GRAND CANYON MONITORING AND RESEARCH CENTER

Integrated Water Quality Program Plan

FY 2002-2007

DRAFT

by

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Abstract

This document summarizes the intent of the Integrated Water Quality Program (IWQP) for fiscal years 2002-2007. It builds upon the plan released in 1999 (Vernieu & Hueftle, 1999) that addressed the existing management objectives and information needs as described in (TWG MOs and Ins, July 1998), as well as results from the Protocol Evaluation Panel findings (Jones et al., 2001) and the subsequent IWQP response (Hueftle et al., 2001).

It will outline the current state of the long-term monitoring program, including the four reach-based components: Quarterly monitoring of the physical-chemical-biological processes of the main channels in Lake Powell; monthly and continuous monitoring of the physical-chemical-biological processes in the reservoir's forebay; monthly and continuous monitoring of the physical-chemical-biological processes in Glen Canyon Dam and tailwaters; and continuous thermal monitoring within Grand Canyon.

This plan will also describe short-term research components of the IWQP which are designed to improve its responsiveness to adaptive management needs, increase data collection efficiency and relevance, and increase integration efforts, particularly within the AMP and GCMRC.

This document will outline how PEP recommendations will be evaluated and implemented, with special attention to implementation plans for programmatic shifts, including development of a hydrodynamic model and shifts in effort as the model successfully predicts reservoir processes. Less attention is given to particular methodology recommendations, which will be addressed in a separate methodologies document to be completed in 2002.

I. Introduction and Background

I. A. 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 the next five years, beginning in fiscal year 2002. 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 will also describe recent accomplishments and the implementation of the recent Protocol Evaluation Panel's recommendations.

I. B. The Protocol Evaluation Process

As required by the GCMRC strategic plan, the IWQP was evaluated by a protocol evaluation panel from November 27 to December 3, 2000. A panel of 6 external experts in the fields of limnology, engineering, modeling, and ecology gathered in Flagstaff and in the field to evaluate the Integrated Water Quality Program's, goals, procedures and methods. The panel was well informed, enthusiastic, and interested in both the program and the resources under review. In February they provided a detailed guiding document to direct IWQP for the next 5-20 years (Jones et al., 2001). The IWQP provided a response to the recommendations to the adaptive management program (AMP) on May 30, 2001. Few recommendations were adopted or rejected entirely. Since many of the recommendations will have resource impacts in terms of funding levels, contracted assistance or cooperative agreements, they will be evaluated and prioritized for implementation in both this document and a detailed methodologies document (in development) prior to implementation.

The greatest repeated themes for high PEP prioritization were:

Develop appropriate models for up- & downstream, collecting appropriate data to calibrate & validate models. Start with physical components and work toward biological modeling. Obtain appropriate assistance and consider convening an expert panel for modeling efforts.

- Use the models to revise the 5-year IWQP and guide AMP decision-making
- Drive integration efforts with focused testable hypothesis
- Shift efforts from uplake to downstream as models are developed and provide predictability

In this document, PEP recommendations will be identified when discussed in the relevant activity.

I. C. Water Quality Monitoring and Adaptive Management Information Needs

The purpose of the IWQP is to conduct monitoring and research to address various Information Needs (INs) developed by the Technical Work Group (TWG) related to water quality of the Lake Powell reservoir, Glen Canyon Dam releases, and the Colorado River below Glen Canyon Dam. These INs were developed to meet the Management Objectives (MOs) of the Adaptive Management Work Group (AMWG) for adaptive management of the Colorado River ecosystem.

II. Water Quality Monitoring Plan

II. A. 1. a) Monitored Parameters

Physical and Chemical

Measurements of common physical and chemical water quality parameters are routinely collected during the reservoir measurements, continuously in the tailwater below Glen Canyon Dam, and in conjunction with the collection of all chemical samples. These measurements are taken using a multi-probe instrument, such as a Hydrolab Surveyor3/H20, Hydrolab Recorder, or YSI 6920. These measurements will include temperature (C), specific conductance (µS), pH, dissolved oxygen (mg/L), and turbidity (NTU).

Temperature and specific conductance are important in reservoir surveys for primarily defining the density of low-turbidity water and, hence, determining 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 concentrations in water. It can also be used in river systems to quantify additional chemical inputs from non-gauged tributaries by mass balance. DO and pH indicate levels of biological metabolism and chemical oxidation. Chemical and biological process rates are also regulated by temperature.

Dissolved oxygen is important to biological processes in aquatic systems, where most organisms have specific oxygen requirements. Further, very low dissolved oxygen levels can result in release of trace elements from sediments and generation of hydrogen sulfide. In the reservoir, dissolved oxygen levels help indicate the relative age of inflow currents, the suitability for release to downstream organisms, and the degree of decomposition of organic and inorganic 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, it indicates amounts of carbon dioxide and the 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 have been collected to characterize the overall chemical makeup of the water being sampled. Laboratory analysis includes specific conductance, pH, alkalinity, total dissolved solids and total suspended solids, which describe the physical aspects of the water. Chemical concentrations have also been determined for the major cations and anions (sodium, calcium, magnesium, potassium, iron, silica, total and dissolved organic carbon, sulfate, chloride, carbonate, and bicarbonate). Alkalinity determinations are also performed in the field concurrently with the collection of a chemical sample.

Samples are collected to determine the concentration of the nitrogen-phosphorus nutrient compounds (total phosphorus, soluble reactive phosphorus, dissolved ammonia nitrogen, total Kjeldahl nitrogen, and dissolved nitrate-nitrite nitrogen). These nutrient compounds, in addition to other micronutrients such as iron, silica, organic carbon and others, support primary productivity in the reservoir and downstream aquatic ecosystem. Phosphorus levels in the reservoir and tailwater are generally low; but improved detection limits have reduced non-detectible samples to less than 15%

since 1999. Further exploration of techniques to achieve lower detection levels and better methods continue to be pursued (Table 1).

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 focusing on broader trends. Separate research programs must address quantifying shorter-term effects from operational experiments or a TCD. IWQP's role below Lees Ferry will be as an integrating force between existing food-base & fisheries studies and known water quality factors as we move to a more pro-active monitoring role. Specific goals of the current 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.   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.

II. A. 1. b) Quarterly Reservoir Surveys

Objectives

The objective of quarterly reservoir surveys is to characterize the chemical, physical, and biological conditions in the major strata of the main channels 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 potential quality of water released downstream. Information from reservoir surveys provides a short-term predictive capability of release water quality or potential water quality problems. It forms a baseline from which the long-term effects of management actions related to dam operations can be evaluated. Findings from quarterly lake surveys are valuable for predicting downstream releases in the short-term and out 2-3 years.

Monitoring Activities

Reservoir surveys are conducted four times per year, coinciding with seasonal patterns observed on the reservoir. Primary focus is given to the main channel of the Colorado River and its major tributaries (San Juan and Escalante channels) in Lake Powell. To a lesser extent, additional efforts have been made to characterize conditions in smaller tributaries and embayments where conditions differ significantly from the main channel.

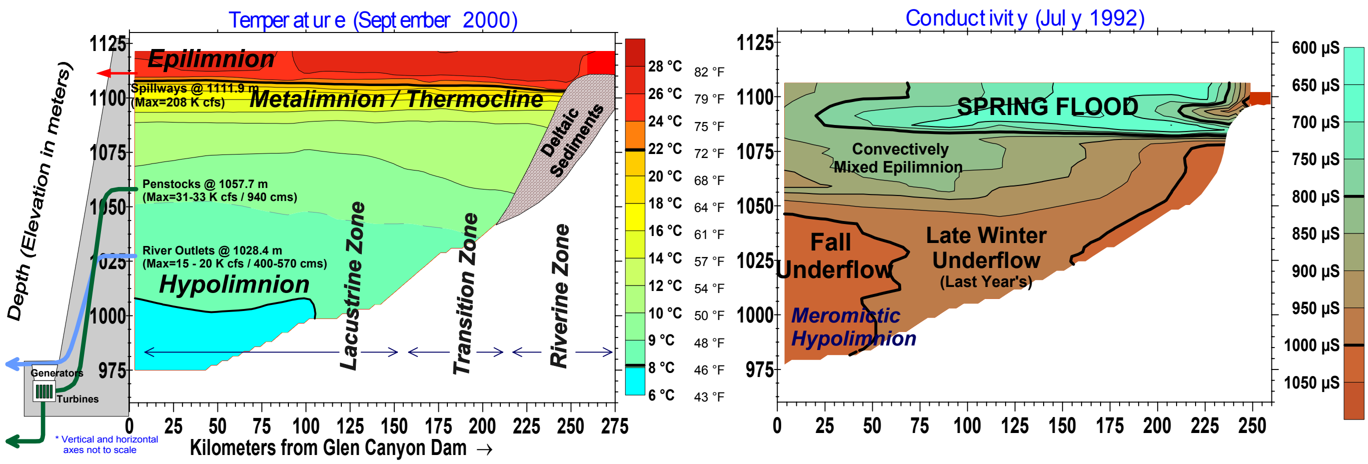

Figure 1: Temperature and conductivity cross-sectional isopleths of Lake Powell demonstrating dominant lake vertical and longitudinal structures.

A thirty-six-year period of record exists for reservoir-wide surveys, varying in quality and frequency from monthly to yearly. Most samples have been taken in the Colorado River channel of the reservoir, but since the 1992, numerous stations have been added from the San Juan and Escalante tributaries, which constitute approximately 8-15% and 3-5% of annual inflows, respectively. Navajo Canyon, near the dam, has also been added as an indicator of side-channel water quality (Figure 2). There are currently 26-29 stations. Sampling efforts are distributed between deep, lacustrine (lake-like) sites and the more dynamic transition and riverine zones uplake (Figure 1). Additions have focused on the transition and inflow zones where water quality is more dynamic, further, as lake elevation changes, length and location of the transition zone and inflows also change.

General field observations of existing weather conditions, water depth, and water clarity (Secchi depth) are made at every station. Additionally, there are two possible levels of sampling; the 14 full stations include measurement of all the physical, chemical, and biological parameters; while all stations receive basic physical profiling and surface chlorophyll.

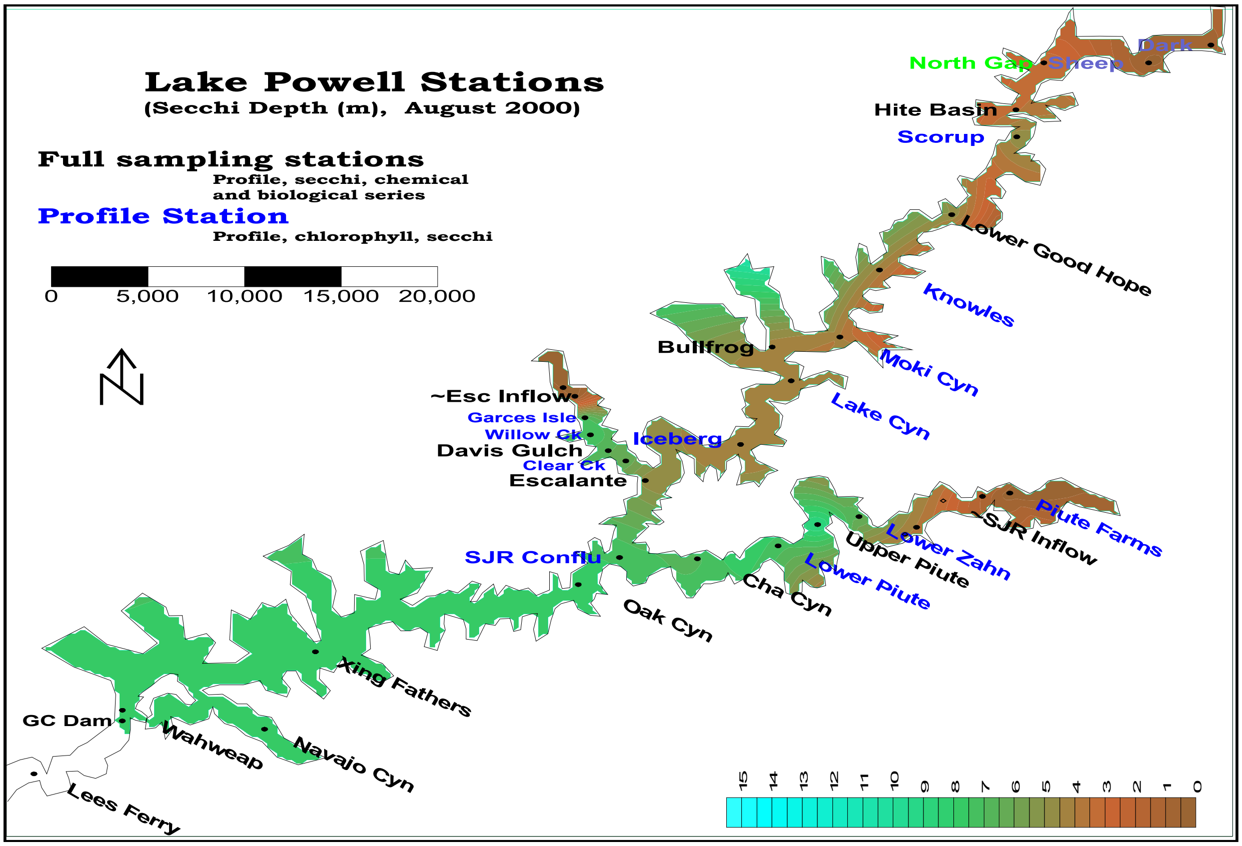

Figure 2: Map of Lake Powell station locations and level of sampling

The longest record exists for temperature, conductivity, dissolved oxygen, pH, and a suite of major ions taken at 8-9 historical locations since 1965. Biological and nutrient samples were not taken consistently until 1992. Current sampling includes a physical, chemical and biological component. Profiles of common physical parameters (temperature, conductivity, dissolved oxygen, pH, turbidity, and oxidation-reduction potential) using a Hydrolab H20 provide a rapid on-site return of lake conditions. Chemical samples for laboratory analysis are collected at the 14 full stations, including nutrients (nitrogen and phosphorus series; organic carbon in the inflow and outflow samples), major cations and anions, as well as total suspended and dissolved solids, alkalinity, pH and specific conductance (see Appendix A). Biological samples include chlorophyll and phytoplankton, which measure primary productivity and community dynamics, and zooplankton measures secondary production.

Sample Timing

Lake-wide surveys are conducted on a quarterly basis to capture significant seasonal processes occurring in the reservoir.

Late Spring

Late spring sampling occurs from mid-May and mid-June, and describes the transition between winter mixing and summer stratification. Peak inflows typically occur by mid-June. The volume of this spring flood will define the thickness and composition of the epilimnion for the next year. By this time, the lake begins to experience significant thermal stratification from spring warming. Primary productivity is peaking in the inflow and transition zones while zooplankton productivity has subsided somewhat from late winter peaks. Corresponding to the high primary productivity, dissolved oxygen concentrations are above the saturation level in much of the epilimnion. The fate of the winter underflow current is apparent by this time, resulting in either a hypolimnetic underflow, interflow, or overflow, depending on the relative densities of the hypolimnion and underflow current. This underflow poses the greatest potential for mixing hypolimnetic waters and is one of the more important features to monitor for projecting long-term reservoir water quality.

Late Summer

Late summer sampling is performed during the period of mid-August to mid-September. It represents conditions when the reservoir is at its maximum degree of thermal stratification and surface warming. Primary productivity is peaking while secondary productivity continues to decline. Clarity is at a minimum due to both algal productivity and clay and calcium carbonate particulates. Inflows have returned to base flows, reaching peak salinity and temperatures, creating a signature of warm but increasingly dense water intruding beneath the plume of spring flood waters. Hypoxia (low dissolved oxygen) begins to develop in the lower epilimnion as a result high oxygen demand from flood-borne organic and inorganic matter and autochthonous production, typically reaching a maximum in early autumn. Hypolimnetic oxygen levels are also degrading.

Late Autumn

Late autumn sampling is 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 maximal homogeneity. Primary and secondary productivity levels are at a minimal. Cooler conditions have been driving convective winter mixing since late summer. The inflow currents are generally low, saline, and have cooled considerably. The resulting late autumn underflow is typically warmer and more saline than the hypolimnion it flows and diffuses through. This underflow is important in that it represents the greatest annual contributor to hypolimnetic salinity, and hence, long-term meromixis, or stagnation of the hypolimnion. Hypolimnetic oxygen levels typically reach an annual minimum prior to possible winter refreshment.

Late Winter

Late winter sampling is conducted between mid-February to early March. The objective of this sampling is to describe conditions when winter cooling and mixing of the reservoir surface has peaked and maximum reservoir homogeneity results. Turnover has occurred in the upper reaches of the reservoir, contributing to the resulting winter underflow current's dimension and composition, typically cold, dilute and bearing higher oxygen than much of the hypolimnion. Levels of discharge and inflow are low. Starting in the transition zones, secondary productivity is peaking while primary productivity is still generally low. Clarity is at a maximum lake-wide.

PEP recommendations and implementation:

Modeling development and needs

The panel identified the highest priority to calibrating and validating a hydrodynamic model (described in section II.A.1.c). The model will be instrumental in driving the future of the reservoir monitoring program. Many of the amendments proposed to the uplake reservoir program are a response to data gaps in model calibration. Others are a reduction in effort to allow redistribution of resources, including personnel. Enhancing inflow sampling efforts, profiling technology, chlorophyll sampling and vertical resolution, addition of meteorological sampling, were all proposed to augment current efforts to aid in model calibration efforts. Collaboration with the efforts of the Upper Colorado Region of the USBR and outside modelers will fine tune exact data needs.

Meteorological data including wind speed & direction from several uplake stations is considered a high priority for model calibration. Installation of instruments on Park Services sewage pump-out docks is planned for FY2002.

More extensive inflow sampling was identified as another modeling need. This effort could entail extensive costs and labor, and so will receive due consideration. The costs of instigating continuous physical and 6-week interval chemical sampling at the existing USGS stations at Cisco, Colorado; Green River and Bluff, Utah will be evaluated against inflow measurements made closer to Lake Powell for FY2002-03.

Collection of total organic carbon and chlorophyll data was indicated as a modeling data need of moderately high priority, and current efforts have already been enhanced. The addition of a Seabird® SBE-19 or SBE-25 profiling instrument was recommended to speed and enhance spatial resolution and chlorophyll profiling efforts on-lake. The cost of this oceanographic-oriented instrument demands careful evaluation for effectiveness on mesotrophic Lake Powell. Field testing of a suitable Seabird is slated for FY2002.

Development of a sustainable 20-year long-term reservoir monitoring program

Following PEP recommendations, as results from the CE-QUAL-W2 model become calibrated and validated, elements of reservoir sampling are targeted for reduction of effort. Some of these elements may be reduced prior to finalization of the model should an evaluation of existing data conclude that the data is adequate, the cost-benefit analysis of continuing such collections is unjustified, or lack a of significant clients for such data collections exist.

Monitoring Locations

The PEP panel recommended reservoir sampling stations be reduced to accommodate increased downstream sampling, and this will be accomplished both through immediate evaluation for minor adjustments, and later, as a result of model findings for greater modifications. The effort will focus on reducing some of the intermediate stations in zones of the lake that are less dynamic (deep lacustrine stations) in favor of the dynamic inflow stations. Somewhat reduced vertical resolution of chemical and biological samplings at intermediate stations is already in progress and will received further evaluation. The PEP panel also recommended a reduced effort in the side-bays and side-arms of the reservoir. While this work proceeds from non-AMP funding sources, an evaluation of historic data and eventual model findings will be accessed to determine the level of detail and necessity of continued collections. It is anticipated this process will be a gradual transition from FY2002 to 2007.

Reduction of major ion and plankton sampling resolution was also identified as a means to reallocate efforts and funding for downstream priorities. A rigorous evaluation of the current program and findings will allow some reduction in effort prior to calibration of the model. Preliminary analysis of major ion data demonstrates a low demand for the results, a high level of correlation with more easily collected specific conductance, and a long history of detailed collections available for study. It is recommended that collections of Ca, Na, Cl, SO4, CO_3, HCO_3 be phased out immediately. Reducing plankton collection efforts from the current 15 sites to the recommended 2 or 3 stations lake-wide will be implemented. Reducing vertical resolution can probably be effected once analyses are more complete without jeopardizing the quality of the dataset, and should take effect in FY2002.

Major Changes

Changes to the reservoir monitoring program include the addition of several continuous thermal monitoring stations in the lake. Tidbit© thermistors are located at the inflow areas of the Colorado River (Sheep Canyon) and San Juan River (Mike's Canyon), logging temperature at 15-minute intervals. In addition, a Hydrolab Recorder monitors temperature, specific conductance, pH and dissolved oxygen at the Sheep Canyon buoy.

Four specially designated water quality buoys have been installed at the Wahweap, Padre Bay, Oak and Escalante stations. These buoys assist in collection efforts at these deep-water stations as well as act as a platform for any deployments of continuous monitors. Chlorophyll sampling protocols have been amended under recommendations of the PEP. TOC, total organic carbon, measurements have been added to DOC measurements already being taken in the inflow areas of the lake.

II. A. 1. c) Monthly Forebay Surveys

Objectives

Monthly forebay surveys 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.

Monitoring Activities

Sampling focuses on characterizing conditions within the strata of the forebay 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 uplake. A thirty-six-year period of record exists for forebay surveys on an approximately monthly basis, with the exception of the period 1982-1990.

Monthly forebay monitoring consists of a profile of physical parameters through the water column; sampling for nutrients, organic carbon and major ions in identifiable strata; chlorophyll in biological active depths, surface phytoplankton, and zooplankton tows from the surface to below penstock depths. Parameters are similar to uplake efforts with the addition of organic carbon and greater vertical resolution. General field observations of existing weather conditions, water depth, and Secchi depth are also be made. These data are provided to researchers involved in both the reservoir and downstream (USBR/TCD, aquatic foodbase, trout, and native fish).

PEP recommendations and implementation:

The PEP panel reiterated that "the forebay station should be considered differently than other lake stations as it represents the upper boundary conditions for reservoir release water quality and provides forecasting of potential water quality problems". Sampling at the forebay station is more detailed and frequent than uplake stations.

The panel recommended the development and calibration of a "smart model" to integrate and predict riverine water quality based on the forebay and operating conditions of the dam. As development of the CE-QUAL-W2 model proceeds, the necessity of additional models will be evaluated during FY2002.

Installation of a forebay weather station to include air temperature, wind speed & direction, incident radiation, precipitation, and relative humidity is slated for installation for FY2002-03. Installing a permanent thermistor chain in the forebay for model calibration will proceed depending on evaluation of data from the temporary thermistor chain already installed.

Major Changes

Changes to the forebay monitoring program include the addition of continuous thermal monitoring at the Wahweap station. Approximately 26 TidBiT® thermistors have been deployed since May 2000 at thermally strategic depths from a specially designated water quality buoy. These thermistors will remain in place for at least two or three years, depending on evaluation of results.

Vertical resolution of chemical samples has been enhanced to include duplicates (top and bottom) of thicker stratum, increased vertical sampling of chlorophyll, and the addition of TOC measurements at all sampling depths, as per PEP recommendations.

II. A. 1. d) Glen Canyon Dam Tailwater

Objectives

The objective of the tailwater monitoring program is to characterize the quality of water released from Glen Canyon Dam and measure changes occurring in the tailwater between Glen Canyon Dam and Lees Ferry. Glen Canyon Dam release water quality varies as a 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 base condition from which changes occur downstream and directly affect the aquatic ecosystem. Monitoring of water quality conditions at Lees Ferry demonstrates changes occurring in the Glen Canyon reach of the river caused by warming and primary productivity processes. Information from this monitoring program supports studies in other resource areas within the Colorado River ecosystem (e.g., primary productivity, trout, and native fish).

Monitoring Activities

Continuous monitoring of tailwater quality will be performed below Glen Canyon Dam and at Lees Ferry. Monitors will be maintained inside Glen Canyon Dam at least one draft tube location, 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, pH, and turbidity will be made at 20-minute intervals and logged within the monitor. Monitors will be downloaded, serviced, and recalibrated on a monthly basis. A continuous record since 1988 record exists for data collected below Glen Canyon Dam; continuous data collection began at Lees Ferry in 1991.

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.

PEP Recommendations

The recent Protocol Evaluation Panel (PEP) suggested that the current location of the continuous monitor immediately below Glen Canyon Dam may not be representative of the water released from the dam under all available release scenarios and that a permanent station should be located some distance downstream of the dam. This comment is believed to be based on the fact that the current location is not able to measure the combined flow of powerplant, river outlet works, and spillway releases, may be influenced by discharge from a seepage drain, and that there may be lateral heterogeneity between the eight powerplant penstocks under certain conditions based on the location and orientation of the penstocks on the dam face.

The IWQP believes that the most representative sampling location, to establish an upper boundary condition of water quality released downstream, is within the powerplant draft tubes. The station immediately below the dam experiences significant dissolved oxygen artifacts from re-aeration due to atmospheric exposure and powerplant operations, such as when generating units are condensing, or placed on spinning reserve. To obtain more accurate dissolved oxygen readings, locations for continuous monitors have been established at the draft tubes of the individual generating units. A monitor is currently placed at a single unit that is determined to be running most consistently through the deployment period. While providing superior dissolved oxygen data compared to the tailwater monitor, a generating unit will commonly experience periodic shutdowns so this record is not always continuous. It is believed that the combination of the continuous tailwater monitor with the more accurate but not as continuous draft tube monitor provides the best representation of the quality of dam releases without incurring the additional expense and effort of placing a monitor at each of the eight draft tubes.

The Panel raised the valid concern that there might be differential water quality released from the eight penstocks across the dam. The assumption has been made that water quality of each penstock is laterally homogenous and is based on the fact that the penstocks all withdraw from the same elevation in the reservoir and no horizontal heterogeneity has been documented in the reservoir near the dam. The basis for this assumption will be evaluated by comparison of paired deployments of monitors on consistently operating generating units through the next year. The deployment locations would be spaced as far apart as possible to maximize any lateral differences in water quality. These deployments would be most important during periods when the potential for any heterogeneity across penstocks would be greatest, such as late winter, when density boundaries are very close to penstock withdrawal zones. An assessment will then be made as to the need for modifying monitoring locations to more accurately represent dam releases.

Major Changes

A set of YSI Model 6920 water quality monitors was installed in January 2001 for monitoring below Glen Canyon Dam and at Lees Ferry. These replace similar Hydrolab Recorders, which have been used since 1995. These units have shown much less sensitivity to flow variations in dissolved oxygen measurements and are providing superior results compared to past instrumentation. Paired monitors in the Glen Canyon Dam draft tubes are also being deployed at widely spaced penstocks to evaluate potential differences between penstocks to address the PEP's concern about the draft tube deployment location. Total and dissolved organic carbon determinations have been added to the suite of chemical analysis parameters collected below Glen Canyon Dam and at Lees Ferry.

II. A. 1. e) Downstream Monitoring

Objectives

The primary purpose for water quality monitoring in Grand Canyon below Lees Ferry is 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. The water quality of Glen Canyon Dam releases forms a baseline from which changes occur downstream; downstream water quality monitoring documents these changes and the effects of tributary inputs. This information supports research regarding the effect of water quality on the downstream aquatic ecosystem.

Monitoring Activities

Thermal monitoring is performed at several sites on the Colorado River in Grand Canyon and at major tributary mouths. Submersible monitors are placed at 8 Colorado River main-channel locations at approximate 50 km intervals, and 9 Grand Canyon tributary sites (Table 1). Instruments are downloaded and serviced on a quarterly basis, in conjunction with other scheduled research trips when possible.

The U.S. Geological Survey Water Resources Division (USGS-WRD) has performed continuous monitoring of some water quality parameters at existing Grand Canyon gaging stations in recent years. Currently, temperature and specific conductance are measured on the Colorado River at Lees Ferry, above the Little Colorado River, and near Grand Canyon. The Colorado River above Diamond Creek gage is part of the USGS NASQAN program and is sampled 8 times a year for a wide variety of water quality parameters. NASQAN sampling at the Lees Ferry gage was discontinued in FY 2001.

As discussed in the following section, water quality monitoring at downstream locations will be augmented or revised, based on an analysis of existing data, assessment of modeling requirements, revised Information Needs, and results of reconnaissance monitoring during the next year.

Table 1. 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

PEP Recommendations

Comments from the Protocol Evaluation Panel and TWG members raised a concern with the low level of water quality monitoring downstream of Lees Ferry and recommended that sampling through Grand Canyon should be increased as needed to calibrate a river water quality model and address questions posed by fisheries or aquatic foodbase investigations.

The IWQP is designed to monitor parameters below Glen Canyon Dam that exhibit measurable changes through Grand Canyon, are affected by dam operations and have a significant effect on biological processes in Grand Canyon.

Current assumptions regarding downstream water quality changes and the effect of dam operations on these changes, combined with the cost and logistics of additional monitoring below Lees Ferry have determined the level of monitoring below Lees Ferry. While the current temperature monitoring meets these criteria there may be other water quality parameters that have significant linkages between dam operations and the downstream aquatic ecosystem.

With the recommendations from the PEP Panel and TWG members, revision of AMP Information Needs, input from other researchers, requirements of a river water quality model, and those of the Grand Canyon Ecosystem Conceptual Model, a revised and augmented water quality monitoring program below Lees Ferry will be developed.

Major Changes

Monitoring at an isolated group of warm springs near Fence Fault (RM 30) identified as potential humpback chub spawning areas has taken place since August 1995. As spring temperatures have been shown to be stable at 21°C, monitoring at these sites has been discontinued. Temperature monitoring in the Colorado River near Spencer Creek (RM 246) has been reinitiated. Continuous monitoring of temperature, specific conductance, dissolved oxygen, and pH of the Colorado River at the Lake Mead Boundary Buoy has been initiated on a reconnaissance basis to evaluate the levels of these parameters and the feasibility of maintaining accurate monitoring of these parameters.

In order to address the PEP recommendation of increased downstream water quality monitoring, provide input to modeling efforts, and improve understanding of water quality changes through Grand Canyon, monitoring of currently collected parameters will be maintained and possibly augmented with other parameters and the inclusion of the Colorado River above Diamond Creek in FY 2002. Sample collection for major ions, nutrients, and biological parameters will be initiated on a reconnaissance level to determine existing conditions and the need for continued monitoring of these parameters. Current and historical data will be evaluated to develop a long-term program of appropriate water quality parameters that will meet the PEP recommendations and support related AMP Information Needs. Based on this evaluation, observed patterns, and experience with the performance of these monitors, parameters and service intervals for the monitors will be more definitely established during the next year.

II. A. 2. Necessary and Complementary Research

II. A. 2. a) Introduction

In order to effectively meet the needs of the Adaptive Management Program (AMP), a research component is incorporated in the IWQP to provide meaningful information for management decisions supported by the results of monitoring efforts. Components of this research component include providing understanding of the linkages between dam operations, water quality conditions, and the affected aquatic resources in Grand Canyon, developing predictive capabilities of water quality conditions, evaluating and refining monitoring activities, and addressing other specific questions or information needs. This section describes several proposed research activities planned for FY 2002 and beyond.

II. A. 2. b) Modeling

A well-calibrated hydrodynamic model could be very valuable to the IWQP for many reasons. If the model can be developed predict to simulate Lake Powell water quality conditions currently being monitored by the IWQP, monitoring efforts on Lake Powell can be reduced, and expenditures can be refocused elsewhere. Simulation of processes in the reservoir can be observed and used to test currently held hypotheses. Scenarios can be posed that would provide more of an accurate prediction and elucidation of the mechanisms of potential water quality problems. Models for the Colorado River below Glen Canyon Dam can be employed to predict and simulate warming patterns and water quality changes downstream in Grand Canyon.

The Bureau of Reclamation Upper Colorado Regional Office has been developing the CE-QUAL-W2 model for use on Lake Powell and several other reservoirs within the Upper Colorado River

Basin. The primary focus of their modeling efforts on Lake Powell has been to evaluate the feasibility and the immediate effects of a proposed Temperature Control Device (TCD) on Glen Canyon Dam. The IWQP has interest not only related to a potential TCD but also to predict and simulate water quality and hydrodynamic conditions under a variety of climatological and operational scenarios to gain more understanding of reservoir processes and improve the efficiency of its monitoring program.

Plans are being developed to collaborate with Reclamation's Upper Colorado Regional Office (UCRO) in the development of CE-QUAL-W2 so that a working model exists to meet the needs of both parties. It is proposed that the UCRO provide the initial development and calibration of the model. The IWQP could provide the necessary hydrological, meteorological and chemical input information and well as in-reservoir monitoring data for model calibration and verification. Other projects, such as revising input bathymetric files, development of water quality and biological components of the model, and other model enhancements, could be evaluated in this collaborative environment and implemented, as necessary.

Downstream model development would proceed by invoking the riverine component of the CE-QUAL-W2 model, or by using other available simulation models for prediction and simulation of downstream changes to water quality.

The output of any modeling effort would be available to incorporate into the existing Grand Canyon Conceptual Model to provide a more accurate water quality input data into the model and to evaluate the response of the model to various potential water quality conditions that may arise in the future.

II. A. 2. c) Downstream water quality integration

The IWQP recognizes that science in the CRE could be advanced at a greater rate with more effective integration between AMP participants and other researchers with existing datasets. IWQP also recognizes that the information collected in the downstream reach may not be adequate to address management objectives and information needs proposed by AMWG. It is suggested that a 3-phase program be considered to fill this gap. This program could be contracted out, where appropriate, via the RFP process, or maintained in-house.

1. Assessment:

An evaluation of downstream researchers' water quality data needs (parameters, collection frequency, and data quality requirements) for addressing AMWG information needs would be conducted. Testable hypothesis will drive research efforts.

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.

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. Priorities of effort will reflect 1) a logical progression of knowledge based on trophic interactions, and 2) urgency of the data needed for collaborating with ongoing or pending research.

3. The research will be used to design an efficient and pro-active water quality monitoring program.

Key projects for downstream:

Downstream primary productivity has shifted in both composition and biomass over the last decade, and causes are still being sought. IWQP can be fundamental in driving integration with the involved researchers to identify causes that may stem from water quality, climatic trends, flow dynamics, natural succession, or other factors.

The role of downstream metabolism is still unknown and could be an important food-base source for higher trophic levels, including endangered fisheries. Basic water quality parameters may prove useful as a low-cost, less intrusive method for detection.

Integrating food-base science toward causes for primary productivity trends, shifts in community structure, differences reach-based metabolism, and effects of tributary influences has been a gap in the current GCMRC program. IWQP can help facilitate integration, identify knowledge gaps, and direct efforts to address data gaps where suitable.

PEP recommendations

The panel emphasized that integration of information and interagency data must be among the program's highest priorities. Efforts to calibrate hydrodynamic and ecosystem models, or establish community succession, energetics, and trophic interactions must be driven by testable hypothesis, sound sampling designs, coordination of effort and collaboration.

IWQP will focus increasingly downstream as modeling efforts allow for redirected efforts.

II. A. 3. Data Management, Analysis, and Reporting

II. A. 3. a) Introduction and Background

Data from the IWQP comes from a variety of sources ranging from hand-written field notes to large data files in electronic format. Consequently, this information usually exists as data in several software applications, depending mostly on the type of data, its point of origination, and the primary analysis application. Much progress has been made in moving these data into a standardized format in a common repository; however, a substantial amount of work remains.

A well-designed and comprehensive database is a necessity for an environmental monitoring program such as the IWQP. It provides a single location for each piece of information in a standardized format that can be easily linked with other data to provide fast and easy access and improve summary and analysis of the data. The data can then be output in a variety of hardcopy formats, graphics, or electronic files for input into other software or modeling programs.

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. Updates to larger public databases such as the USGS NWIS and the EPA STORET system can also be made

An existing data structure exists for the IWQP water quality information and is being used to store much of the data collected from the water quality-monitoring program. Because of its ease of use, availability, and capabilities, Microsoft Access has been designated as the primary database for development and population. Once the GCMRC Oracle database becomes operational, the relational structure of the database and its contents will be migrated to that database as a permanent repository. Until this progress is made, the existing Access database, with some proposed enhancements, will continue to be used and refined.

II. a. 3. b) Progress and Proposed Activities

Significant progress has been made with major components of WQDB, the IWQP MS Access database. The STATION table, a table describing locations, photographs, geographical coordinates, etc., of each sampling location has been completed.

All recent information has been entered into the SURFACE table, which describes each site visit to a particular reservoir monitoring location. Historical SURFACE information has been retrieved from the Ingres database, developed by Reclamation in 1995. This data will be incorporated into WQDB in the next year to provide a complete history of site visits.

Data from the corresponding PROFILE table, which lists measurements made at each depth in a water quality profile at a given station, is currently stored in SAS, in separate files corresponding to specific sampling trips. As SAS is the primary application software to process these data, the current plan is to keep the data in SAS files and establish linkages from MS Access to these files using the OLE and/or ODBC protocols. Remaining work in this area involves consolidating the individual files into a single master file and incorporating historical data from the Ingres database.

Information from analyses of major ion, nutrient, and other chemical parameters is currently stored in spreadsheet format. These data are stored in several files with different formats and have significant amounts of redundant information. This information will be converted to the WQDB database within the next year. Converting this information to a relational database format will facilitate protocol evaluation efforts to determine the need for a particular analysis and refinement of future monitoring activities.

Information from the biological sampling has been stored in various applications and processed separately. Efforts will be made in the next year to design an appropriate structure to organize these data and convert them into the WQDB.

II. A. 3. c) 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

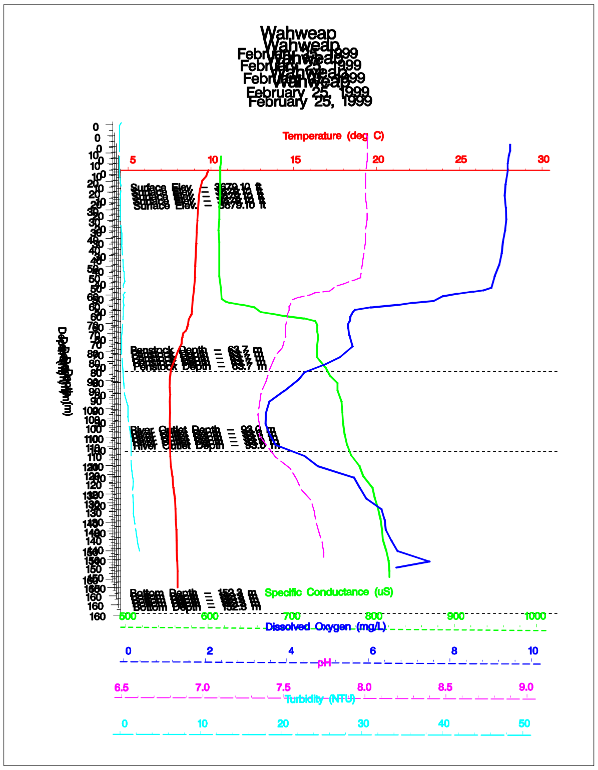

Figure 3. Reservoir water quality profile.

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 3) and graphical analysis of time series information (Figure 4). 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 5), or which changes across the reservoir at a specific time (Figure 6). 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.

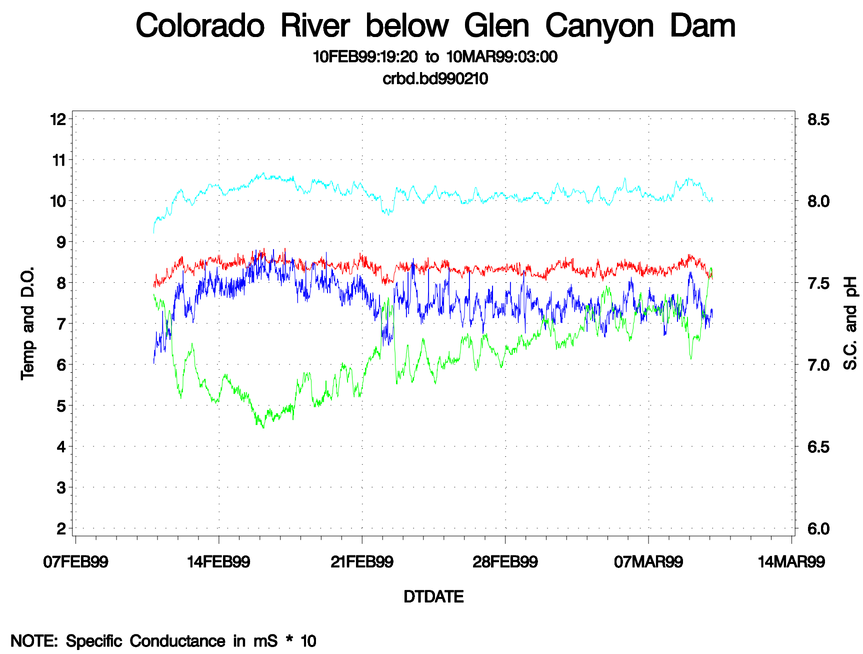

Figure 4: Time series of water quality at Glen Canyon Dam.

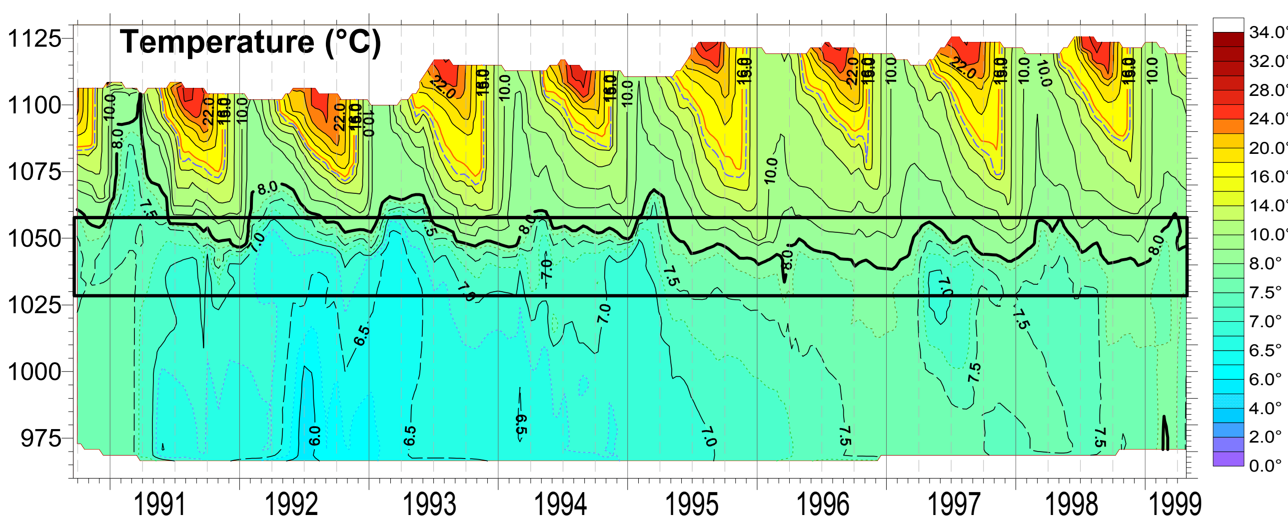

Figure 5. Time series temperature isopleth of Wahweap forebay station, with penstock intakes and river outlet works intakes indicated at 1058m and 1028 m, respectively.

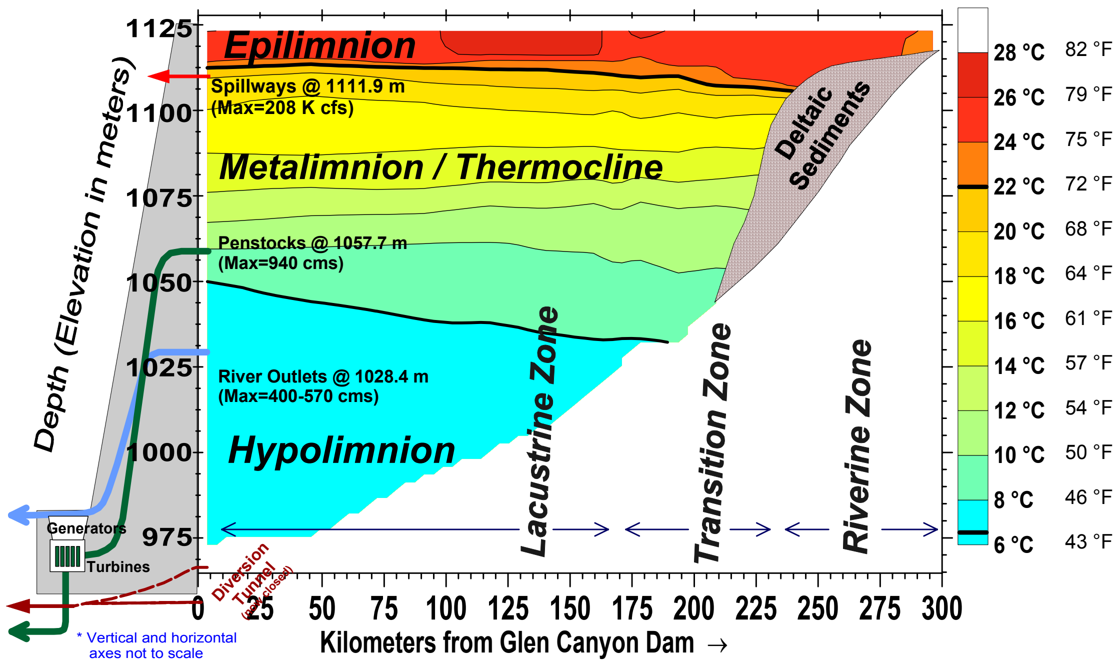

Figure 6. A cross-section of an isopleth of main-channel reservoir temperature.

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.

II. A. 3. d) Database Design

The design of the IWQP database has developed 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.

It is anticipated that the current design and structure of this database will be dynamic in the future, as population of the database proceeds, further optimization of the existing design occurs, and efforts begin to integrate with the Oracle database. A main goal of the database design is that the data exist in a modular format for ease of analysis and 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 7.

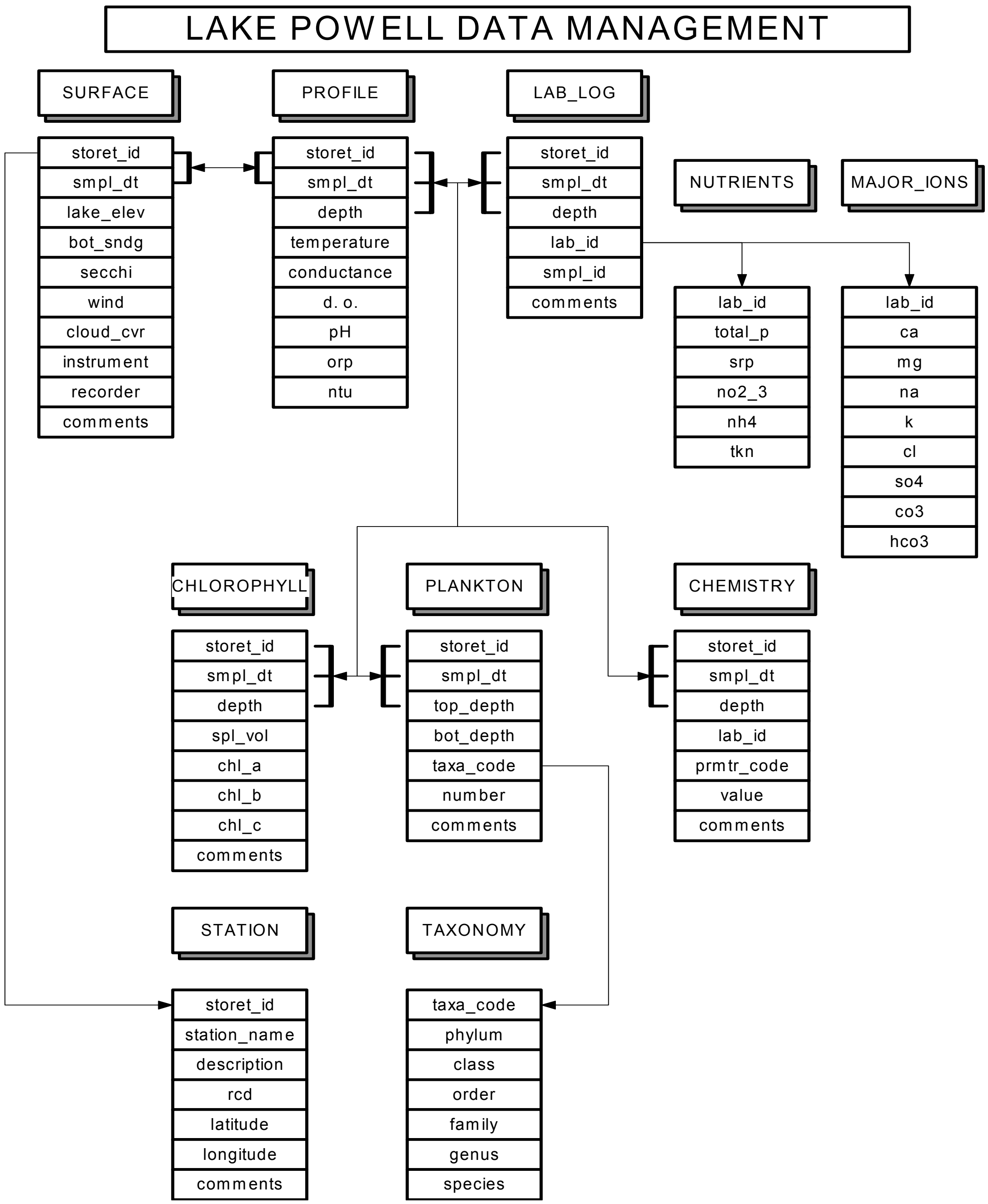

Figure 7. Water quality relational database structure.

The relational structure of WQDB is comprised of several *tables,* which contain items of information, or *records* that describe a particular component of the monitoring program. Tables can be linked together on common fields so that information can be shared between tables and redundant information is eliminated, as in this example of three main tables in WQDB. For example, the STATION table describes all the locations at which monitoring activities can take place. Each record in the STATION table contains a set of fields that describe a particular sampling location, such as its identification code, its geographical coordinates, and a verbal description.

The SURFACE table describes information and observations about a given site visit to a particular station, such as the time of the visit, maximum depth, and water clarity. One record in SURFACE describes one site visit at a particular station. There may be many records in SURFACE that correspond to one record in the STATION table.

The PROFILE table contains each individual measurement from a water quality profile, performed during a specific site visit at a particular station. Uniquely identified by the sample depth, site visit time, and location, each record list the value of each parameter (temperature, pH, dissolved oxygen, etc.) at a single depth. Many PROFILE records relate to a single SURFACE record.

II. A. 4. 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.

II. A. 4. a) Temperature control device

Modifications at Glen Canyon Dam for the installation of a temperature control device (TCD) have been proposed. This device would withdraw warmer water from the epilimnion of the reservoir at a higher elevation than is 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 higher biological productivity and generally more dilute chemistry than at penstock depths. This experiment will require modification to the existing water quality program to include more detailed baseline data, the need to document changes under operation of the device, and an evaluation of its effect to longer-term reservoir and downstream water quality patterns.

Findings from a TCD workshop in January 2001 (Kubly, et al., 2001) identified a number of water quality data requirements and issues that would need addressing upon approval of a TCD. These include alterations to the stratification, composition, and trophic dynamics of the epilimnion; differential entrainment of organic matter, nutrients and deleterious fish or pathogens, downstream and upstream ecological interactions, adequacy of modeling efforts and development, engineering alternatives, and others. Telemetered data would become a higher priority under TCD operation, and suitable budgetary adjustments would be necessary.

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, light penetration, 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 would be developed by GCMRC. At this point, the monitoring plan described in this document does not include specific activities related to the TCD. Maintenance of the current program, however, ensures that minimal baseline data is being gathered.

PEP recommendations

The panelists identified additions to sampling protocol should the operation of a TCD become imminent. These included continuous telemetered monitoring of temperature, flow and conductivity in the lake inflows, as well as installation of a telemetered programmable in-situ multi-parameter profiling station in the forebay, greater resolution of continuous tailrace monitoring, telemetered thermal monitoring in Grand Canyon in 3 locations, and possible use of automated sampling devices such as an IPSCO water quality sampler.

While not telemetered, continuous temperature is currently available with the thermistors in place at the forebay and inflows. Conductance values are available monthly from the forebay and continuously from the Colorado River inflow, though long-term deployment would require some modification. Telemetered data and a continuous multi-parameter station could be effected once TCD funds are made available and the specific data needs are identified and more immediate.

II. B. Resource Requirements

PEP recommendations and equipment

Conforming to PEP recommendations may require the purchase of a Sea-bird SBE-25 multi-parameter submarine profiling instrument. This unit can be adapted with various probes for basic physical parameters as well as in-situ chlorophyll, light penetration, and others. It is an oceanographic tool designed to collect rapid, high density vertical profiles. Startup costs could run $27,000 to $28,500. If suitable for Lake Powell, it could significantly reduced station time and personnel needs. The purchase of additional YSI monitors is proposed to provide assessment and replication of tailwater monitoring.

The addition of 4 meteorological stations to the reservoir could cost approximately $10,000-12,000. A full weather platform (air temperature, wind speed & direction, incident radiation, precipitation, and relative humidity) near the dam could run $4000-$6000 plus annual maintenance costs. In addition, several uplake stations including wind speed & direction would cost approximately $1000 each, plus installation and maintenance.

Alteration of the current chemical sampling scheme may redistribute costs, as some uplake samples are reduced and forebay and TOC samples are increased.

II. C. Staffing

Presently, the GCMRC IWQP is being conducted with two permanent full-time, and one term full-time staff positions. Ancillary help is received from an Interagency Acquisition from the National Park Service and Reclamation's Upper Colorado Regional Office, as well as part time term appointees and volunteers as available.

Staffing requirements include field activities of sampling and instrument deployment. These activities include trip planning and preparation, adequate acquisition and maintenance of supplies and equipment; and sample processing, shipment and equipment maintenance following a field survey. Instrument downloading, maintenance, calibration and servicing are performed in the field or in a laboratory setting. Data management, statistical summarization, and graphical analysis of the data are required prior to interpretation and subsequent reporting and presentation. Attendance and participation of scientific, AMP or other meetings or conferences is required, as well as community outreach projects.

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Reference:

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Sea-Bird Electronics, Inc., 1808 136th Place NE, Bellevue, WA 98005.

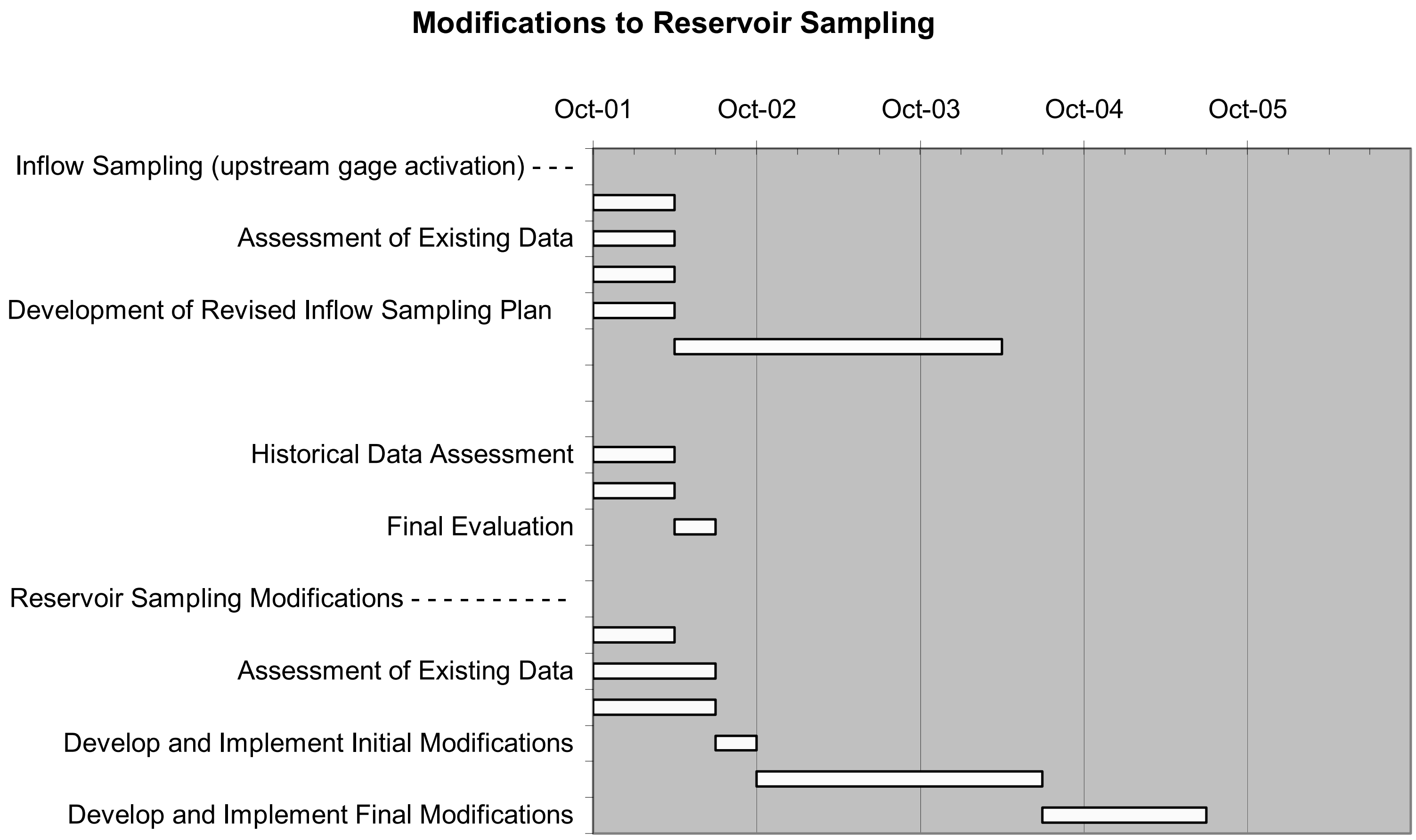
APPENDIX A

Detection limit and EPA Methodology of chemicals analyzed for the IWQP

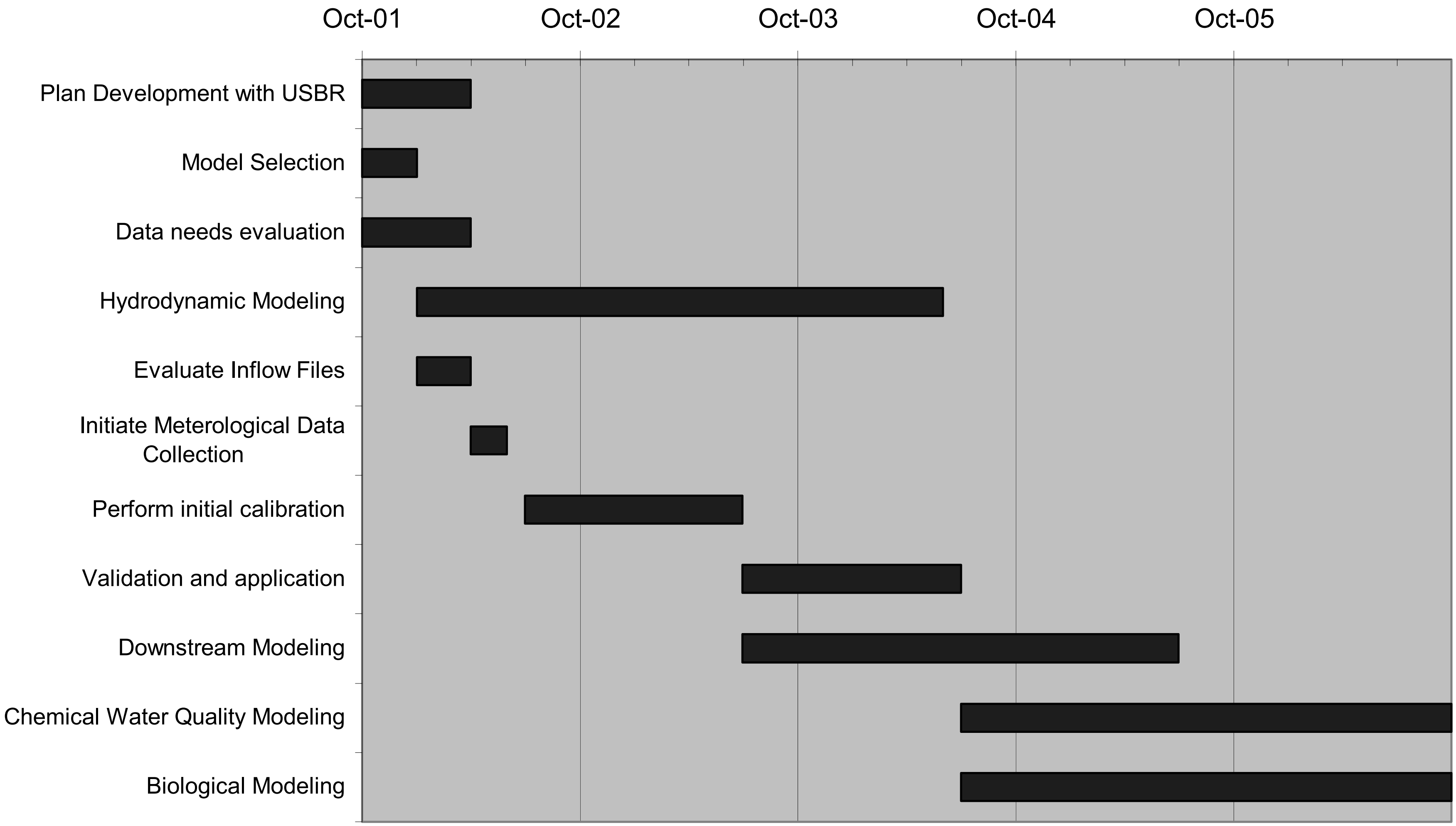
Analyte	Symbol	Sample Units	Detection Limit	EPA Method
Physical (Hydrolab profiles)				
Temperature	T	°C	0.1	
Specific Conductance	EC	µS/cm	1	
PH	pH	pH	0.01	
Dissolved Oxygen	DO	mg/L	0.01	
Oxidation-Reduction	ORP	mV	1	
Turbidity		ntu	0.1	
Major Ions				
Specific Conductance	Lab EC	µS/cm	2	120.1
pH	pH	pH	N/A	150.1
Alkalinity	CaCO3	mg/L	1.0	310.1
Total Suspended Solids	TSS	mg/L	4	160.2
Total Dissolved Solids	TDS	mg/L	10	160.1
Calcium	Ca	mg/L	0.03	200.7
Magnesium	Mg	mg/L	0.03	200.7
Iron	Fe^{+3}	µg/L	4.0	200.7
Sodium	Na	mg/L	0.03	200.7
Potassium	K	mg/L	1.0	200.7
Silica	SiO_2	mg/L	0.02	200.7
Carbonate	$CO^{3=}$	mg/L	1.0	310.1
Bicarbonate	HCO^{3-}	mg/L	1.0	310.1

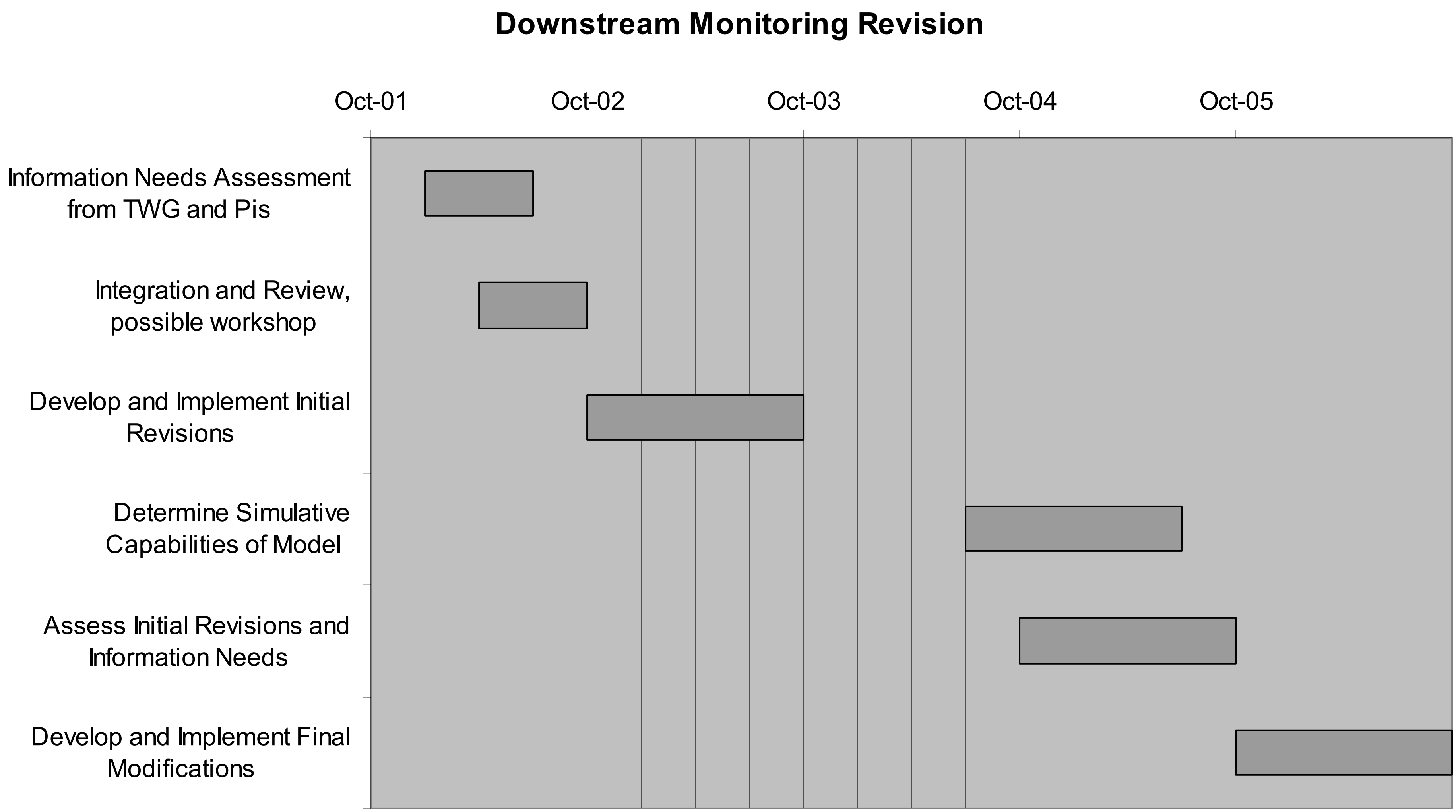
Analyte	Symbol	Sample Units	Detection Limit	EPA Method
Chloride	Cl^-	mg/L	1.0	300.0A
Sulfate	$SO_{4=}$	mg/L	1.0	300.0A
Nutrients				
Total Phosphorus	TP-P	mg/L	0.003	365.1
Soluble Reactive Phosphorous	OP-P	mg/L	0.001	365.1
Ammonia	NH_3-N	mg/L	0.003	350.1
Nitrate +Nitrite	NO_3 + NO_2-N	mg/L	0.003	353.2
Total Kjeldahl Nitrogen	TKN-N	mg/L	0.05	351.4
Organic Carbon	TOC DOC	mg/L	0.5	415.1
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			

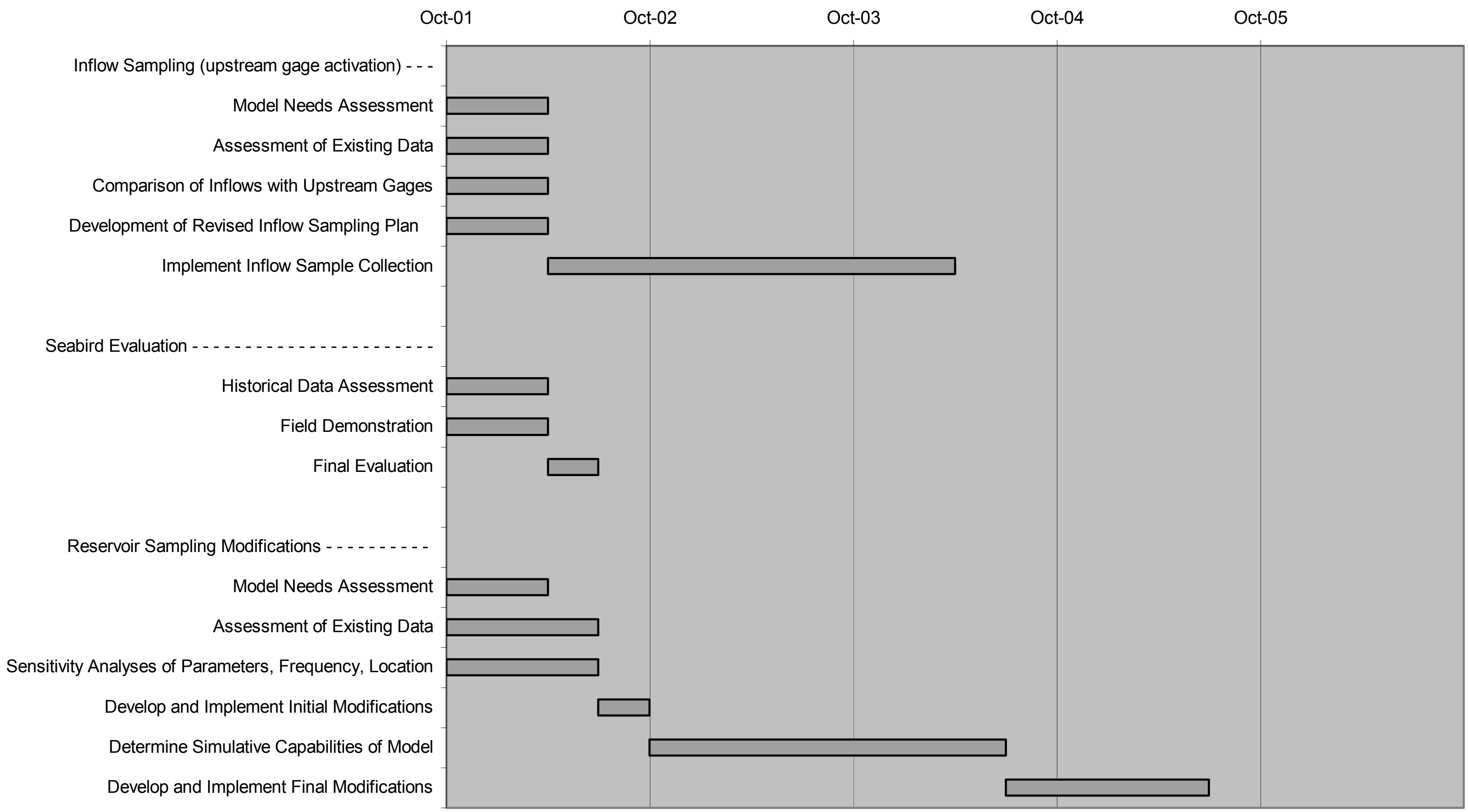
APPENDIX B


Modifications to Reservoir Sampling
Oct-01
Oct-02
Oct-03
Oct-04
Oct-05
Inflow Sampling (upstream gage activation) - - -
Assessment of Existing Data
Development of Revised Inflow Sampling Plan
Historical Data Assessment
Final Evaluation
Reservoir Sampling Modifications - - - - - - - - - -
Assessment of Existing Data
Develop and Implement Initial Modifications
Develop and Implement Final Modifications

IWQP Modelling Activities




Downstream Monitoring Revision
Oct-01
Oct-02
Oct-03
Oct-04
Oct-05
Information Needs Assessment from TWG and Pis
Integration and Review, possible workshop
Develop and Implement Initial Revisions
Determine Simulative Capabilities of Model
Assess Initial Revisions and Information Needs
Develop and Implement Final Modifications


Oct-01
Oct-02
Oct-03
Oct-04
Oct-05
Inflow Sampling (upstream gage activation) - - -
Model Needs Assessment
Assessment of Existing Data
Comparison of Inflows with Upstream Gages
Development of Revised Inflow Sampling Plan
Implement Inflow Sample Collection
Seabird Evaluation -
Historical Data Assessment
Field Demonstration
Final Evaluation
Reservoir Sampling Modifications - - - - - - - - - -
Model Needs Assessment
Assessment of Existing Data
Sensitivity Analyses of Parameters, Frequency, Location
Develop and Implement Initial Modifications
Determine Simulative Capabilities of Model
Develop and Implement Final Modifications