Grand Canyon Monitoring and Research Center Water-Quality Program Review

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Summary of review panel comments

The panel was impressed with the monitoring program and the dedication of the staff from multiple government agencies who have worked together to maintain the program in the face of daunting logistical challenges and bare-minimum funding. The long-term data record is invaluable for understanding how the linked Lake Powell-Grand Canyon Ecosystem functions, how management of the dam may affect ecosystem functions, values and services both above and below the dam, and how future changes in climate and runoff regimes may impose changes on the ecosystem.

The justification for the monitoring program, encompassing both the Grand Canyon as well as Lake Powell, is clearly articulated in the GCDAMP FY 2017 Knowledge Assessment. The major environmental concerns in the Grand Canyon are closely tied to the quality of water discharged from the dam, including nutrients as well as temperature and dissolved oxygen (DO), which in turn reflect limnological conditions in the reservoir. Therefore it is critical to understand the Lake Powell ecosystem from the standpoint of maintaining and enhancing the Grand Canyon ecosystem as well as protecting environmental values and recreational and aesthetic services afforded by the reservoir itself.

Altered temperature, high salinity and low DO are water quality attributes of particular concern, but inorganic phosphorus (measured as soluble reactive phosphorus, SRP) may prove to be important as well. There is also increasing concern about high temperature fluctuations that can favor non-native fish species. Ongoing study may reveal other attributes of concern. The water quality at the penstock depth, and therefore below the dam, is determined not only by the rivers that feed Lake Powell but also by a suite of incompletely understood, complex drivers including vertical heterogeneity in the water column, sediment-water interactions, and planktonic growth in the reservoir. The monitoring program also has considerable value for understanding the Lake Powell ecosystem in and of itself; this is of interest to the substantial number of boaters and other tourists who visit the Glen Canyon National Recreation Area, and to the National Park Service who is responsible for stewardship of the lake and its surrounding lands.

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The panel identified areas that are in need of improvement in the Lake Powell monitoring program, and a number of these apply as well to monitoring of downstream waters. The most important priorities to be addressed can be grouped into these categories:

- Improve data management including metadata.
- Analyze existing data to reveal trends and inform future monitoring
- Increase vertical sampling resolution of the reservoir water column at key sites
- Use the results of modeling experiments and analysis of previous data to consider reducing the spatial extent (number of sites) during quarterly sampling
- Implement more detailed and formalized sensor calibration and QA/QC of field and lab procedures

The four questions posed to the review panel are answered below. We also added a section at the end of the report describing recommendations for improved data management, which we identified as being a high priority.

1. **How does our ability to model dissolved oxygen, temperature, nutrients, and conductivity in both Lake Powell and in its outflow compare to predictive capability in other systems using the same or different modeling approaches? What, if any, improvements can we make on our current modeling techniques?**

The current model, CE-QUAL-W2, seems adequate given its widespread use in reservoirs and the heavy investment so far for Lake Powell. The hydrodynamic model seems to be working adequately, and we suggest that the greatest improvements to the model will be gained from better temperature, meteorological, and bathymetric data. The General Lake Model (GLM; see below) is stable and relatively easy to use and could be implemented in order to compare its performance alongside CE-QUAL-W2 for Lake Powell. The temperature and DO predictions are priorities for improvement, and additional temperature data from one or more thermistor strings is recommended because of the primacy of temperature and stratification in controlling lake physical and chemical properties. Variables such as SRP will require more research before they can be added to the model. Finally, while modeling cannot supplant the need for monitoring, it can help inform the best use of the limited resources for monitoring. We recommend using CE-QUAL-W2 to determine which sampling locations are most critical for model performance with the expectation that some of the current 37 quarterly monitoring locations will probably be discontinued, leaving fewer stations which can be sampled more intensively.

The current model seems adequate, particularly for hydrodynamics within Lake Powell.

CE-QUAL-W2 was developed for large, run-of-the-river reservoirs and has been used on those systems for decades. Although it is somewhat cumbersome to use because it is based

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on Fortran and therefore has very specific requirements for data input, it is also very versatile. Small errors in input can create big problems with model output so it is best to have someone responsible for the model who is familiar with building and running it.

One alternative is the GLM model (http://aed.see.uwa.edu.au/research/models/GLM/), which has gained wide acceptance because of its versatility, stability, and ease of implementation. GLM is a one-dimensional model and so assumptions would need to be made about the validity of vertically-averaged model results. Nevertheless, its ease of use would make it useful to compare against CE-QUAL-W2 or for exploratory analyses as described below.

The current model produces reasonable month-to-month results for predicting temperature and salinity. Two factors that can typically improve results for the CE-QUAL-W2 model are better temperature and meteorological data.

The Lake Powell CE-QUAL-W2 model currently uses meteorological data from the Page, AZ, airport. Data from the stations at Hanksville, UT and Bluff, UT were also used in previous years, but those stations were discontinued. Placing an additional weather station on a raft in Lake Powell could improve modeling results. Meteorological forcing is a primary driver of surface temperature and mixing depths, therefore improved meteorological data will improve model performance. The proposed meteorologic station should be added at a location upstream of the dam to provide the best possible representation of regional weather patterns. Bullfrog Marina is recommended because of its distance from the dam and because it is a site which should allow for relatively easy maintenance. Because solar radiation is not measured at the Page weather station, it should be measured at the new site.

The Bureau of Reclamation's Upper Colorado Regional Office updated Lake Powell bathymetry in October 2017 and this data is currently being compiled (personal communication, Nick Williams). Improved bathymetry should also further improve the accuracy of any modeling efforts.

DO and temperature are priorities for improvement, but improving the predictive capability for temperature should also improve results for DO. Better meteorological data will improve temperature modeling, as discussed previously. Adding a thermistor string at a location upstream of the dam could be used to improve vertical temperature resolution, although that also increases the effort required to run the model. A good location for the thermistor string would be at Wahweap. That location typically integrates most of the flow from farther upstream and additional data at that point could improve predictions for water quality leaving the dam.

Because temperature data are probably the most critical input for the operation of CE-QUAL-W2, adding additional thermistor strings at additional upstream locations would probably improve modeling results more than adding loggers for DO or other water quality variables. Recommended upstream locations would be Bullfrog on the main stem of the lake and Cha Canyon on the San Juan arm. Both of those locations are deep enough to avoid undue impacts from suspended sediments. The additional locations may only create significant differences in model output during extreme weather events and are not as critical as the Wahweap site.

Another factor that may be adversely affecting current modeling results is high wind speeds. The greatest variation between observed and predicted temperatures at the lake outlet occurred when wind speeds were greater than 20 m/sec. The potential for adjusting model results to account for this observation should be evaluated.

Phosphorus (P) modeling may need to await further information on controls on P concentrations in the reservoir; modeling should be a longer term goal.

While it will take time to incorporate P into Lake Powell modeling efforts, the current monitoring program is already collecting much of the data that will be needed to model P concentrations (hydrodynamics, nutrients, chlorophyll a, zooplankton, and major algal groups). The hypothesized importance of SRP downstream awaits confirmation and may influence the effort to be invested in understanding P cycling in the reservoir. Current observations suggest that P concentrations are typically low although large overall variability has been observed (up to an order of magnitude). Therefore, P modeling can wait until after the hydrodynamic modeling is enhanced and the approaches to resolving questions of the influence of P on the downstream ecosystem are more formulated more completely.

The largest changes in Lake Powell phosphorus levels so far have occurred when flood events disturb sediment deltas that are exposed during periods of extended drought and lowered water levels. Inclusion of a sediment diagenesis compartment in CE-QUAL-W2 could potentially be very important in predicting P concentrations at very low lake levels and how this phosphorus moves through the reservoir.

GLM may be useful for predicting phosphorus and chlorophyll *a* concentrations in Lake Powell because of its ease of use. It may be advisable to use the GLM model first when P modeling is incorporated to evaluate critical factors affecting P levels. That could reduce the effort needed to get good nutrient results with CE-QUAL-W2.

The current model could inform which Lake Powell sampling stations are critical to water quality prediction at the dam intake and in the main body of the lake.

Sequentially eliminating stations from model runs and comparing results to runs that incorporate all stations should show which stations are the most important. It is likely, however, that some of the upstream stations may not be critical when the reservoir is at or near full pool but could become increasingly important as water levels drop. *Modeling cannot supplant the need for field sampling.* Although the current sampling program could be altered slightly to target specific areas of interest in the future, continued collection of

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field data is required to understand hydrodynamics and nutrient cycling in Lake Powell and should be continued.

Linking the lake temperature predictions to downstream water temperatures immediately below the dam and in the downstream river reaches should already be possible with current information and models.

In some cases, errors in temperature at the lake outlet are currently larger than desired; however, it should be possible to reduce those errors if the above recommendations (i.e., adding one or more thermistor strings and an additional weather station at upstream locations) are incorporated into the monitoring program.

2. How should analysis of the historical dataset be prioritized to improve our understanding of how management actions and natural mechanisms affect phosphorus dynamics in Lake Powell?

Analysis of historical records is important not only to show past trends but also to determine whether measurements should continue in future.

There may be undiscovered data of value, for example from the Bureau of Reclamation's Boulder City lab.

Metadata records need improvement for P (and other measurements). Changes in methods including detection limits present a challenge to interpretation of the data.

Ultimately, placing past and future data into USGS National Water Information System (NWIS) would be a good goal.

In the context of the current program review, the analysis of historical records has focused largely on phosphorus dynamics in the lake as a potential driver of downstream fish productivity. While this is a laudable goal and should be pursued given the current interest and need to evaluate drivers of fish productivity, the analysis of historical data, from either a historical perspective or at the time of collection, has been a shortcoming of past GCMRC activities. While past staff did excellent work to develop and implement a sampling program that has provided a wealth of data on Lake Powell, the analysis of these data has been minimal at best. The lack of data analysis in the past is a significant driver of the management disconnect between the limnology of Lake Powell and its influence on downstream conditions. A comprehensive, dedicated analysis of past data is essential for rebuilding the link between these systems in the context of the management of this regulated river. For example, the reservoir appears to act as a very significant sink for phosphorus, an assertion which has been noted here, in the literature, and in discussions held during the in-person meeting, but this requires quantification and verification. In addition, there is strong support in the literature and in our discussions that organic material transported by the Colorado River through Glen, Marble, and Grand Canyon has also been severely reduced. The ramifications of this include both the reduction in organic material available to support the food base and a shift toward autochthonous support of the food web, which is then more sensitive to changes in phosphorus delivery. Answering these and other questions requires dedicated analysis of historical records collected by GCMRC, by others, and collected prior to the closing of Glen Canyon Dam.

While the GCMRC dataset is extensive and has benefitted from consistency of execution in the close collaboration of the three partner agencies, it is not the only dataset that should be considered in assessing system dynamics. The most recent example of sampling efforts that may benefit the understanding of Lake Powell and Colorado River dynamics is the work being done to characterize the impact of the Gold King Mine release. While the contaminant monitoring will provide information on near and long term health and ecosystem impacts, the data should also be considered in the broader context of assessing basic ecosystem dynamics. This broader context approach should be expanded to include a search for data collected before the impoundment of the reservoir, data collected by other agencies (like the Reclamation SLC office) or by other groups within existing agencies. This review should include state, tribal and federal agencies, universities, and potentially nonprofits or public interest groups that may have focused data collected in the past. Into the future there may be value in expanding partnerships that currently exist between federal agencies to include university partners or citizen science as sources of focused data. These types of partnerships have benefitted efforts in understanding Lake Powell (Wildman et al. 2011; Wildman et al. 2017) and the downstream food base (Kennedy et al. 2016) and can have lower costs than more structured long term efforts

Metadata is essential for evaluating data quality, detection limits, analytical methods and appropriateness. Analysis of past data can be problematic or ill-advised without this information. These problems are particularly vexing for variables like phosphorus in systems where concentrations are frequently at or near the limits of detection for even the most sensitive methods. The assembly of metadata for all of the data collected in past efforts by GCMRC, to the extent possible, should be prioritized. Consistent documentation is critical to ensure that future analysis includes the capability to recreate changes in analytical methods, detection limits, and sampling techniques and goals. Additionally any special conditions (e.g., storm events; algal blooms; flow conditions; etc) that may have been observed during the sampling will not be known by those attempting to analyze the data in the future. Metadata, particularly for nutrient analyses, chlorophyll concentrations, and DO measurements, will be essential if this information is to be included in future modeling expansions. For example, knowledge of past phosphorus analytical limitations was necessary to modelers developing the Lake Mead 3 Dimensional Water Quality Model because updated, lower detection-limit analyses were needed to better predict future conditions in Lake Mead.

Placing past and future data into a curated, publicly available database such as the Water Quality Data (WQX) will benefit Colorado River science and management, will make the data more broadly available to outside researchers, state, federal, and tribal agencies, and will increase the data management requirements and standards. While the broadly defined quality of the existing data appears to be high, the collection and incorporation of metadata will eventually facilitate its application and use. The benefits of using a system such as WQX are: 1) the data infrastructure and public-facing access already exist; and, 2) the requirement to adhere to data quality and presentation requirements of an 'outside' repository would encourage and require a more proactive approach to data curation. The historical Lake Powell data that have been organized into database files in the past have been integrated into the Lower Colorado River Water Quality Database (LCRWQD) maintained by the Southern Nevada Water Authority. While this does encourage the use of these data by those who know of its existence, the database does not have the data management standards or metadata requirements of databases such as WQX. Furthermore, WQX is incorporated into the widely-used Water Quality Portal (https://www.waterqualitydata.us/), which is accessible online and through automated search routines in the programming language R (https://www.r-project.org/). The LCRWQD takes data from outside agencies but does not independently verify, audit, or validate the data or require metadata or impose quality standards or evaluation. These tasks remain the responsibility of the original agency, and in the case of the Lake Powell data the work has largely been restricted to importing the information and gross error checking. Incorporation into WQX would bring much higher levels of confidence to the use of this data.

3. **Is current monitoring being conducted at an appropriate number of depths and/or sites and at an appropriate temporal frequency to give accurate information on the current status and trends of water-quality conditions and to inform predictions using either the current modeling approach or a potentially improved model?**

The Lake Powell monitoring program was established as part of the Salinity Control Act to understand how the lake influences downstream environments with a focus on understanding the distribution of salinity (TDS and conductivity), temperature, DO, and sediments, and modeling export of water to the river below the dam. The program shifted in the 1990s to increase spatial coverage of sampling sites and a new focus on nutrients and other water quality constituents, but sampling had limited vertical resolution. We recommend expanding vertical sampling resolution at sampling sites closest to the dam. We also suggest options for prioritizing monitoring locations in order to streamline the sampling protocol and allow a greater emphasis on vertical sampling resolution. We believe this will be beneficial to understanding a number of chemical characteristics of the lake, including nutrient dynamics, which may influence downstream fish communities.

Other than the Wahweap station, which is sampled at multiple predefined depths during quarterly and monthly sampling, other sampling locations are only sampled at 1 m below the surface and 1 m above the bottom. Additional samples can be collected throughout the water column, but the rules for doing so are not well defined. Profile data and presentations shared with the review panel highlight the unique features of Lake Powell, including: deep chlorophyll maxima, inflow currents with varying density, and DO minima and maxima. Increased vertical resolution in sampling stations near the dam will improve the understanding of lake processes that may influence downstream environments. Formalizing how these features are monitored will help the monitoring program to continue to meet its objectives, as defined in the chemical data summary prepared by Vernieu in 2015: "The main objective of the sampling effort was to characterize chemical conditions near the surface, near the bottom, **and in each major stratum of the water column**. A secondary objective was to describe unusual phenomena that may occur **at specific depths** such as a metalimnetic DO deficit or an inflow plume flowing into an intermediate layer in the reservoir."

The vertical resolution of sampling should be expanded and formalized. A written protocol should be developed and executed which explicitly states when sampling occurs at various depths. Currently, additional samples are collected at various depths when stratified conditions are observed during quarterly sampling but not during monthly sampling at the Wahweap station. It is unclear whether or not there are formal methods or criteria outlining when and where this additional sampling occurs (defining what is considered a "major stratum" and "unusual phenomena"). It is important to formalize data collection at an increased vertical resolution with appropriate scientific justification to ensure these data are consistently collected and are useful for discerning long-term trends and the effects of sub-surface anomalies on downstream conditions.

As a first step in expanded vertical sampling, the panel suggests sampling at more depths based on observed stratification and chemical differentiation (SeaBird profiles) at the Wahweap and Crossing of the Fathers stations. Data from these stations can be analyzed and may inform expanded vertical sampling at other sites. Ideally, we suggest identifying several sampling depths within the epilimnion or euphotic zone and following a specific protocol for when and where the samples are collected across all sites. Although the ideal representation of surface water chemistry requires collecting an integrated sample from the epilimnion or euphotic zone, this is limited from a practical standpoint because the euphotic zone can reach 40 m in Lake Powell. Instead, we recommend identifying additional sampling depths and developing a formal protocol that defines when these samples are collected. The recommended changes to the discrete sampling depths are:

- The deep chlorophyll maximum (DCM) when it exists. Included within this recommendation is a formal definition of a DCM. Our suggestion is to define a DCM as a layer which has a chlorophyll concentration > 2 x the surface concentration, based on the SeaBird chlorophyll profile.

- Any apparent interflow layer. The SeaBird conductance profile could be used to objectively define the interflow layer. For example, a > 100 μS cm^{-1} change in mid water column could be used as the threshold to indicate a chemically distinct interflow layer.
- The current routine includes sample collection at 1 m above the bottom. This collection method risks disturbing the sediments and contaminating the sample. We recommend collecting deep water from the middle of the hypolimnion, as defined by the SeaBird profile. A trial using paired samples from 1 m above the bottom and the middle of the hypolimnion could be conducted and if the samples compare well, the deeper samples should be discontinued.
- In addition, we recommend that the current sampling scheme at 1 m below the surface, a deep water sample, and at the penstock depth for the forebay site, should be maintained for long-term continuity. Therefore, the recommendations would result in an increase in the number of samples collected at each monitoring location.

Quarterly sampling of multiple stations in Lake Powell:

As mentioned in section 1 (p. 4), the current quarterly monitoring sites should be evaluated in terms of whether they inform the CE-QUAL model. It is possible that some sites could be eliminated with little effect on the modeling effort. Deciding which sampling sites to maintain should be prioritized based upon whether they are important to model outcomes as well as sites with long-term records (pre-1990s) to maintain continuity at high-value long-term sites.

4. Are there additional types of measurements or newer methodologies that should be incorporated into the routine monitoring program?

We have a number of specific recommendations about improvements to existing observations or additional observations that could be made to further support the goals of the monitoring program. Many of the recommendations involve better QA/QC and verification of SeaBird data, and these activities should be prioritized because of the central role SeaBird data plays in model implementation. We also recommend analyzing historical plankton samples and dissolved organic carbon (DOC) data to determine whether sample collection is worth continuing. We discuss how additional data from a weather station, automated sampling platform, and/or thermistor string would be likely to improve model performance and utility, but acknowledge that this expanded data collection would add to the expense of sampling and so must be considered carefully. Finally, contaminant research does not seem to be a priority for the Lake Powell Monitoring Program and could be handled with a lower priority.

The SeaBird data serve as the backbone of field limnological observations and so we recommend prioritizing efforts to ensure that data collection continues and is of the highest quality. The SeaBird unit is likely to need replacing soon. It would be wise to replace it before it fails and use the current unit as a backup. A primary concern is that the annual calibration of the SeaBird does not provide enough temporal resolution to know about potential shifts in instrument performance that would affect interpretation of the data. We acknowledge that the SeaBird is a complex instrument that is recommended to be calibrated only by the manufacturer. However, empirical support from paired samples or a paired Sonde, which can be easily calibrated in-house, would allow greater knowledge about the rate of drift of the SeaBird and provide independent verification of the data. Obtaining information from the manufacturer on calibration status when the SeaBird is sent in for maintenance but before it is recalbrated would also provide valuable information on the rate of drift.

Several measurements collected by the SeaBird should be upgraded or further verified. Switching to an optical DO sensor is recommended. The panel acknowledges that the response time is longer and varies with temperature and pressure for the optical DO probe. However, the Seabird unit should have the instrument lags programmed into data interpretation. More importantly, Clarke-type membrane probes are known to be unstable and require frequent calibration. The annual calibration by Seabird is not likely to be adequate to ensure data quality. The quality of the pH and chlorophyll data are not known and so should be treated as estimates only. Recommendations for improving QA/QC of the pH and chlorophyll observations are described below.

We recommend the collection of field pH because lab pH measurement occurs after carbon dioxide equilibration with the atmosphere and so it may not match the in-situ pH. Consider recording field pH at the water sampling depth in addition to lab pH measured much later. This can be done in the boat if samples are collected to avoid air equilibration, and transferred to the pH electrode using a closed-system method. A recently-calibrated Sonde probe or a laboratory-grade pH electrode could be used in the boat. However, we stress that the critical piece is the routine calibration of pH because annual calibration is highly likely to be inadequate. It is common practice to calibrate pH probes before every field sampling trip and to perform daily verification that drift has not occurred. A field pH protocol would also provide a means for verifying or correcting the pH data provided by the SeaBird.

Unless proven otherwise, SeaBird chlorophyll estimates should be considered approximate and not used to replace the “filter-based” lab measurements, nor can they be reliably compared with earlier lab measurements. They are critical for relative observations, such as identification of a deep chlorophyll maximum or seasonal changes, but the accuracy of the absolute concentrations must be verified. Fluorometric measurements of chlorophyll with the Welschmeyer non-acidification protocol may be desirable for lab measurements, which are subject to their own issues. Earlier practices of working with chlorophyll samples in the open sunlight and the current practice of not freezing them in the field raise questions about those data. The validity of this method should be tested and documented. Tests should be conducted to establish whether these practices affect the measurements and better procedures should be adopted from now on (see below). Conversely, if these comparisons have been made, the results should be documented.

Phosphorus measurements could be enhanced by adding a SeaBird HydroCycle-PO4 to detect short-term fluctuations. A unit should be obtained on loan and tested against lab measurements before considering purchase. The instrument has a relatively high detection limit (3 μg l^{-1}) compared to median concentrations in the lake (5 μg l^{-1}) and so its utility may be limited in areas other than the inlets where P concentrations are higher. Consider total dissolved P (TDP) in addition to Total P to be able to distinguish particulate P, dissolved organic P, and acid-extractable P. If after a year of measurements TDP is found to be nearly equal to acid-extractable P this could be stopped. However this is unlikely where there are significant suspended sediments (i.e., in and near the inflows to the lake).

A thermistor string near the dam boom would be useful for understanding temperature and verifying model performance. This recommendation overlaps with recommendations made for CE-QUALL W2 modeling improvements (p. 3). The thermistor string could include DO and conductivity sensors at penstock depth, or better yet a full Sonde, kept in place by a subsurface float. A full profiling platform like those in Lake Mead would be ideal. A single station at Wahweap would be beneficial and an additional station well upstream would be even better to provide advance warning of an DO-depleted plume or unusual warming.

Long-term sampling of plankton and DOC should be analyzed and critically evaluated in order to decide whether to continue data collection. Plankton data could become extremely valuable in light of the Quagga mussel invasion. For example, zebra mussels have been implicated in promoting *Microcystis* in non-eutrophic waters elsewhere. Other invasive invertebrate and fish species may change the plankton community in the future. The DOC data need to be evaluated. Similar data collection in Lake Mead has not been informative.

Sample handling also needs to be improved or demonstrated to be adequate. Nutrient and chlorophyll samples should be frozen or at least cooled in the field. Freezers or refrigerators for field use on boats are available. Chlorophyll and SRP are especially subject to change during storage. Consider using a sample splitter for subsampling, especially when suspended sediments or colonial phytoplankton are present. We also stress that if any changes are made to protocols, even if they seem to be inconsequential, those changes should be recorded as metadata that follow the data wherever they end up. Examples include sample collection methods, filter type, filtration methods, and sample storage and preservation. Furthermore, changes in sampling protocol should be accompanied with a period of method comparison in which both methods are used so the comparability between the old and updated methods can be evaluated.

During the face-to-face meeting, several instances of poor replication and possible contamination of field samples were given. We strongly recommend formalizing the QA/QC procedures in order ensure that the highest quality data are produced. SRP seems to show sporadic variation among replicates, suggesting contamination of glassware or during sample handling. The source of this potential contamination needs to be determined. We recommend testing blank water (i.e. field-preserved DI water) and running 2x reagent blanks in the lab to test the importance of reagents or water as sources of contamination. Formalizing QA/QC should include duplicates, field blanks, and field spikes. Blind standards could be submitted to the lab. Furthermore, inter-laboratory comparisons for sample mean and variation between replicates are available for certain analyses that are prone to error, such as total P.

Contaminant research does not seem to be a priority for the Lake Powell monitoring program. While selenium and mercury have been identified, few options are available for management of contaminants within the lake or river system. Trace metals in the anoxic plumes may be worth measuring at least synoptically (but see USGS study). The Gold King Mine release may be significant but is being handled separately.

5. Recommendations for improving data management and accessibility.

During the face-to-face meeting, the panel noticed that there does not seem to be a central repository for data collected as part of the long-term monitoring program. Discussions about long-term data resulted in members of the USGS or the Bureau of Reclamation learning, on the spot, about methods, what sort of data were available, and the quality of some of the data. **The panel views improved data management as a primary recommendation.** The sampling efforts on Lake Powell are unique, high-quality, long-term, and ultimately extremely valuable. The panel worries that without a concerted effort to improve data curation, the excellent work done by the group will be lost. Our primary recommendation is to use an existing data infrastructure as a repository, a vehicle for public access, and motivation to improve data curation, metadata development, and documentation. National databases such as the USGS National Water Information System (NWIS) or the EPA Water Quality Data (WQX) should be considered. Biological data, such as the plankton samples, would be better stored in a database such as BioData.

Proper data management would require dedicated time of a data manager. The first task would be to identify where the data are currently located and what curation procedures are currently in place. The GCMRC is collaborating with Utah state agencies, so it is possible that the data are already being entered into the EPA WQX database. Duplicating data would be extremely undesirable, so this step should be taken first. Other steps include developing the metadata, identifying all data sources, determining which samples could be placed into a database, and documenting the QA/QC procedures. Going through this process would be time consuming, but would likely be worth it ultimately. If the NWIS system were used, one possibility would be to partner with the USGS Utah or Arizona Water Science Center. They have staff who are knowledgeable about NWIS and could be contracted to serve as technical assistance in this regard. Either the Utah or Arizona Water Science Center would also be the gatekeeper to ultimately decide whether the Lake Powell data could be served on NWIS. Whether WQX or NWIS were used, public access to the data would be greatly enhanced through web interfaces, the Water Quality Portal, and through tools in the R programming language that allow interactive downloads of the data to be used by researchers, managers, and the general public.