physical Science Program. Thermal monitoring through Grand Canyon and selected tributaries was administered through the Biological Science Program. Lake Powell and tailwater monitoring were separate from these programs.

In order to coordinate water quality monitoring and research activities, reduce redundant data collection, facilitate data integration, and standardize methodology, these activities were combined to form the GCMRC Integrated Water Quality Program (IWQP) as part of the GCMRC strategic planning process. This program now falls under the direction of the GCMRC Biological Science Program. This reflects the direct linkage of the aquatic ecosystem to the water quality conditions that sustain it. This program encompasses all water quality activities conducted by the GCMRC office.

The GCMRC IWQP is designed to address the various water quality-related information needs developed by the TWG to meet the management objectives of the AMWG for adaptive management of the Grand Canyon ecosystem.

The proposed GCRMC IWQP consists of four main components of monitoring activities:

1. Quarterly reservoir water quality surveys

2. Monthly water quality surveys in the immediate forebay above Glen Canyon Dam

3. Continuous monitoring and monthly sampling of the Glen Canyon Dam tailwater immediately below the dam and at Lees Ferry

4. Downstream monitoring within Grand Canyon and major tributaries

Based on the above definitions, Items 1 and 2 would fall under the Grey category and be funded by Reclamation while Items 3 and 4 would remain the responsibility of the AMP.

It is proposed that, regardless of funding source, these components remain as part of the GCMRC IWQP and continue to be accomplished with GCMRC resources. GCMRC would continue to define the scope of work, in coordination with Reclamation and AMWG information needs, and would make revisions to the monitoring program as needs change and other information becomes available. Contracting for specific work items would occur as needed according to established GCMRC protocols. This proposal is based on the following:

These monitoring activities have been designed and implemented by personnel staffed at GCMRC with extensive experience with Reclamation reservoirs.

These activities have been conducted consistently, producing high-quality information using standardized methods and procedures for the past nine years.

They have built upon and integrate with the previous 26-year program conducted by the Bureau of Reclamation and were modified to address issues related to the effects of dam operations on downstream water quality.

Provide for integration of all data collected in a common system for availability to all interested parties according to GCMRC information packaging protocols and plan.

They address AMP water quality-related management objectives and information needs for Lake Powell and downstream resources.

They take advantage of a broad array and substantial investment of equipment, expertise and experience, and protocol development residing within GCMRC.

Appendix B Methodololgy

Field activities associated with the Lake Powell monitoring program will be generally conducted at established main channel stations throughout the reservoir from a 31-foot Uniflite sedan powered by twin inboard engines. This vessel provides workspace for sampling activities on its aft deck and living quarters for a crew of four to six people for weeklong reservoir surveys. At times, a smaller runabout will be used in addition to the Uniflite to increase the efficiency of the sampling effort.

At each station, several activities will be conducted to gathered information and collect samples representative of the reservoir at that location. Initial observations characteristic of the location and time of sampling will be recorded. A depth profile of physical water quality parameters will be recorded. Water samples from several discrete depths will be collected and processed for later analysis. Finally, measurements and samples of biological conditions are taken at selected locations in the water column. These activities are described in detail below.

Initial Observations

Upon arrival at a sampling location, a general time will be recorded, which is used to nominally identify the profile and all samples collected during the site visit. General meteorological observations will be recorded describing cloud cover, wind speed and direction, air temperature, and wave height. Secchi depth readings will be recorded, using the unaided eye and a subsurface viewing scope. The surface elevation of the lake is obtained from daily National Park Service radio reports and the bottom depth will determined using a Lawrence X-16 sonar depth finder.

These readings are descriptive of conditions measured at the surface for a single site visit. They will be recorded on the header of the field data sheet and form one observation in the data table SURFACE in the IWQP database. This observation will be uniquely identified by the station code and time identified for the site visit, which are the key fields of the SURFACE data table. See 0 for a description of the WQWM database.

Secchi disk transparency will be recorded using a standardized 20-cm disc with alternating quadrants of black and white. The secchi disk is attached to a metric surveyors tape or a calibrated line marked in tenths of meters. The disk will be lowered over the side of the boat to a depth at which it disappears from view. This observation is made over a sufficient time to allow for variations in surface disturbance and glare. Frequently, several measurements will be made by different observers that will be later averaged after an evaluation of quality. The secchi depth, observer's initials, and quality of observation conditions will be noted on the field data sheet. Beginning in 1994, a subsurface viewscope (Lawrence Enterprises, Aqua Scope II) will be employed to eliminate effects of glare or surface disturbances. Viewscope secchi depths are usually greater than those obtained by traditional methods. While they probably represent more accurate estimates of water transparency, they are not comparable to the depths obtained by traditional methods. Therefore, secchi depths by both methods will be recorded for comparison purposes.

Water Quality Profiling

Water quality profiles in Lake Powell will be obtained with the use of a Hydrolab H20/Surveyor 3 multi-parameter measurement system. The H20 is a submersible, multi-parameter sonde unit capable of measuring temperature, specific conductance, dissolved oxygen, pH, oxidation-reduction potential, and turbidity. Formal calibration procedures will be followed, according to established protocol and manufacturers guidelines, in a controlled laboratory setting before and after use in the field. Accuracy checks will be made while in the field, but actual calibration will be avoided due to the unstable environment affecting the equilibrium of the instrument's sensors.

The H20 will be connected to the Surveyor 3; a shipboard display and datalogger unit used for calibration of the sonde and for display and logging of the profile readings. These units will be connected by a 165 m underwater cable mounted on an AC powered motorized reel. A palmtop computer (HP 200LX) will be connected to the Surveyor 3 and is used to temporarily store readings for immediate display after the profile is completed. This immediate display aids in the identification of sampling depths throughout the water column. Permanent readings will be stored in the Surveyor 3 for subsequent downloading and processing.

After the initial surface observations have been made the water quality profile will be conducted. The H20 sonde will be lowered to selected depths throughout the water column; readings will be stored in the Surveyor 3 datalogger after equilibration at a given depth is achieved and readings have stabilized. The main objective of the profiling effort is to characterize the major limnological strata which comprise the water column with sufficient resolution to accurately define boundaries of the strata and identify other significant phenomena such as inflow density currents and depths at which dissolved oxygen minima or maxima occur.

Initial subsurface readings will be taken immediately below the surface and at approximately 0.5 to 1- meter intervals for the first few meters to determine any surface warming phenomena. Below these initial measurements, the "Rule of Fives" will be observed to determine intervals between measurements. The "Rule of Fives" states that if the value of any parameter changes by more than a decimal fraction of five units (i.e. 0.5 units for temperature and dissolved oxygen, 0.05 units for pH, or 50 μS for conductance), a smaller depth interval should be chosen, usually with 0.5 meter being the minimum interval. If parameters are not changing at this rate, a larger interval (up to 10 meters) may be selected. This allows for sufficient vertical resolution in the profile while allowing for a reasonable time on station to conduct the profile and allow full equilibration between measurements.

The profile will be conducted from the surface to the bottom, with efforts made to come as close to the bottom as possible without disturbing bottom sediments, which can foul sensors and cause ambiguous readings. After the bottom reading is recorded, the datalogging equipment will be disconnected, the reel rotated into its vertical retrieval position and the sonde retrieved. After retrieval, it will be stored in a cylinder filled with lake water between stations.

After the profile is conducted, the structure of the water column will be determined from readings recorded on the field sheet or from the graphic display of data recorded on the palmtop computer. From this information, depths at which discrete water quality samples will be collected are determined based on the sampling objectives described below.

The readings recorded at each depth are descriptive of the physical conditions at that point in the water column. They form one observation in the data table PROFILE (Figure 8). The station code, time, and depth of the reading uniquely identify each observation.

Chemical Sampling

Water samples for determination of major ion and nutrient concentrations will be collected at various depths from all regular long-term stations on Lake Powell. Detection limits currently obtained are indicated in **Table 4.**

Table 4. Detection limit and EPA Methodology of chemicals analyzed for the IWQP.

Analyte	Symbol	Sample Units	Detection Limit	EPA Method
Physical (Hydrolab profiles)				
Temperature	T	°C	0.1	
Specific Conductance	EC	μS/cm	1	
PH	pH	pH	0.01	
Dissolved Oxygen	DO	mg/L	0.01	
Oxidation-Reduction	ORP	mV	1	
Turbidity		ntu	0.1	
Major Ions				
Specific Conductance	Lab EC	μS/cm	2.	120.1
pH	pH	pH	N/A	150.1
Total Suspended Solids	TSS	mg/L	4.	160.2
Total Dissolved Solids	TDS	mg/L	10.	160
Calcium	Ca	mg/L	0.03	200.7
Magnesium	Mg	mg/L	0.03	200.7
Sodium	Na	mg/L	0.03	200.7
Potassium	K	mg/L	1.0	200.7
Carbonate	CO3=	mg/L	1.0	310.1
Bicarbonate	HCO3-	mg/L	1.0	310.1
Chloride	Cl-	mg/L	1.0	300
Sulfate	SO4=	mg/L	1.0	300
Silica	SiO2	mg/L	0.02	200.7
Alkalinity	CaCO3	mg/L		Calc.
Nutrients				
Total Phosphorus	TP-P	mg/L	0.005	365.1
Soluble Reactive Phosphorous	OP-P	mg/L	0.005	365.1
Ammonia	NH3-N	mg/L	0.01	350.1
Nitrate + Nitrite	NO3 + NO2-N	mg/L	0.03	353.2
Total Kjeldahl Nitrogen	TKN-N	mg/L	0.05	351.4
Biological				
Chlorophyll-a		mg/m3	0.01	
Chlorophyll-b		mg/m3	0.1	
Chlorophyll-c		mg/m3	0.1	
Pheophytin-a		mg/m3	0.01	
Phytoplankton		Mostly spp.		
Density		#/L &%		
Biovolume		mm3/L &%		
Zooplankton		Mostly spp.		
Density		#/L & %		
Biovolume		mm3/L & %		
Fecundity		egg ratios		

The main objective of the sampling effort will be to characterize chemical conditions at the surface and in each major stratum, or layer of distinct water, through the water column. A secondary purpose will be to describe unusual phenomena that occur at specific depths such as a severe metalimnetic oxygen deficit or a narrow inflow plume inter-flowing into an intermediate layer in the reservoir.

Samples are seldom collected at depths that characterize rapidly changing values of the profile parameters. Since all samples will be correlated with the previously collected profile measurements (temperature, conductance, pH, dissolved oxygen, etc.), the chance of erroneously equating a sample with a profile measurement made at a slightly different depth in that rapidly changing environment becomes significant. In that case, the chemical conditions represented by the water sample are not representative of the measurements from the water quality profile. Furthermore, the water present in this rapidly changing transition zone is not representative of any major stratum in the reservoir and reduces the value of a sample collected at this point, except to identify unusual phenomena.

All samples for chemical analysis will be collected in high-density polyethylene bottles that have been pre-cleaned to EPA Contract Laboratory Program (CLP) specifications (I-Chem 300 Series). The pre-cleaning process involves acid washing and DI water rinsing under controlled conditions to remove any impurities from storage conditions or the manufacturing process which may affect the determination of low-level analytes.

Sample Collection

Samples will be collected using Van Dorn samplers attached to a 160-m stainless steel cable connected to a motorized winch. This task involves two people, one to operate the winch and one to attach and remove the samplers. The cable is marked at one-meter intervals for accurate sampling depths. Samplers are lowered in a string to their desired depths and are activated by a weighted messenger that travels down the cable. As one sampler is tripped, it releases a second messenger which, in turn, trips the sampler below. The samplers are retrieved, noted as to which depth they were deployed, and set aside for sample processing.

For both major ion and nutrient analysis, a total of four sub-samples will be collected, which include two unfiltered sub-samples of 250 ml and two filtered sub-samples of 125 ml. The unfiltered major ion sub-sample will be used for the laboratory determination of total suspended solids, pH, specific conductance, and alkalinity. The filtered major ion sample will be used for the determination of major dissolved ion concentrations. The unfiltered nutrient sample will be used for the laboratory digestion and determination of total phosphorus and total Kjeldahl nitrogen. The filtered nutrient sample will be used for the determination of dissolved compounds of phosphorus and nitrogen. Both nutrient sub-samples will be preserved with sulfuric acid in the amount described below.

Sample Filtration

The Environmental Protection Agency states that samples to be analyzed for the determination of dissolved substances are to be filtered thorough a 0.45 μm membrane filter as soon as possible after collection, preferably in the field (EPA, 1983). This will be performed on shipboard for Lake Powell samples immediately after their collection, within 15 minutes. This will be accomplished using a peristaltic pump (Geotech Series II) with silicon tubing connected directly to the Van Dorn sampler. A segmented flow of air and sample is used to thoroughly rinse the pump tubing before connecting to the filter apparatus. The filter apparatus is a 47 mm in-line filter holder (Millipore Swinnex 47) housing a 47 mm 0.45 μm polycarbonate membrane filter, low in water extractable compounds (Poretics #1035, lo extractable).

After approximately 50-100 ml pass through the filter apparatus, the filtered sub-sample is collected into a high density polyethylene bottle which has been pre-cleaned to EPA Contract Laboratory Program (CLP) specifications (I-Chem 300 Series). The pre-cleaned bottles will also be used for the collection of unfiltered sub-samples.

Preservation

Both types of samples will be stored and shipped on ice; the nutrient samples will be acidified with 1+9 sulfuric acid (approximately 1.2 N H_2SO_4) in a proportion of 1 ml acid per 250 ml sample. The acid preservation solution is supplied by Reclamation's Denver Laboratory. Fresh acid preservation solutions will be used for each reservoir survey.

The purpose of preserving samples collected for later analysis is to 1) retard biological activity, 2) reduce chemical changes occurring between collection and analysis, 3) reduce volatility of constituents, and 4) reduce adsorption affects with the sample container.

Acid preservation is not currently recommended by some sources for the determination of soluble reactive phosphate; however, it has been selected for the IWQP for several reasons. Recommended methods of preservation include the addition of mercuric chloride ($HgCl_2$) (USGS, 1989), and chilling to 4°C with no preservative and analyzing within 48 hours (EPA, 1983). Neither method is practical for use on Lake Powell. The use of $HgCl_2$ has obvious environmental consequences if spilled and will poison cadmium reduction columns used for nitrate determination. Analysis within 48 hours is not possible due to logistical constraints on shipping samples from remote locations on Lake Powell. The primary reason against using H_2SO_4 is due to possible hydrolysis of polyphosphate compounds that could cause an overestimation of SRP. However, high levels of polyphosphates are typically more characteristic of sewage effluent discharges and not expected in significant concentrations in Lake Powell. Furthermore, concentrations of SRP in Lake Powell are usually well below a detection limit of 5μg/l; any overestimation due to hydrolysis is negligible.

Documentation

The location of all samples collected at a specific station will be noted on the field sheet for that station, along with the identifier of the particular Van Dorn sampler that would be used, the person collecting the sample, and a sequential field number for each sample. The four bottles comprising the nutrient/major ion sub-samples at a given depth are treated as a single sample. Quality control samples collected at a given station are treated and numbered in the same manner as all other samples.

Starting with the first sample of the trip, a sequential field number is assigned to each sample for identification and tracking purposes. This number is recorded on the cap of each bottle as well as on the field sheet and sample labels. A circled field number on the bottle cap identifies nutrient sub-samples. This allows rapid inventory of the samples before shipment and aids identification in the event of mislabeling.

Each sub-sample receives a label which identifies the station code and name, sampling time and depth, field number, type of analysis requested, and the presence of any preservative. Label material and marking pens are chosen that are resistant to damage from submersion.

The combination of station code, time, and depth of sampling uniquely identify each sample collected. These fields and other information pertaining to the sample such as laboratory ID numbers for each analysis comprise one observation in the data table LAB_LOG. The LAB_LOG table is used to link sample collection information with the actual analytical results from the laboratory, which are contained in the tables, MAJOR_IONS and NUTRIENTS (Figure 8).

Transportation and Shipment.

After sample processing, samples will be stored on ice in coolers for the duration of the reservoir survey. Nutrient samples will be stored in a separate cooler from major ion samples. On return from the field, samples will be checked to ensure all samples are accounted for and proper documentation has been performed. The coolers will be re-iced and shipped via overnight delivery to Reclamation's water quality laboratory in Denver, CO for analysis.

Trace Element Sampling

Samples for trace element determination will not be routinely collected as part of the IWQP, but non-quality controlled preliminary ICAP scan values will be made available on demand. They will also be collected on occasion as part of other special studies relating to the reservoir (Miller, personal communications, Vernieu, 1995). Depending on the objectives of the particular study, special methods will be employed when collecting this type of water sample. A non-metallic Kemmerer sampler will be used (e.g. Wildco #1290), nylon line instead of stainless steel cable will be used for deployment of the sampler, plastic gloves will be used at all times during the sampling process, reagent grade rinse water will be used to clean equipment and ultra pure nitric acid (HNO_3) or other solutions will be used to preserve the samples.

Quality Assurance

Quality control procedures are a critical part of the chemical sampling program for the IWQP. The procedures employed will 1) verify the lack of contamination of samples from the collection process, 2) establish the variability of sampling methods in the field, and 3) provide an additional means of establishing the precision and accuracy of laboratory analyses over and above the laboratory's internal quality assurance program. Precision is a measure of the variability of multiple measurements or analyses performed on a given sample. Accuracy is a measure of how closely a result comes to the actual value of the parameter being measured.

Through the course of a reservoir survey, approximately 10% of the total number of samples collected will be quality control samples. Three basic types of quality assurance samples collected will be 1) replicates, 2) blanks, and 3) spikes.

Replicate Samples. Replicate samples will be collected to determine the precision of a sampling or analytical technique. Replicates resulting from separate sampling efforts, or sample replicates, are used to evaluate the variability or precision of sampling activities. This type of replicate would not routinely be collected as part of the monitoring program. It is assumed, for the parameters being analyzed, that the variability of samples collected from a repeated effort at given site is low; previous sampling of this type has shown this to be true.

Replicates resulting from the same sample, or laboratory replicates (also called "splits") will be used to evaluate the precision of the laboratory analytical process. These samples are collected from a continually mixed sampler and identified as two separate samples.

Blank Samples. Blank samples will be used to determine the presence of, or verify the absence of, any contamination in the sampling or sample processing efforts. A field blank is used to evaluate any sources of contamination from any aspect of the sampling or sample processing steps. For this sample, reagent grade water is passed through every step of the sample processing process. The Van Dorn sampler is rinsed three times with reagent grade water then filled with a sufficient volume to fill all sample bottles. This water is used to rinse the filter apparatus in the same manner that an actual sample in used. It is finally collected into pre-cleaned sample bottles. Field blanks for nutrient analysis are preserved with sulfuric acid; unfiltered blanks are not passed through the filtration apparatus. Any detectable analyte that shows up in these samples is indicative of contamination occurring somewhere in the sampling process.

A reagent blank is collected to verify the presence of absence of contamination in the sampling bottles, reagent grade rinse water or acid preservation solution. For this sample, reagent grade water is collected directly into pre-cleaned sample bottles and preserved as appropriate for the analysis. No filtration step is performed, although the bottles for dissolved constituent analysis are still labeled as being filtered. Any detectable analyte that shows up in these samples indicates contamination from sources other than the sampling or filtration apparatus.

Spike samples. Spike samples will be collected for two purposes, 1) to determine the accuracy of an analytical process and 2) to ascertain the loss of a particular substance from volatilization or adsorption. To evaluate these characteristics, a field spike is prepared by collecting a known volume of a laboratory replicate of the sample and adding a known volume of a solution of known concentration. This spike solution, prepared at the Denver laboratory, is prepared with known concentrations of the nutrient compounds that are determined in the laboratory analysis. The solution contains concentrations of 10 mg/l SRP (PO_4 as P), 100 mg/l nitrate nitrogen (NO_3 as N), and 10 mg/l ammonia nitrogen (NH_4 as N). Volumes of the spike solution are added to a measured volume of sample such that resulting concentrations are well into the range of detectability and not more than 10 times the concentration of the sample itself. The resulting "spiked" sample is then either transferred directly to sample bottles (for unfiltered sub-samples) or passed through the filtration apparatus (for filtered sub-samples). When possible, a larger Van Dorn or other type sampler (Wildco 6.2 l Beta Bottle #1900) will be used for this type of sample so that the original sample, the laboratory replicate and the spike may be collected from the same sampler.

Another type of spike sample, a reagent spike, is prepared by adding a known amount of spike solution to reagent grade water. The purpose of this type of spike sample will be to provide a measurement of analytical accuracy in the absence of any sample matrix effects and to verify the concentration of the spike solution being used.

The purpose of laboratory replicates and field spike samples are primarily to evaluate the performance and quality control of the analytical laboratory. They will be sent to the laboratory as blind samples. An accurate evaluation of these samples requires that the laboratory treats them the same as any other sample and not give any preferential treatment to them. To accomplish this, most quality control samples are labeled and identified with station codes, times, and depths in the same manner as other samples. These blind samples are sent to the laboratory for analysis with the actual samples. On field sheets and in the database, these samples will be properly identified as quality control samples and not included in analyses of representative conditions. Exceptions are samples that are included as sample replicates, reagent blanks or reagent spikes; these will be identified as such to the laboratory.

Biological Sampling

Field Collection

Zooplankton

Zooplankton samples will be collected using a closing Wisconsin- style plankton net. This will allow single tows to the surface or discreet tows at depth. It has a 12.7 cm (5 inch) diameter mouth, and 80 μm nylon monofilament mesh. This collects "net" phyto- or zooplankton; which includes the largest zooplankton or ichthyoplankton down to most rotifers and all but the smaller nannoplankton. (APHA 1992, Wildco 1998)

The net will be weighed to speed its descent to the desired depth. After a brief pause to allow disturbed plankters to recolonize the water column, the net is towed back to the desired depth at a consistent rate of 0.5 m/s. The line is maintained in a vertical position by adjusting the boat and/or one's position on the boat. A messenger trips the net at depth if a sub-surface tow is required. The net is rinsed 3 times in the lake to clean the sides of the cone into the net's bucket. The bucket is then rinsed into a small (~125 ml) polyethylene bottle, immediately preserved with 1% Lugol's solution and stored in a cool dark location. Bottles will be labeled with station name, date, time, tow depths, and a sequential field number.

In flowing water, if a reliable vertical sample cannot be taken, a known volume (minimum of 100 liters) of water will be poured from a bucket through the net. Within the dam, water is routed from a penstock by-pass valve through the plankton net for a known period of time (minimum of 20 minutes). Several bucket tests gage the discharge of the valve at the start and finish of the collection. If none of these methods are appropriate, (i.e., too much lateral drift, shallow water, etc.) a horizontal tow may be taken. This will probably be a qualitative sample only.

Phytoplankton

Phytoplankton samples will be collected at the surface (-1 meter) depth with a 6.2-Liter vertical Beta bottle whole water sampler. In non-uniform flowing conditions, an integrated composite sample may be taken using a weighted (swimming pool) hose to a depth of 5 to 15 meters. The chlorophyll sample will be taken from the same bottle. A one-liter whole water sample is taken in a polyethylene bottle pre-preserved with of 1% Lugol's solution (~10-15 ml) and pre-labeled for station name, date, depth, time and a sequential field sample number. The sample will be cataloged and stored in a dark cooler or box until shipped for analysis.

Chlorophyll

Chlorophyll samples will be taken at every station a physical profile is measured. Because of the ease of collection and low cost, this is a relatively cheap measurement for indicating primary productivity. The sample will be taken from the 6.2-Liter vertical Beta bottle whole water sampler. It will always be taken from the same sample as the phytoplankton sample, as they reflect similar measurements. Since much of Lake Powell and the tailwaters are oligotrophic (low productivity), a large volume sample (minimum of 3 liters) is required. The sample is quickly filtered in field upon retrieval through a 1.0 mm glass filter (Whatman GF/C #1822C47 or Gelman type A/E #61631). The filter is removed from the filter holder, assessed for general color, folded in half and placed in an envelope labeled for station name, date, depth, time, and volume filtered. The sample is immediately placed in a plastic ziplock and stored on dry ice on quarterly sampling trips. Samples may be desiccated if dry ice is not available. Controlled experiments demonstrated that quickly desiccating the filter on a darkened hot surface is a reliable alternative to dry ice if there is a low number of samples, such as on monthly samplings.

Sample Locations

Zooplankton and phytoplankton samples will be taken at the full water quality stations on the lake during the quarterly sampling trips. This includes 11-13 stations on the main channel, 3-5 on the San Juan, and 2-4 on the Escalante. Inflow and transitional zone samples may vary in location with lake elevation, seasonality, and inflow dynamics. The transitional zone can be more dynamic, both in location and plankton response, and sampling will be flexible enough to respond to this if both cost and return of information are to be balanced.

Pending further analysis, the depth of zooplankton tows will include a 0-30 m surface tow, which typically (but not always) encompasses the densest communities (Ayers and McKinney 1996, Sollberger 1988, Horn pers. comm., Hueftle unpublished) and a 30-60 m tow. Deeper tows may be required if deeper populations are identified. This sampling neglects some of the short-term dynamics of diel fluctuations, variable light, temperature, and nutrient availability, and predation dynamics; but will provide baseline data on overall productivity and community structure.

On the monthly trips, the forebay station will have 4-5 discrete depth tows from the surface to below the penstocks to a depth of ~100 or more meters. Typically this will be 0-15 m, 15-30 m, 30-50 m, 50-75 m, and 75-105 m, compensating for changes in lake elevation to ensure samples will be taken at penstock and river outlet works depths. Monthly collections will be made from the dam draft tubes and in flowing water from the upstream end of the dock at Lees Ferry.

Phytoplankton will be taken 1-meter deep at the same stations as the zooplankton, both during quarterly and monthly trips. Although time consuming, composite collections for phytoplankton are more representative of the community and are preferable. Algal communities typically congregate as far as 5 to 10 meters below the surface of the lake, especially as water temperatures rise (Blinn 1993, Stewart and Blinn 1976, Thornton 1992, Haury, unpublished). A composite sample from 0-15 m would better characterize the phytoplankton community. It is also preferable to sample all plankton communities in daylight hours as many species migrate on a diurnal basis (Ayers and McKinney 1996, Wetzel 1975 and others). Samples are not regularly taken at depth, but are seasonally indicated by metalimnetic oxygen minima or maxima. Approximately 25 samples are taken on quarterly trips and 3 on monthly trips.

Chlorophyll samples will be collected at all sites where a physical profile is measured and always accompany phytoplankton samples, as they offer a check on biomass estimates. Sampling frequency increases in the transitional zone. This includes 30-40 samples per quarterly trip including several sets of duplicates or triplicates. Monthly trips will include 3-5 samples.

Quality Control

Replicate samples will be taken for all parameters. Chlorophyll analysis will be most rigorously evaluated. Duplicate or triplicate samples are taken on each quarterly trip and occasionally on monthly samplings. Calculations for relative percent difference are made for each of these samples. Replication is less frequent for zooplankton and phytoplankton samples. Split samples are periodically sent to different labs for analysis.

Preservation

Phytoplankton and zooplankton samples will be preserved with Lugol's solution. This is a versatile non-toxic preservative that affords the least damage to short and long-term storage of organisms, including delicate structures. It consists of 20 g potassium iodide (KI); 10 g iodine crystals in 200 ml distilled water containing 20 ml glacial acetic acid. (APHA 1992). Samples are preserved with 1% Lugol's, or about 10 ml /Liter, and are stored out of light in polyethylene bottles.

Sample Analysis

Contracting Procedure

Sample analyses will be performed according the standard methods procedures (EPA 1992) unless stated otherwise. Outside laboratories will be contracted for all analyses. Currently, chlorophyll is contracted to a Bureau of Reclamation lab in Boulder City, NV under the management of David Hemphill.

Following a thorough search, several suitable labs will be identified for the analysis of zooplankton and phytoplankton. Prices, services, and experience with this region will be criteria for selection. Several of these labs have been used historically and their prices, quality of work and experience with southwestern reservoir assemblages is known.

Contract Specifications

Zooplankton

Three sub-samples will be analyzed unless the sample has less than 200 zooplankters. Large, unusual organisms will first be enumerated (fish eggs, macro-plankton, etc.). The samples will be enumerated and identified to species. Fecundity status and measurements for the determination of bio-volume will be made on each of the Wahweap and below dam samples, while quarterly trips will pool measurements by reach and trip, as specified at the time of shipment. Nannoplankton in the tows will be identified to genus and given a subjective abundance classification.

Phytoplankton

For each sample, 400 individuals or colonies will be counted and identified to species. Three replicate sub-samples will be counted and identified if the sample has more than 400 phytoplankters. Wahweap, Glen Canyon Dam and Lees Ferry samples will be identified to species. Quarterly lake-wide trip groupings will also be identified to species.

Bio-volume estimates will be calculated based on length/width measurements for each of the Wahweap and below dam samples, while quarterly trips will pool measurements by reach and trip, as specified at the time of shipment. A minimum of 10 measurements will be made for each species. Calculations for species density (# / Liter), relative abundance on the mean replicates, measurements, bio-volume, and bio-volume abundance will be reported for each sample.

Chlorophyll

Samples will be analyzed according to standard methods (APHA 1992). The filters are ground and the chlorophyll is extracted in an acetone solution. A spectrophotometer returns trichromatic readings to determine amounts of chlorophyll-a, -b and -c, which reflect amounts of algal biomass. Chlorophyll-a is present in all photosynthetic algae, while chlorophyll-b represents green algae and euglenophytes and chlorophyll-c represents diatoms and others. Pheophytin-a concentrations (a degradation product) are determined from readings taken on acidified and non-acidified samples. Samples are spectrally corrected for turbidity.

If available, a fluorimeter may be used in the future to collect chlorophyll profiles in vivo.

Archiving

After analysis, phytoplankton and zooplankton samples will be concentrated and archived in 35 ml polyethylene bottles. Future uses of the sample may include confirmations in speciation, biomass, chemical or lipid analysis.

Data Processing and Analysis

Data will be organized in a standard spreadsheet and entered into the available database software (ultimately the Oracle Database). Statistical analysis will be performed in spreadsheets or with an appropriate statistical package. Biomass and density estimates by family, genus and species will be performed. Diversity indices, similarity indices, and taxa richness will be evaluated for trend analysis. Trophic status will be evaluated and correlations done to determine limiting nutrients or conditions. Data may be clumped into reaches to simplify analysis and interpretation, where appropriate. Raw data may be made available on the web once it has been verified.

Lake Powell Site Coding and Geo-referencing

Using the ARC/INFO geographical information system, a digitized map has been developed from mosaic Digital Line Graphs (DLG) of USGS 1:100,000 scale maps of the Lake Powell region. The maps include the pre-dam Colorado River channel and those of other major tributaries. Additional information has been manually digitized and added to the maps. Overlays to this map have been developed to include surface hydrology; natural features, roads and other man made features, registered sampling locations, and other pertinent annotations.

Sampling stations on the reservoir have had their geographic coordinates determined using Global Positioning system (GPS) technology. Written descriptions and photo documentation for each station have been recorded to aid in relocating a station based on landmarks and other physical features.

Using the GPS coordinates, the sampling stations will be incorporated into the digital map as a GIS overlay. Using dynamic segmentation methodology, river channel distances (RCD) to each station, from a fixed reference point, may be determined (Table). The base reference point is Glen Canyon Dam for Colorado River main channel stations. For stations on tributary arms, the reference point is the confluence of the tributary with the Colorado River main-channel.

From this information a revised station coding scheme can be developed which incorporates the general project code, the stream channel of the station and the river channel distance from the given reference point. Historically, stations were numbered sequentially in the order of their establishment. Frequently, there is no information in the station name or code to locate a particular station with reference to another. The new coding scheme will allow the location of a station within a particular tributary arm to be determined from its station code.

The station code for a particular station is an eight character alphanumeric string. The first two letters represent the project; in this case, LP represents the Lake Powell project. The second two to three letters represent the tributary arm; CR represents the Colorado River, SJR the San Juan River, ESC the Escalante, and so on. The remaining characters are integers expressing the number of river channel kilometers in tenths from a given reference point for the tributary arm.

For example, the Cha Canyon station which resides 19.3 river channel kilometers from the pre-dam Colorado River channel on the San Juan River arm of Lake Powell has historically had a station code of SCUCLP15. Under the revised coding scheme, this station has an 8-character identification code of LPSJR193.

This station code uniquely identifies a main channel station. This code, along with other information such a station name, geographical coordinates, state, county, hydrologic basin code forms a record in the water quality database table STATION which includes all information required by the EPA STORET system to sufficiently identify a sampling location. Each entry to the database for a given sample or measurement will have a station code identifier associated with the data.

Appendix C VITAE OF CO-AUTHORS

William S. Vernieu

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EDUCATION

B.S. Biology, University of Utah, 1979
Emphasis in environmental biology, limnology, chemistry, and mathematics
Further study in geology, hydrology, and environmental engineering

EMPLOYMENT

Hydrologist, GCMRC ***1996-Present***
Grand Canyon Monitoring and Research Center, Flagstaff, AZ

Developed long-term water quality monitoring program in Lake Powell and Colorado River downstream of Glen Canyon Dam. Combined disparate water quality monitoring effort to form integrated plan to meet needs of Glen Canyon Dam Adaptive Management Program. Worked closely with Adaptive Management Work Group and Technical Work Group regarding planning issues. Developed assessment of operational effects of Glen Canyon Dam on reservoir and downstream water quality. Conducted monitoring and research to evaluate effects of experimental Beach/Habitat Building Flow on reservoir and downstream water quality. Maintained and enhanced data management and analysis system for water quality.

Hydrologist, Bureau of Reclamation ***1990-1996***
Glen Canyon Environmental Studies, Flagstaff, AZ

Restructured and directed Bureau of Reclamation long-term water quality monitoring program on Lake Powell. Work involved using available technology to increase spatial and temporal resolution of limnological measurements while maintaining resource expenditures. Augmented and maintained continuous monitoring program in Glen Canyon Dam tailwater. Revised existing structure of limnological database for Lake Powell and integrated 30 years of historical information from Lake Powell long-term monitoring program. Developed methods for statistical summary and graphical representation of reservoir water quality information. Directed field efforts and training of technical personnel.

Maintained data management system for hydrological and water quality information for the Colorado River in Grand Canyon and its tributaries. Data from several different sources including WATSTORE (USGS), STORET (EPA), and HYDROMET (USBR) databases was integrated with data from other research and monitoring programs to create information clearinghouse utilized by Grand Canyon researchers and other interested parties.

Physical Scientist, Bureau of Reclamation ***1982- 1990***
Upper Colorado Regional Office, Salt Lake City, UT

Conducted reservoir water quality surveys on Upper Colorado reservoirs. Performed nutrient chemistry analysis on reservoir water samples. Developed methods and programming for automated flow injection analysis of phosphorus and nitrogen compounds. Analyzed phytoplankton and zooplankton samples for species identification and enumeration. Designed and developed relational databases for storage and management of Bureau of Reclamation reservoir water quality data. Implemented continuous water quality monitoring in tailwaters of several reservoirs. Designed water quality monitoring programs in support of fishery investigations.

Performed environmental monitoring activities and participated in sampling program design for hazardous waste studies including air-borne particulate studies and x-ray fluorescence of soil samples.

Arterial Blood Gas Technician, LDS Hospital ***1976-1982***
Intermountain Health Care, Salt Lake City, UT

Collected and analyzed arterial blood for determination of pulmonary function. Developed expertise with electronic instrumentation to measure physical and chemical parameters such as dissolved oxygen, carbon dioxide, pH and bicarbonate concentrations.

SPECIAL SKILLS

Seventeen years experience in water quality, limnological, and other environmental monitoring activities. Emphasis on sampling design of long term monitoring programs. Strong educational and employment background in aquatic and environmental chemistry.

Strong data management skills with proficiency in Ingres, Rdb, dBase, and MS Access databases. Particular expertise with SAS System software for data warehousing, client-server database integration, statistical summary, and graphical analysis

23 years experience with electronic instrumentation for measurement of physical and chemical parameters in aqueous solutions.

PUBLICATIONS AND PRESENTATIONS

Susan J. Hueftle and Vernieu, William S.
Assessment of impacts of Glen Canyon Dam operations on water quality resources in Lake Powell and the Colorado River in Grand Canyon
Grand Canyon Research and Monitoring Center, Flagstaff, AZ. (In progress)

Marzolf, R.M , C.D. Bowser, R.Hart, D.W. Stephens and William S. Vernieu
Photosynthetic and Respriatory Processes: and Open-Stream Approach. In. The Controlled Flood in Grand Canyon. R.H Webb, J.C. Schmidt, G.R Marzolf and R.A. Valdez eds. Geophysical Monograph 110. American Geophysical Union, Washington, D.C. 1999.

Marzolf, R.M and William S. Vernieu
Effect of controlled flood on primary productivity in the Colorado River: Glen Canyon Dam to Lees Ferry.
Poster presentation at 1996 Fall Meeting of American Geophysical Union. San Francisco, CA. December 15-19, 1996. (Abstract submitted)

Vernieu, William S.
Effects of reservoir drawdown on resuspension of deltaic sediments in Lake Powell.
Lake and Reserv. Management. Vol 12. No 3. 1996(in press).Submitted July 19, 1996

McGavock, Edwin H., W.R. Victor, and W.S. Vernieu
Projected hydrogeologic conditions in the Navajo Sandstone aquifer near Page, AZ after hydraulic equilibrium is reached with Lake Powell.
Poster presented at the 8th Annual Symposium of the Arizona Hydrological Society, Tucson, AZ. September 14-15, 1995

Vernieu, William S. and Susan J. Hueftle
Long term monitoring and data management on a large Colorado River reservoir.
Oral presentation at the 14th Annual International Symposium of the North American Lake Management Society, Orlando, FL. October 31 - November 5, 1994

VITAE

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EDUCATION:

B.S.	Geology, *with distinction*	University of Nebraska at Lincoln	May, 1982
M.S.	Environmental Science, Water Resources	Washington State University, Pullman, Washington	August, 1992

Thesis: Effects of winter drawdown on aquatic macrophytes in Twin Lakes, Washington

HONORS AND MEMBERSHIPS

Nominated for Outstanding Woman Graduate Student in spring of 1990. Phi Beta Kappa (1982), Phi Eta Sigma, Alpha Lambda Delta (1978-1979) and National (1978) Honor Societies. Dean's list (1978-1982). Schramm and Rex Monahan Scholarships (1978-1982). North American Lake Management Society, Society of Wetland Scientist, American Society of Limnologist and Oceanographers, North American Benthological Society.

EXPERIENCE:

Limnologist, GCES & GCMRC, Flagstaff, AZ.

Grand Canyon Monitoring & Research Center

&

Glen Canyon Environmental Studies:

March 1993 to present.

Forged and instigated downstream interagency cooperative efforts to integrate and link reservoir limnology with downstream foodbase and fisheries science.

Organized and conducted water quality field monitoring & research on Lake Powell and in the Colorado River.

Integrated a 30+ year physical, chemical and hydrologic database from many formats and locations to produce a history unique to reservoir science. Presented and analyzed data in a easily comprehensible format that elucidated relationships and trends. Discovered hydrodynamic processes previously unrecognized in reservoir science.

Organized, populated, evaluated and analyzed physical and chemical data and literature of the long-term monitoring program of Lake Powell.

Instigated a more robust biological component of the long-term monitoring program of Lake Powell. Organized, populated, evaluated and analyzed biological data and literature.

Developed advanced usage of 3-dimensional analysis of extensive and large data-sets.

Developed multiple regression analysis of physical, chemical and biological components in the reservoir. Analyzed trophic status.

Facilitate and participate in interagency cooperative water quality research efforts in Lake Powell

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June 1987-
February '93

Research Assistant, Washington State University, Water Research Center.

Lake Project Supervisor: Supervisor for 3 lake research projects in western Washington. Responsibilities included organizing field trips, supervising field crews, public contacts and media interviews, data collection and management, overseeing and maintaining lab operations and equipment, and hiring lab support.

Lab/Field Technician: Extensive experience with aquatic macrophytes including field sampling, identification, biomass and nutrient analysis. Other lab experience included digestion and automated analyses of ortho-phosphate, total phosphorus, total Kjeldahl nitrogen and sulfate.

Spring 1991

Teaching Assistant: WSU, Dept. of Environmental Engineering. Prepared and conducted a graduate level lab class; "Engineering Aspects of Aquatic Biology," requiring instruction in the sampling, identification, and ecology of aquatic

	plants, algae, zooplankton, and invertebrates.
August 1986-May 1987	*Teaching Assistant* for an introductory level environmental science course at Washington State University. Prepared and conducted discussion groups.
Summer 1986	*Field Assistant* for paleontological dig in Agate Fossil Beds National Monument near Harrison, Nebraska.
Summer 1985	*Field Assistant* for ecological study at Marsh Lakes near Valentine, Nebraska. Trapped, evaluated, and tagged rodent populations in wetland meadows. Inventoried plant communities and analyzed predator/prey interactions.
1984-1985	*Lobbyist, field manager, and canvasser* for Nebraska Water Conservation Council, a non-profit organization protecting water resources though organizing and public education.
1979-1982 (SUMMERS)	*Field assistant for archeological digs:* Conducted field survey for sites; transit, plane table-alidade and bruntan mapping and map drafting of sites, field excavation, sample sorting.
HONORS and MEMBERSHIPS	Nominated for Outstanding Woman Graduate Student in spring of 1990. Phi Beta Kappa (1982), Phi Eta Sigma, Alpha Lambda Delta (1978-1979) and National (1978) Honor Societies. Dean's list (1978-1982). Schramm and Rex Monahan Scholarships (1978-1982). North American Lake Management Society, Society of Wetland Scientist, American Society of Limnologist and Oceanographers, North American Benthological Society.

PUBLICATIONS:

Juul, S.T.J., and S.J. Hueftle, 1992. A Report on the Water Quality of Twin Lakes, Washington, Before and After Restoration Efforts. Washington Water Research Center Report No. 86. Washington State University, Pullman, Washington.

Hueftle, S. J. 1994. Glen Canyon Environmental Studies newsletter.

Hueftle, S.J., 1995. Lake Powell; The Future of a Reservoir. Lakeline, 15: 1:20-23,41.

Hueftle, S. J. and W. S. Vernieu. Quarterly Report of the June 1995 Lake Powell survey. Glen Canyon Environmental Studies Report. Flagstaff, AZ.

Hueftle, S. J. Quarterly Report of the September 1995 Lake Powell survey. Glen Canyon Environmental Studies Report. Flagstaff, AZ.

Hueftle, S. J. Aug. 1995. Proposal: Lake Powell Long-Term Monitoring Program, Submitted for Fiscal Years 1996 and 1997, Glen Canyon Environmental Studies. Flagstaff, AZ.

Hueftle, S. J. and W. S. Vernieu. Assessment of Impacts of Glen Canyon Dam Operations on Water Quality Resources in Lake Powell and the Colorado River in Grand Canyon. Grand Canyon Monitoring and Research Center, Department of Interior. Washington, D.C. (In review).

Hueftle, S. J. and L.E. Stevens. 1999. Experimental Flood Effects on the Limnology of Lake Powell Reservoir, Southwestern USA. Ecological Applications. (In review).

Benenati, E. P., J.P. Shannon, D.W. Blinn, K.P. Wilson, and S.J. Hueftle. 1999. Reservoir-river linkages: Lake Powell and the Colorado River, Arizona. (In review).

PRESENTATIONS:	May 1999	Water quality trends and long term trends in Lake Powell. For Colorado College. Flagstaff, Arizona. *By invitation*
	Apr 1999	Reservoir water quality trends and downstream implications. SWCA native fisheries planning session. Flagstaff, AZ *By invitation*
	Feb 1999	Water Quality Trends in Lake Powell and the Tailwaters 1998. Grand Canyon Monitoring & Research Center Science Symposium. Grand Canyon Arizona
	Dec 1998	Water Quality Trends in Lake Powell and the Tailwaters. Lake Powell Interagency Cooperators Meeting. Salt Lake City, Utah
	Nov 1998	Hueftle, S.J., and Stevens, L.E. Effects of an Experimental Flood on Grand Canyon and the Limnology of Lake Powell. North American Lake Management Association, Banff, Canada
	Oct 1998	Water Quality Trends and Sedimentation in Lake Powell. Glen Canyon Institute Annual Conference. Salt Lake City, Utah. *By invitation.*
	Sept 1998	Water quality trends of the Lake Powell system. Adaptive Management Work Group, Page Arizona
	Aug 1998	Water quality trends of the Lake Powell system. Protocol Evaluation Panel, Flagstaff, Arizona
	July 1998	Update on the Lake Powell Assessment. Adaptive Management Work Group, Phoenix, Arizona
	June 1998	Lake Powell, What is a Reservoir? Upward Bound College Prep Program, Northern Arizona University, Flagstaff, Arizona
	June 1998	P.L. Benenati, S..J. Hueftle D.W. Blinn, J.P. Shannon, and K.P. Wilson. Benthic Tailwater-Reservoir Linkages as Affected by Climatic Patterns in the Colorado River, Arizona & Utah. North American Benthological Society Annual Conference. Prince Edward Island, Canada.
	Dec 1997	Hueftle, S.J., Vernieu, B.S. An Assessment of Dam Operations on Lake Powell. North American Lake Management Association, Houston Texas.
	Oct 1997	Assessment of Dam Operations Effects on Lake Powell. Colorado Plateau Studies Biennial Conference, Flagstaff, Arizona
	Aug 1997	Release of the Lake Powell Assessment to the Adaptive Management Work Group, Phoenix, Arizona
	Mar 1997	Spike Flood and Water Quality Results for 1996 at Lake Powell. Lake Powell Interagency Cooperators Meeting. Page, AZ.
	Oct 1996	20th Anniversary Conference of the Lake Powell Research Project, Salt Lake City, UT.
	Mar 1996	Water Quality Results for 1995 and pre-Spike Conditions at Lake Powell. Lake Powell Interagency Cooperators Meeting. Page, AZ.
	Nov 1995	Flow Patterns in a Large Southwestern Reservoir. North American Lake Management Association, Toronto, Canada.
	Oct 1995	Hueftle, S.J. & Wegner, D.L. Transformation of Water Quality through Lake Powell. Colorado Plateau Studies Biennial Conference, Flagstaff, Arizona.
	Oct 1993	Hueftle, S.J., Wegner, D.L., & Matter, M.A. Physical Limnology and the Effects of Lake Powell on the Colorado River. Colorado Plateau Studies Biennial Conference, Flagstaff, Arizona.
	Oct 1992	Winter drawdown effects on macrophyte communities in Twin Lakes, Washington. Washington Lake Protection Association Annual Conference, Spokane, WA.