BACTERIA WATER QUALITY DATA ANALYSIS AND INTERPRETATION

GLEN CANYON NATIONAL RECREATION AREA

Barry A. Long and Rebecca A. Smith

Technical Report NPS/NRWRD/NRTR-95/46

WATER RESOURCES DIVISION

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Bacteria Water Quality Data Analysis

and Interpretation

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Barry A. Long[1] and Rebecca A. Smith[2]

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EXECUTIVE SUMMARY

Since 1988, Glen Canyon National Recreation Area has been monitoring bacteria levels in Lake Powell to assess potential impacts from recreational bathing and boating. Due to high bacteria levels, advisory notices were posted at several beaches during the last few years. The park requested that the Water Resources Division analyze and interpret the bacteria data, and help them develop a way to measure acute levels of bacteria contamination in time to warn recreational users.

Fecal coliform bacteria was the primary parameter sampled, and average colony counts ranged from a high of 1,412 colony forming units per 100 milliliters (cfu/100 mL) to a low of zero. One duplicate sample collected from Hobi Cat Beach in 1991 contained 1,840 cfu/100 mL. Seventy-five violations of state of Utah water quality standards occurred at 18 sites in the park between 1988 and 1993. Seven violations occurred at six sites in Hansen Creek, Moqui Canyon, and Stanton Creek during 1991. Sixty-seven violations occurred at 13 sites in Davis Gulch, Farley Canyon, Forgotten Canyon, Hite Marina, Llewellyn Gulch, Moqui Canyon, Oak Canyon, and Upper Bullfrog Bay during 1992. One violation occurred at Hobi Cat Beach during 1993. The water quality standard is a geometric mean calculation of 200 cfu/100 mL from five or more samples in a 30-day period. Some sites did not post violations because they were sampled too infrequently to calculate valid geometric means. More frequent sampling at fewer sites may provide better data to assess compliance with water quality standards, warn users of potential health risks, and strengthen the validity of management decisions related to posting warnings or closing beaches.

The results of these analyses indicated that bacteria contamination may be a concern at certain beaches, but correlations between high bacteria counts and visitor use patterns or lake levels were not significant. The lack of standardized visitor use indices probably contributed to the weak statistical relationship. Annual or seasonal lake levels may have influenced bacteria dilution; however, the lack of sufficient seasonal lake level and bacteria data prevented further analyses to test these hypotheses. Accumulated visitor use during the week prior to sampling may be a better indicator than use on the day of sampling. Lake level adjustments coupled with rainfall indices may provide better inputs for early warning models than visitor use, especially in areas where visitor management is logistically difficult.

INTRODUCTION

Glen Canyon National Recreation Area (GLCA) has been monitoring bacteria levels in shoreline waters of Lake Powell to assess impacts from recreational bathing and boating since 1988. The Water Resources Division (WRD) contributed to the development of the GLCA bacteria monitoring program via recommendations made in a report titled *Water quality alternatives for the Glen Canyon National Recreation Area Water Resources Management Plan* (Flora and Wood 1986) and the park's *Water Resources Management Plan* (Wood and Kimball 1987). Recent data have shown an increase in bacteria levels at some beaches during the current drought. It is speculated that this trend may have resulted from less bacteria dilution at lower lake levels and/or changing recreational use patterns. GLCA posted advisory notices at several beaches during the last couple of years due to exceedences of the Utah primary-contact recreation (swimming), and Arizona full body-contact, water quality standard for fecal coliform bacteria of 200 colony forming units per 100 milliliters (cfu/100 mL). In 1991, high bacteria counts resulted in the closure of five beaches: Hansen Creek, Stanton Creek, Hobi Cat Beach, Moqui Canyon, and Farley Canyon. Eight canyons were posted with no swimming signs in 1992: Moqui Canyon, Farley Canyon, Government Housing, Llewellyn Gulch, Oak Canyon, Upper Bullfrog Bay, Hite Marina, and Forgotten Canyon. Subsequently, Llewellyn Gulch was posted as closed due to bacterial contamination. Llewellyn Gulch remained closed to public access until May, 1994. In 1993 and 1994, coliform counts were low and no new advisories or beach closures occurred. Water levels in Lake Powell rose over 50 feet in response to spring runoff during 1993.

In response to these data and increasing concerns regarding interpretation of the results by park management, staff, and the public, the park requested that WRD analyze and interpret the bacteria data collected between 1988 and 1993, and help them develop a way to measure acute levels of bacterial contamination in time to warn recreational users. The purpose of this paper is twofold: (1) to present a clear and concise explanation of what we know, and (2) to recommend changes in field, laboratory, and data management procedures which result in the most effective and efficient use of this information in making management decisions.

BACKGROUND

Previous and Ongoing Studies

Initial investigations into the bacterial water quality at popular swimming areas in Lake Powell were conducted by Walther (1971), Kidd (1975), and Cudney (1977). All three studies concluded that though the water was unsuitable for drinking, water quality standards generally were met for primary and secondary contact recreation. A later study (Fitzgerald et al. 1985) in-part, corroborated these results, but found elevated bacteria levels at certain locations. Related studies conducted by Brickler and Tunnicliff (1980), Tunnicliff and Brickler (1984), and Doyle et al. (1985) on riverine environments within and adjacent to GLCA, came to similar conclusions regarding bacterial water quality. In addition, these studies pointed out that resuspension of sediments could pose potential water quality hazards because of suspected accumulations of bacteria in river bed sediments. Some researchers believed that these results should also be applied to resuspension of lake bed sediments.

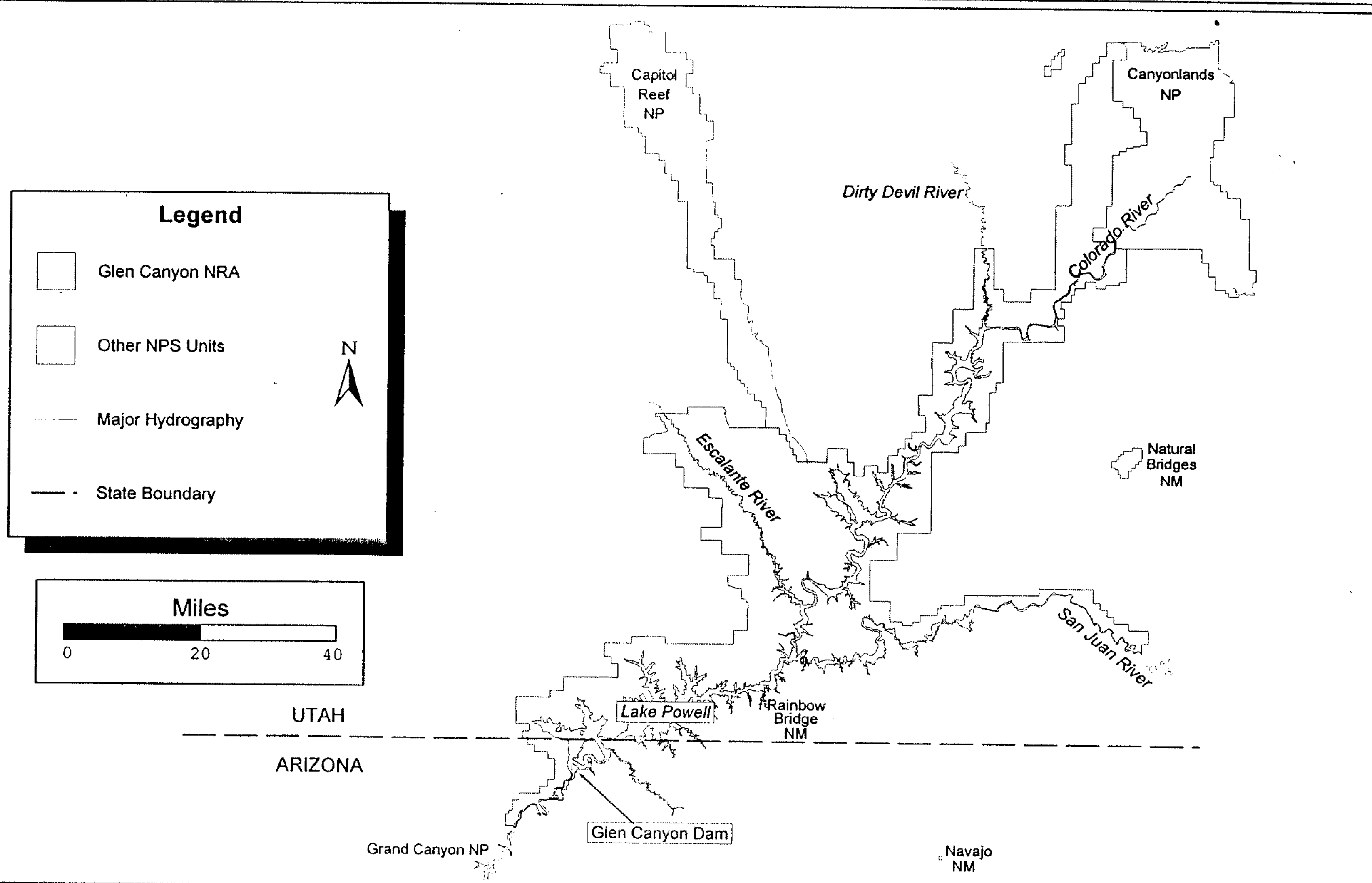
By 1988, although the water quality of Lake Powell was reported to be generally very good, a combination of increased recreational use, concerns for visitor safety, and recommendations by water resources professionals (Flora and Wood 1986; Wood and Kimball 1987) prompted GLCA to implement a routine bacterial water quality monitoring program at primary swimming beaches and marina areas. In the beginning, park staff collected water samples, and filtered and incubated the samples without the aid of a laboratory in the park. Often, samples were analyzed after they had exceeded their holding times. During this time the Utah Department of Health, state of Arizona, and Coconino County laboratories assisted the park by analyzing samples and recommending needed equipment. In 1991 and 1992, GLCA established bacteria water laboratories at downlake and uplake locations in the park, respectively. These laboratories became certified by the Utah Department of Health in 1994.

Study Area Description

GLCA was established in 1972, primarily to provide for public outdoor recreation use and enjoyment of Lake Powell. Lake Powell, created by Glen Canyon Dam in 1963, is the major water feature of GLCA (Figure 1). The major sources of inflow to Lake Powell include the Colorado River, San Juan River, Dirty Devil River, and Escalante River. The total drainage area above Glen Canyon Dam is approximately 112,000 square miles (mi^2). At a maximum pool of 1,128 meters (m) (3,700 feet) (ft) in elevation, Lake Powell covers a surface area of 660 square kilometers (km^2) (255 mi^2), stores a volume of 33 billion cubic meters (m^3)(27 million acre feet) of water, and has over 3,000 km (1,900 mi) of shoreline. Lately, the normal pool of Lake Powell has ranged between 1,103 - 1,118 m (3,620 - 3,670 ft), with a storage volume as low as 16 billion m^3 (13 million acre-feet [ac-ft]) in February, 1993, during a recent drought. Lake Powell is characterized as a warm monomictic lake, mixing once a year during winter, with advective circulation due to density differences between spring and winter inflows. Typically, the waters of Lake Powell are moderately saline and low in nutrients.

GLCA receives an average of six to seven inches of precipitation per year; however, the Colorado River drains some areas which receive considerably more annual precipitation. Spring snowmelt and summer thunderstorms are the primary sources of natural hydrologic adjustments in Lake Powell and its contributing rivers. Irrigation withdrawals and dam operations upstream, and the operation of Glen Canyon Dam, are the primary sources of artificial level adjustments in Lake Powell. In 1993, GLCA had 3.58 million visitors, and 4 million were expected in 1994.

Figure 1. Glen Canyon National Recreation Area



METHODOLOGY

Field Sampling

The majority of sampling sites on Lake Powell were selected because they had a history of high visitor use and/or high fecal coliform counts in the past (Figures 2, 3 and 4). Also, some sites which sustain little historical use, and have expected low counts were chosen as control sites. Forty-two sites were sampled in 1988, 46 sites in 1989, 49 sites in 1990, 63 sites in 1991, 44 sites in 1992, and 52 sites in 1993. A list of site identification codes and site names is included in Appendix A. Prior to 1992, sampling occurred only during the peak visitation period from May through September. Beginning in the winter of 1992-1993, sampling was done year round at sites which showed high counts during the summer of 1992. In 1992 and 1993, samples were collected once every two weeks, and immediately following holiday weekends at most sites. Some sites were only sampled once a month. When a sample had greater than or equal to 200 cfu/100 mL, the site was resampled until the samples dropped below 200 cfu/100 mL.

Samples were collected by boat where the water depth was four feet (Miller and Pinnock 1991; Tinkler 1992; Tinkler 1993). Beginning in 1993, a Van Dorn water sampler was used to collect water four inches below the water surface. Subsamples of 50 mL and 100 mL were extracted from this larger sample and put in plastic bottles which had been sterilized for 15 minutes at a temperature of 270°F. Sampling bottles and equipment were sterilized up to two weeks prior to sampling. Sampling date, sampling time, weather, air temperature, water temperature, location use, location condition, lake elevation, and turbidity were recorded on data sheets.

Sample Handling

Once the water samples were put in sterilized plastic bottles, they were packed on ice (Miller and Pinnock 1991; Tinkler 1992; Tinkler 1993). When all the samples were collected in one area, the samples were transported by boat and plane to one of the two laboratories in GLCA. Through 1991, there was only one laboratory which was housed in the Wahweap maintenance area. In 1992, an additional laboratory was established at Hite, and in 1993 this laboratory was moved to Bullfrog. In 1993, samples from 32 downlake sites were analyzed at the Wahweap laboratory and samples from 20 uplake sites were analyzed at the Bullfrog laboratory. Samples were transported to the laboratories as quickly as possible so that they could be analyzed as close as possible to the six-hour time-limit recommended by *Standard methods for the examination of water and wastewater* (APHA 1985) in order to avoid "unpredictable changes". The establishment of the second laboratory at Bullfrog greatly assisted in enabling the samples to be analyzed within six hours after collection. In 1993, the time each sample was processed was recorded on the data sheet. This new procedure permitted monitoring the elapsed time between sample collection and analysis in order to check the validity of the fecal coliform results.

Figure 2. Glen Canyon National Recreation Area - South

Water Quality Sampling Sites

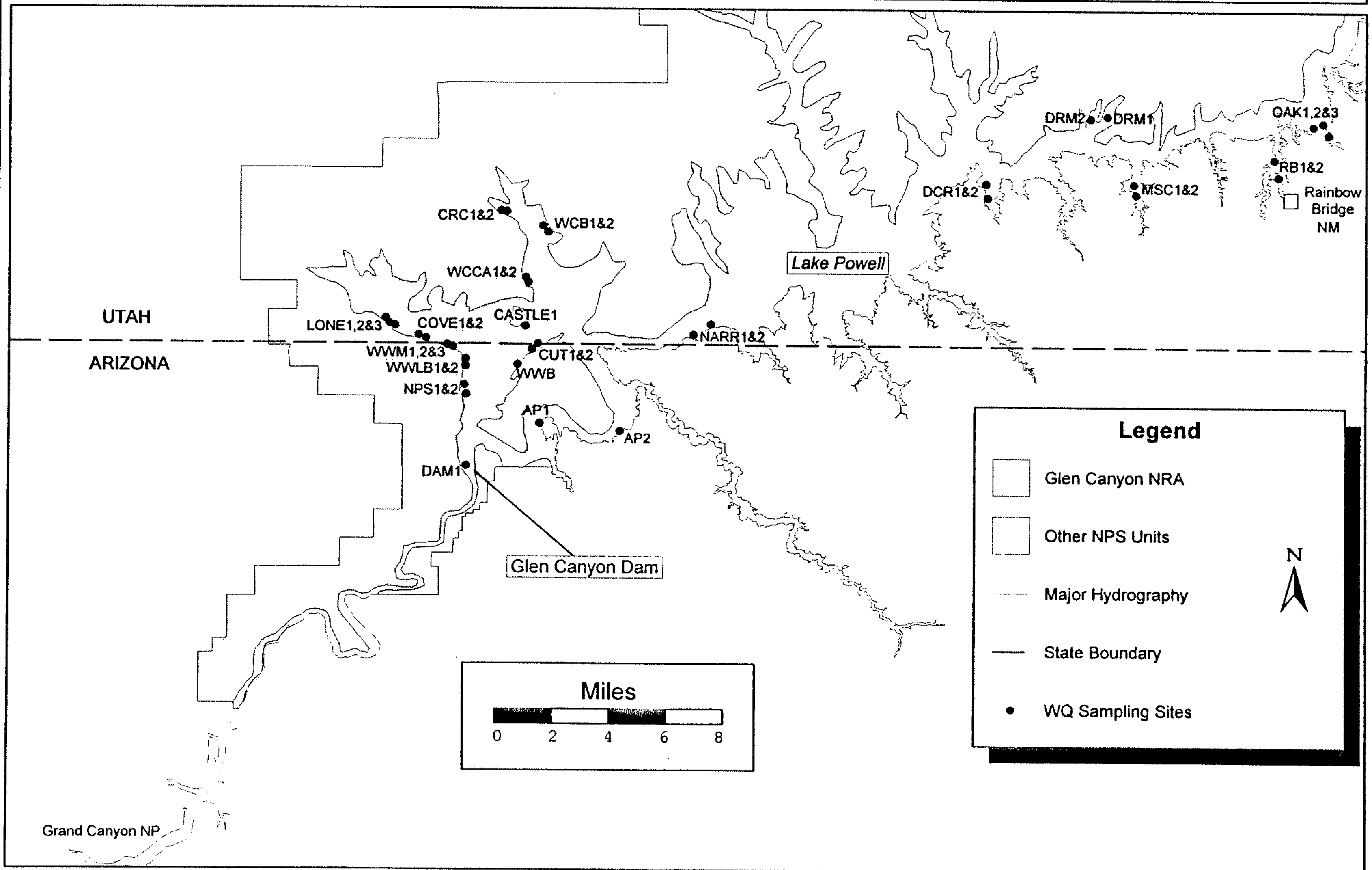


Figure 3. Glen Canyon National Recreation Area - Middle

Water Quality Sampling Sites

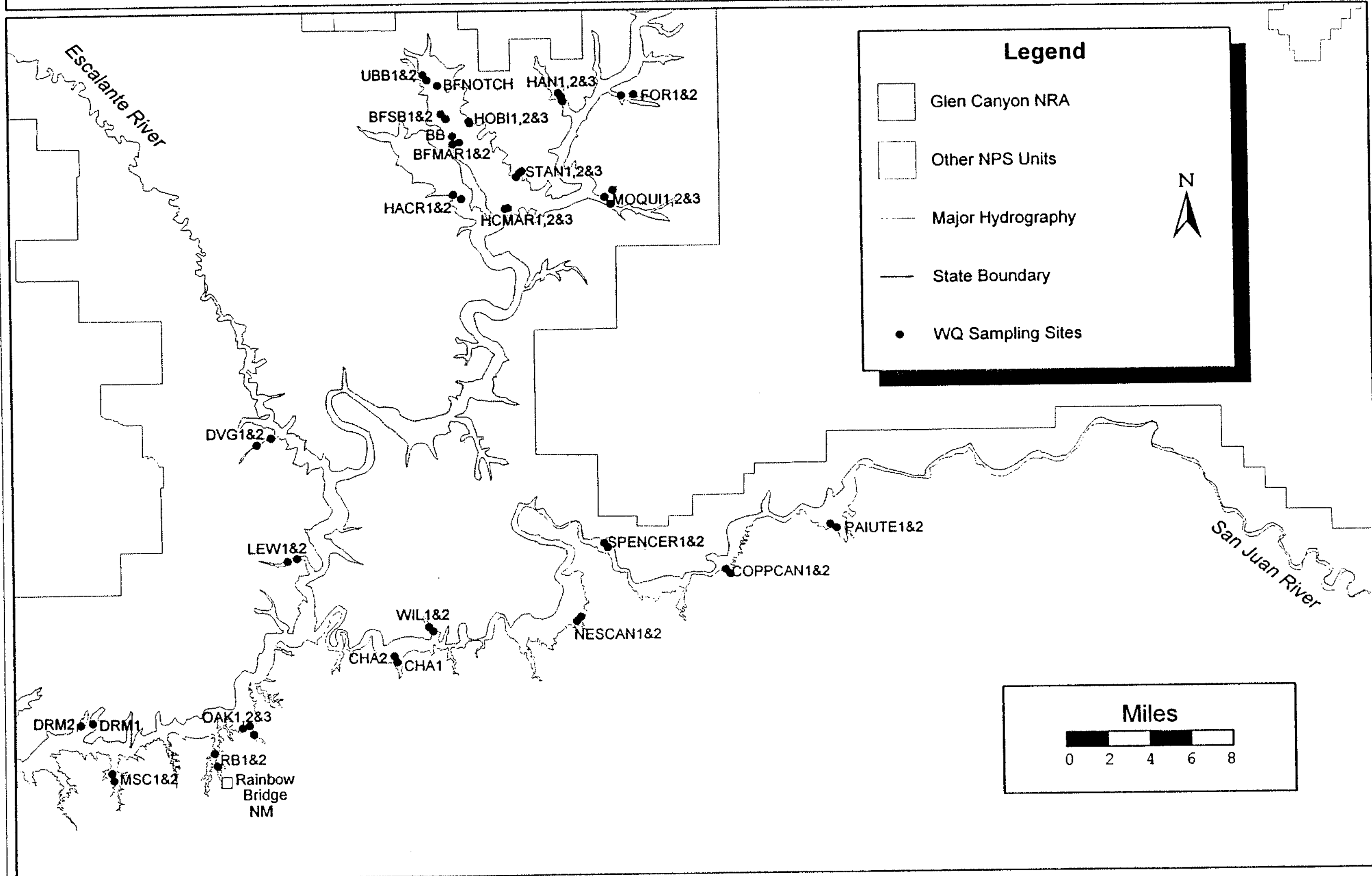
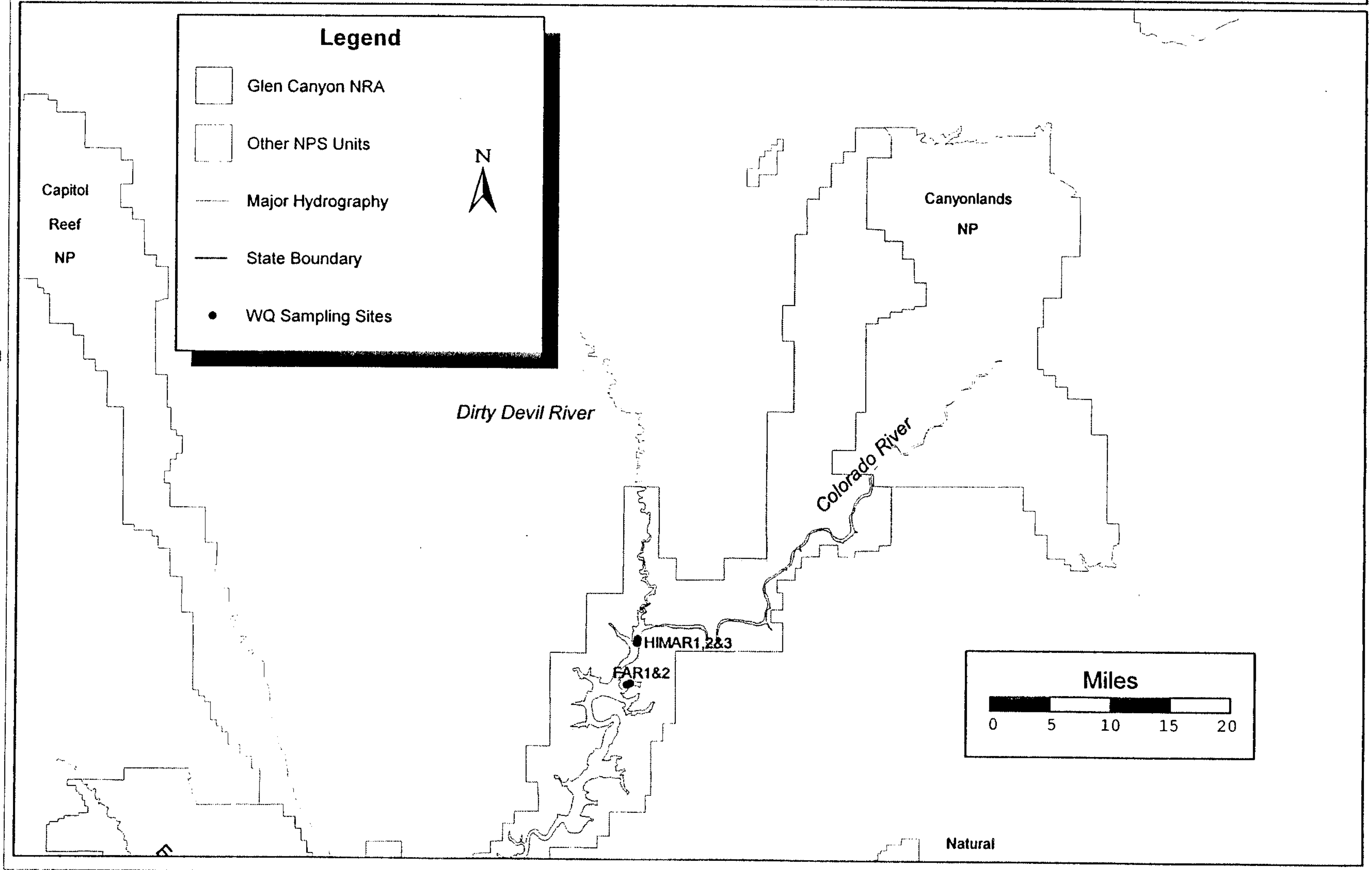


Figure 4. Glen Canyon National Recreation Area - North

Water Quality Sampling Sites



Laboratory Analysis

The Membrane Filter (MF) technique was used to analyze water samples for fecal coliform (Miller and Pinnock 1991; Tinkler 1992; Tinkler 1993). These analyses were conducted in accordance with the procedures in *Standard methods* (APHA 1985). A detailed description of the laboratory procedures used by GLCA is given in *Water laboratory quality control program, Glen Canyon National Recreation Area* (Tinkler et al. 1993).

In 1988 and 1989, water samples were tested for fecal streptococci as well as fecal coliform. The fecal coliform/fecal streptococci ratio was used to determine whether the source of the contamination was human or animal. Analysis for fecal streptococci was discontinued in 1990 because: (1) fecal streptococci counts were relatively low, (2) most sites were thought to be contaminated by human sources, and (3) there is no regulatory standard for fecal streptococci.

Data Management

All water quality sampling data were entered by GLCA into separate database files for each year in DBASE III+ software format. In order to conduct statistical analyses for the entire period of record, the six separate files were merged into a single file named ARCHIVE.DBF using DBASE IV software. This merged file contained the following information: site identification code, sampling date, sampling time, time sample was filtered in the laboratory, site name, weather, air temperature, wind, clarity of the water, choppiness of the water, number of boats, number of vehicles, number of people, site usage, number of sanitary stations, condition of the site, water elevation, water temperature, turbidity, fecal coliform count, fecal streptococci count, and fecal coliform/fecal streptococci ratio. Not all of these parameters were recorded for all years. Several changes were made to the data in this merged file. Field lengths and names were standardized prior to appending each file. Site identification codes were standardized (some of these codes had changed over the years as different people performed the sampling and laboratory analyses from year-to-year). Site names were added to the file. Since DBASE III+ and IV replaced blank numeric fields with zeros, it was impossible to distinguish missing data from actual zeros. Consequently, all zeros known to be missing data were replaced with -9s. Since -9 cannot be a real value for most parameters, it should be clear that these represent missing data. Several data entry errors were corrected by checking suspect values against the data sheets, and the database was sorted by site identification code and date. Lastly, data values reported as "too numerous to count" (TNTC) were changed to 1,000 cfu/100 mL for statistical purposes.

Once the data in the merged file had been corrected and standardized, two analysis files (ANALYSIS.DBF and ANALGEOM.DBF) were created from the ARCHIVE.DBF file. Fecal coliform counts in ANALYSIS.DBF were averaged when more than one sample was collected in a single day. Field names in this file were shortened to eight characters and some descriptive fields were deleted. This file was used for the summary statistics and correlation analysis, and to generate box-and-whiskers plots. ANALGEOM.DBF contained only the following three fields: site identification code, date, and fecal coliform count. Duplicate fecal coliform values were included in this data set, and a text version of the file was used in the geometric mean analysis. Descriptions of text, graphic, program, and database files which were used in the report are included in Appendix B. Detailed file structures for all database files are contained in Appendix C.

In addition, all data included in the ARCHIVE.DBF file were uploaded into the Environmental Protection Agency's national database STORET. Stations in STORET were created for each site and all data labeled with STORET parameter codes (see file structures in Appendix C) were entered into the database. Data from this database are available to all federal and state agencies. Other information related to the STORET database, and data that reside in STORET, can be found in the *Baseline water quality data inventory and analysis report for Glen Canyon NRA* (National Park Service 1994).

Summary statistics were performed on the fecal coliform data (ANALYSIS.DBF with duplicates averaged) in order to determine the following annual and period-of-record statistics: mean, standard deviation, 10th percentile, 25th percentile, median, 75th percentile, 90th percentile, minimum, and maximum (Appendix E). These statistics were calculated using the Proc Univariate procedure in SAS software, version 6.03. A Pearson correlation matrix and regression plots (Appendix F) were produced by SYSTAT software, version 5.03.

Annual box-and-whiskers plots (Appendix E) were produced by SigmaPlot software, version 1.02a. For the box-and-whiskers plots, the solid horizontal lines within the box represented the median value of the data group. The dashed horizontal line represents the mean value. The bounds of the box represents the 25th and 75th percentiles of the data values. The whiskers display the range of data values which fall within the 10th and 90th percentiles. Data values outside the 10th and 90th percentiles are plotted as solid dots. In order for a site to generate a annual box-and-whisker plot, it must have had a minimum of two years of data containing three or more values per annum. In addition, SigmaPlot requires a minimum of three values to compute the 25th and 75th percentiles, five values to compute the 10th percentile, and six values to compute the 90th percentile.

Geometric mean tables and time series graphs (Appendix G) were generated using a geometric mean program developed by Dean Tucker of WRD. This program averaged duplicate fecal coliform samples and calculated a geometric mean using the formula:

> **Geometric Mean = antilog [1/n (log sample 1 + log sample 2 + log sample 3 + log sample 4 + ... log sample n)], where n is the number of sample observations**

The criterion used for calculating a valid geometric mean was greater-than or equal to five samples in a 30-day period. Data values that met this criterion are represented by box symbols on the geometric mean graphs and values that didn't meet this criterion are represented by plus symbols. Geometric mean values were compared with the Utah and Arizona state water quality standards for fecal coliform of 200 cfu/100 mL (state of Utah 1994; state of Arizona 1992). Fecal coliform standard tables are included in Appendix H for use designations that apply to Lake Powell, in each state.

RESULTS

Summary Statistics

Fecal Coliform Bacteria—Fecal coliform results were highly variable, typical of bacteria data. Average colony counts ranged from a high of 1,412 cfu/100 mL to a low of zero (or "none detected"). One duplicate sample collected from Hobi Cat Beach in 1991 contained 1,840 cfu/100 mL. Average colony counts greater-than or equal to 1,000 cfu/100 mL were measured at several beaches during 1988-1993, including: Antelope Point Beach, Bullfrog Marina, Cha Canyon, Dangling Rope Marina, Davis Gulch, Farley Canyon, Hansen Creek, Hite Marina, Hobi Cat Beach, Llewellyn Gulch, Lone Rock, Moqui Canyon, Mountain Sheep Canyon, Government Housing, Oak Canyon, Rainbow Bridge, Stanton Creek, Upper Bullfrog Bay, and Wilson Creek. The highest median colony counts were from samples collected at Bullfrog Marina #2, Cha Canyon #1, Davis Gulch #1, Forgotten Gulch #1, Hansen Creek #1, #2 and #3, Hobi Cat Beach #1, Llewellyn Gulch #1 and #2, Lone Rock #2, Moqui Canyon #1, Oak Canyon #1, Rainbow Bridge #1, Stanton Creek #2, and Wahweap Marina #1 and #2. The lowest median colony counts were from samples collected in Copper Canyon, The Narrows, Neskahi Canyon, Paiute Farms, and Spencer Camp. No fecal coliform colonies were detected in 408 out of 2,420 averaged samples (17%). Summary statistical tables and annual box-and-whisker plots for each site are presented in Appendix E. It is interesting to note that, in general, higher maximum values were measured in 1991, and higher median values were measured in 1992. This phenomenon may be the result of actual bacteria fluctuations due to natural and/or human caused events, or possibly sample handling problems.

Fecal Streptococci Bacteria—Fecal streptococci colony counts were relatively low during 1988 and 1989, possibly due to mortality of the colonies and/or minor contributions of bacterial contamination by animal sources. Again, colony counts ranged from a high of over 1,000 cfu/100 mL to a low of zero (Appendix E). Median values were highest in Cha Canyon, Copper Canyon, Farley Canyon, Hite Marina, Lone Rock, Moqui Canyon, Neskahi Canyon, Paiute Farms, Spencer Camp, and Warm Creek Cattle Area. No fecal streptococci colonies were detected in 250 out of 384 samples (65%). Since the park discontinued sampling for fecal streptococci after only two years of sampling, which resulted in few samples to analyze, no further analyses were conducted or conclusions made on these data.

Fecal Coliform/Fecal Streptococci (FC/FS) Ratio—FC/FS ratios were calculated for the data collected in 1988 and 1989 (Appendix E). Based on this analysis, FC/FS ratios consistently were less than 0.7 during 1988, which indicated contamination from animal sources (APHA 1985). In 1989, FC/FS ratios varied from 0.001 to 73.0, which indicated contamination from a mixture of animal and human sources. However, the FC/FS ratios in Appendix E are biased because no ratios were calculated when either value was zero.

Fecal Coliform Geometric Mean Standards Analysis

The geometric mean standards analysis identified 75 violations of state of Utah water quality standards for fecal coliform bacteria at 18 sites (Appendix G). Seven violations occurred at six sites in Hansen Creek, Moqui Canyon, and Stanton Creek during 1991. Sixty-seven violations (89% of the total) occurred at 13 sites in Davis Gulch, Farley Canyon, Forgotten Canyon, Hite Marina, Llewellyn Gulch, Moqui Canyon, Oak Canyon, and Upper Bullfrog Bay during 1992. Geometric means from Llewellyn Gulch exceeded the standard of 200 cfu/100 mL, seventeen times during 1992. One violation occurred at Hobi Cat Beach during 1993. One hundred and seventy-seven geometric means were calculated which met the criterion of five samples within 30 days. The geometric means ranged in value from a high of 531 cfu/100 mL at Hansen Creek #2 to a low of 12 cfu/100 mL at Wahweap Lodge Beach #2. Obviously, a significant factor in this analysis was the number of samples collected within a 30-day period. Some sites with potential exceedences of water quality standards did not post violations because they were sampled too infrequently.

Fecal Coliform Correlation Analysis

The correlation analysis produced a Pearson correlation matrix, a matrix of probabilities, and a frequency table which compared relationships between the variables: air temperature, number of boats, number of vehicles, number of people, site usage, water elevation, water temperature, turbidity, and average fecal coliform count (Appendix F). None of the correlations with fecal coliform were statistically significant; therefore, no conclusions were drawn regarding factors which may explain bacteria fluctuations at these sites, or model and predict potential concern levels using visitor use or other environmental variables. Additional data for environmental and visitor-use parameters would be required to make these determinations.

DISCUSSION AND RECOMMENDATIONS

Significance of Water Quality Indicators

Fecal coliform bacteria was the primary parameter sampled to assess the sanitary conditions of shoreline recreational bathing and boating waters in GLCA. Fecal streptococci bacteria were sampled during 1988 and 1989, but not thereafter due to the reasons previously stated. In addition, fecal coliform/fecal streptococci ratios were calculated; however, their significance in determining potential sources of contamination has been questioned because of potential sample pH, salinity, and fecal streptococci total count and survival capacity influences (U.S. Environmental Protection Agency 1978). For example, if fecal streptococci counts are less than 100 cfu/100 mL, ratios should not be applied. *Standard methods for the* *examination of water and wastewater* (APHA 1989) recommends that FC/FS ratios should not be used as a means of differentiating between human and animal sources of pollution.

Recent guidelines have suggested that E. coli and enterococci be used instead of fecal coliform (U.S. Environmental Protection Agency 1986). E. coli and enterococci are better indicator species for pathogens in fresh and marine waters, and criteria have been established which eventually may be adopted by all states. WRD recommends that GLCA continue with fecal coliform monitoring until such time as the states of Utah and Arizona change their regulatory standards for bacteria water quality.

Water Quality Standards Compliance

The water quality standards evaluation proved valuable in assessing chronic bacteria problems at individual sites and regulatory compliance with state water quality standards. Based on this evaluation, it appears that the state of Utah 30-day geometric mean fecal coliform water quality standard was exceeded multiple times at Farley Canyon, Forgotten Canyon, Hansen Creek, Hite Marina, Llewellyn Gulch, Moqui Canyon, Stanton Creek, and Upper Bullfrog Bay. However, insufficient numbers of water samples were collected per annum at some sites with potential bacteria contamination problems to adequately assess compliance with water quality standards. For example, Cha Canyon summary statistical data (e.g. mean, median, percentiles, etc.) exhibited high bacteria levels, but did not meet the criterion used for calculating valid geometric means as specified by state water quality standards. Other sites exhibited high median coliform counts during individual years where few samples were collected.

If the primary objective of the bacteria monitoring program is to assess compliance with water quality standards to warn users of potential health risks, then WRD recommends that GLCA consider modifying their sampling program to collect a greater number of samples on a more frequent basis from a fewer number of high priority locations. This would allow the calculation of more geometric mean values to assess compliance with state standards, and strengthen the validity of management decisions related to posting warnings or closing beaches.

Characterization of Water Quality Trends

Summary statistical tables and annual box-and-whisker plots were used to assess water quality trends (Appendix E). Based on these results, it appears that fecal coliform bacterial contamination was widespread at several bathing beaches and marinas during 1991 and 1992, particularly during August of 1992. In 1993, bacteria levels were dramatically lower than the two previous years, which seems to coincide with a greater than 50-foot rise in the level of Lake Powell. However, park staff reported that some site locations change with varying lake levels, and trend results from those sites may be difficult to substantiate (Dodson, pers. com.).

No time series analyses were performed due to the lack of data required to report significant time trends. Also, seasonal analyses of these data were not performed due to low numbers or absence of data in two of the four hydrologic seasons used by WRD in the *Baseline water quality data inventory and analysis report for Glen Canyon NRA* (National Park Service 1994). WRD recommends that GLCA consider sampling during all hydrologic seasons, at varying intensities, to assess seasonal patterns in bacteria water quality.

Field Sampling and Laboratory Analysis Protocols

Field sampling, sample handling, and laboratory analysis procedures have improved significantly during the water quality monitoring effort from 1988 to 1993. Consequently, confidence in the accuracy of the fecal coliform counts has increased each year. A manual prepared in August 1993, titled *Water laboratory quality control program, Glen Canyon National Recreation Area*, is a good aid to ensure consistency in sampling and analysis methods among field staff, and between the two laboratories. The establishment of a second laboratory in the northern portion of the lake assisted in decreasing the time between sampling and analysis to within the six-hour limit recommended by *Standard methods* (APHA 1989), in most cases. Also, the hiring of water quality technicians in 1992 improved consistency in sampling dates and procedures.

Duplicate samples were collected at most sites during most years. Two sample volumes (50 mL and 100 mL) were filtered for each site. Occasionally, replicate samples of 25 mL and 50 mL were filtered at sites with elevated bacterial counts. Seven methods of quality assurance/quality control were used in the laboratory analyses (Tinkler et al. 1993). These were: (1) a positive control designed to show that the condition of the media and the water bath are conducive to the growth of *Escherichia coli*, (2) a negative control *Enterobacter aerogenes* which should show no growth at appropriate incubator temperature, (3) UV controls to determine if the UV sterilizer was working properly, (4) blank controls to ensure buffer sterility and lack of contamination, (5) a media control, (6) rinse controls, and (7) final rinse controls. All controls operated properly in 1993 with the exception of the positive control on September 7, 1993. In 1992, the blank and media controls worked properly, but the positive control failed on two dates (May 27, 1992, at the Hite laboratory, and July 15, 1992 at the Wahweap laboratory). The negative control failed 65 percent of the time at the Wahweap laboratory and 80 percent of the time at the Hite laboratory. The UV control failed 65 percent of the time at the Wahweap laboratory and 60 percent of the time at the Hite laboratory.

Several problems were noted in 1991. In regard to field sampling and sample handling, samples were taken at improper depths, propellers were allowed to stir up bottom sediments where samples were collected, sample bottles were not stored in adequate amounts of ice after the samples were collected, and samples were not returned to the laboratory in adequate time to keep the samples viable. Positive and negative controls consistently failed in the park laboratory. These controls were obtained from a state of Arizona laboratory in Flagstaff, and checked there for viability. For an unknown reason, the controls did not work well in the park laboratory and failed to produce colonies of the proper color.

WRD recommends that the park continue to improve their laboratory procedures for data validation as detailed in the park manual. In addition, WRD recommends that expanded subsample dilutions (e.g., 1/10/100 mL, 1/50/100 mL, 0.1/1/10/100 mL, etc.) be extracted from future samples collected at historically contaminated sites to eliminate the 1,000 cfu/100 mL ceiling for plates which are "too numerous to count". Sample volumes for fecal coliform testing should yield approximately 20 to 60 colonies and not more than 200 colonies per filter (APHA 1989; Border et al. 1978). It is relatively easy to accurately measure bacteria colony counts of several thousand using dilution techniques.

Data Management Protocols

It is important to standardize the site identification codes and consistently use them from year to year so that all the data gathered from a site are attributed to the correct site. Data in the computer files should be checked at least once, preferably by a different person than the one who performed the data entry. This is an important step in insuring the accuracy of the data set before any analyses are preformed. When entering data into numeric fields, a substitute number such as -9 or -99, should be inputted for missing data to prevent blank records from being converted to zeros by DBASE III+. Also, it is helpful to sort or index the files by site identification code and date.

WRD recommends that GLCA use the files attached to this report and discard any older files of the same data. New files which are created can be appended to the master file, but will need to have the same database structure as the master file (Appendix C), and have -9s substituted for missing values before they are appended. Currently, WRD is developing a park-based Water Quality Data Management System software program for use on personal computers which is designed to assist parks in managing their water quality data in standardized formats. This user-friendly program should be available to parks in 1995.

CONCLUSIONS

GLCA is fortunate to have the support from management and staff to establish and maintain a long-term bacteria monitoring program in Lake Powell to ensure that recreational users and resources are safeguarded. Bacteria monitoring, with the objective to warn recreational users of unsafe conditions, is very difficult to accomplish; especially in sparsely populated areas where visitors are relatively unmanaged. Sampling, alone, doesn't necessarily predict when contamination levels may be high enough to impact human health and other natural resources, such as aquatic organisms and avian wildlife. The next step is perhaps the most difficult step, and poses the following two questions. (1) How can we identify ranges of measurable parameters which appear to relate to, or can be correlated with high, medium and low bacteria levels in different parts of the lake? Although water temperature, runoff, and dilution have an effect on bacteria levels, discharge of human waste by recreational users is likely the primary source of bacteria in Lake Powell. Since bacteria levels are expected to be highest during heavy-use periods, park staff should schedule rigorous sampling during holiday weekends in the summer. (2) How do we use a series of these measurements to predict a corresponding response in bacteria levels early enough to post warnings or close beaches prior to the analyses of samples containing threatening bacteria levels? Automated sampling systems which are linked telemetrically to satellites or other relay stations may be the most practical solution for early warning devices. However, these types of platforms and sensors are very expensive and difficult to maintain. In addition, measured or predicted bacteria levels don't necessarily preclude erroneous conclusions regarding disease susceptibility without rigorous testing to statistically correlate bacteria counts with disease outbreaks from various pathogens.

The current database does not provide sufficient data to make these types of predictions with any confidence. Several of the parameters which were measured, such as visitor use and lake level, may offer information which could help the park infer that bacteria contamination may be a concern at certain beaches at certain times. However, none of the parameters were strongly correlated with bacteria counts. The lack of standardized visitor use indices and sufficient seasonal lake level and bacteria data probably contributed to the weak statistical relationships. More frequent sampling of these parameters is required to provide sufficient data for statistical comparisons. In addition, more emphasis on standardization of these indices and measurements in association with bacteria monitoring during various recreational use periods, hydrologic seasons, and periods of lake level adjustments is needed before predictive models can be developed to assist those making management decisions. Accumulated visitor use during the week prior to sampling may be a better indicator than use on the day of sampling. Lake level adjustments coupled with rainfall indices may provide better inputs for early warning models than visitor use, especially in areas where visitor management is logistically difficult. Lastly, the successful implementation of a program which achieves these objectives may require additional trained staff and resources at the park level.

LITERATURE CITED

American Public Health Association. 1985. *Standard methods for the examination of water and wastewater.* 16th ed. Washington, D.C.

American Public Health Association. 1989. *Standard methods for the examination of water and wastewater*. 17th ed. Washington, D.C.

Border, R.H., J.A. Winter, and P.W. Scarpino. 1978. Microbiological methods for monitoring the environment: water and wastes. Cincinnati: U.S. Environmental Protection Agency, Environmental Monitoring Systems Laboratory EPA-600/8/78-017.

Brickler, S.K., and B. Tunnicliff. 1980. *Water quality analyses of the Colorado River Corridor of the Grand Canyon*. Tucson: University of Arizona. College of Agriculture Paper 350.

Cudney, R.A. 1977. *A survey of coliform organisms in Lake Powell.* Napa: The John Muir Institute for Environmental Studies.

Dodson, Susan. 1995. Glen Canyon NRA, pers. com.

Doyle, J.D., B. Tunnicliff, and S.K. Brickler. 1985. *Recreational water quality assessment of the San Juan River.* Tucson: University of Arizona. College of Agriculture.

Fitzgerald, J.A., K.J. Brenneman, and H.K. Speidel. 1985. *A survey of bacterial indicators of fecal pollution in Lake Powell, Glen Canyon National Recreation Area.* Flagstaff: Northern Arizona University. College of Biological Sciences.

Flora, M.D., and C.W. Wood. 1986. *Water quality monitoring alternatives for the Glen Canyon National Recreation Area Water Resources Management Plan.* Fort Collins: National Park Service Water Resources Report No. 86-3.

Kidd, D.E. 1975. *Bacterial contamination of Lake Powell waters: an assessment of the problem*. Albuquerque: University of New Mexico. Department of Biology.

Miller C., and C. Pinnock. 1991. *Report for water quality monitoring of Lake Powell, 1991.* Page: National Park Service.

National Park Service. 1994. *Baseline water quality data inventory and analysis, Glen Canyon National Recreation Area.* Fort Collins: National Park Service Technical Report NPS/NRWRD/NRTR - 94/33.

State of Arizona. 1992. Title 18 environmental quality, Chapter 11 water quality boundaries and standards, Article 1 water quality standards for navigable waters. A.G. Rule No. R92-006. Phoenix: Arizona Department of Environmental Quality.

State of Utah. 1994. Standards of quality for waters of the state. R317-2, Utah Administrative Code. Salt Lake City: Utah Department of Environmental Quality.

Tinkler, D. 1992. *Lake Powell water quality report, May - October, 1992.* Page: National Park Service.

Tinkler, D. 1993. *Lake Powell water quality report, May - September, 1993.* Page: National Park Service.

Tinkler, D., J. Fleming, and K. Stangl. 1993. *Water laboratory quality control program, Glen Canyon National Recreation Area.* Page: National Park Service.

Tunnicliff, B., and S.K. Brickler. 1984. Recreational water quality analyses of the Colorado River Corridor in Grand Canyon. *Applied and Environmental Microbiology* 48(5): 909-917.

U.S. Environmental Protection Agency. 1986. *Quality criteria for water 1986.* Washington: U.S. Environmental Protection Agency EPA-440/5-86-001.

Walther, G.E. 1971. *Fecal coliform in the Colorado River system.* Mimeographed report.

Wood, C.W., and D.B. Kimball. 1987. *Water resources management plan and environmental assessment.* Page: National Park Service.

APPENDICES

Appendix A

Site Identification Codes and Site Names

The following table provides the site names corresponding to the site identification codes used in this report.

List of Site IDs and Site Names for GLCA Water Quality Sampling Locations	
SITE ID	**SITE NAME**
AP1	Antelope Point Beach
AP2	Antelope Point Intake
BB	Bullfrog Bay
BFMAR1, BFMAR2	Bullfrog Marina
BFNOTCH	Bullfrog
BFSB1, BFSB2	Bullfrog
CASTLE1	Castle Rock
CHA1, CHA2	Cha Canyon
COPPCAN1, COPPCAN2	Copper Canyon
COVE1, COVE2	The Coves
CRC1, CRC2	Crosby Canyon
CUT1, CUT2	The Cut
DAM1	The Dam
DCR1, DCR2	Dungeon Creek
DRM1, DRM2	Dangling Rope Marina
DVG1, DVG2	Davis Gulch
FAR1, FAR2	Farley Canyon
FOR1, FOR2	Forgotten Canyon
HACR1, HACR2	Halls Creek Bay
HAN1, HAN2, HAN3	Hansen Creek
HCMAR1, HCMAR2	Halls Crossing Marina
HIMAR1, HIMAR2, HIMAR3	Hite Marina
HOBI1, HOBI2, HOBI3	Hobi Cat Beach

List of Site IDs and Site Names for GLCA Water Quality Sampling Locations	
SITE ID	**SITE NAME**
LEW1, LEW2	Llewellyn Gulch
LONE1	Lone Rock Beach North
LONE2	Lone Rock Beach Middle
LONE3	Lone Rock Beach South
MOQUI1, MOQUI2, MOQUI3	Moqui Canyon
MSC1, MSC2	Mt. Sheep Canyon
NARR1, NARR2	The Narrows
NESCAN1, NESCAN2	Neskahi Canyon
NPS1, NPS2	Government Housing
OAK1, OAK2, OAK3	Oak Canyon
PAIUTE1, PAIUTE2	Paiute Farms
RB1, RB2	Rainbow Bridge
SPENCER1, SPENCER2	Spencer Camp
STAN1, STAN2, STAN3	Stanton Creek
UBB1, UBB2	Upper Bullfrog Bay
WCB1, WCB2	Warm Creek Beach
WCCA1, WCCA2	Warm Creek Cattle Area
WIL1, WIL2	Wilson Creek
WWB	Wahweap Bay
WWLB1, WWLB2	Wahweap Lodge Beach
WWM1, WWM2, WWM3	Wahweap Marina

Appendix B

Computer Files Transmitted With

Water Quality Data Analysis Report

The three computer disks accompanying this report include seven compressed (ZIP) files containing digital copies of all the tables, figures, and other materials used to produce this report. To decompress these files, you must use the commonly available shareware program PKUNZIP. The command to type at the DOS prompt is:

PKUNZIP -E *COMPRESS.ZIP FILENAME.EXT*

where COMPRESS.ZIP is the name of one of the seven compressed (ZIP) files listed below and FILENAME.EXT is the name of the file you wish to extract. If you want to decompress all of the files in COMPRESS.ZIP, simply omit the FILENAME.EXT. To simply obtain a listing of all the files compressed into a particular ZIP file, type the following:

PKUNZIP -V *COMPRESS.ZIP* | MORE

where COMPRESS.ZIP is the name of one of the seven compressed (ZIP) files listed below. Once you see the file you wish to obtain, substitute this file name for FILENAME.EXT in the first command line to extract and decompress this particular file.

The following seven compressed (ZIP) files are included on the disks accompanying this report:

(1) <u>GLCADATA.ZIP</u>

This compressed file contains three DBASE III+ and one ASCII file containing all data received from GLCA. Detailed database structures for each of the DBASE III+ files are found in Appendix C. In the DBASE III+ files, missing data are represented by -9s. The files compressed into this file include:

(a) ARCHIVE.DBF - All data for each site for the period from May 1988 to January 1994.

(b) ANALYSIS.DBF - This file is a subset of the data contained in ARCHIVE.DBF. It contains the data used in the SAS statistical analysis. Fecal coliform results from samples taken on the same day were averaged, field names were shortened to 8 characters, and some fields unnecessary for the statistical analysis were deleted.

(c) ANALGEOM.DBF - This file is also a subset of the data contained in ARCHIVE.DBF. It contains only three fields - site id, date, and colcount. Duplicate samples were not averaged.

(d) ANALGEOM.TXT - This is the same file as ANALGEOM.DBF, but in ASCII text format, and is the file that was run through the geometric mean program.

(2) GLCAPRGM.ZIP

This compressed file contains two executable files written in BASIC and ASSEMBLY language that were used by WRD to compute geometric means and generate plots. The programs are not finished products and do not have documentation or support. These files include:

(a) GEOMEAN.EXE - Program which computes geometric means of input data.

(b) PLOTTHEM.EXE - Program which prints plots generated by the geometric mean program.

(3) GLCAMAP.ZIP

This compressed file contains the four maps which appear in this report (Figures 1-4). These files are in Windows Clipboard (CLP) format which can be imported and/or edited in most Windows-based word processors and graphics packages. The files included in this compressed file are named FIGURE_1.CLP, FIGURE_2.CLP, FIGURE_3.CLP, and FIGURE_4.CLP.

(4) GLCABOX.ZIP

This compressed file contains all of the box-and-whiskers plots which appear in this report. These files are in Windows Clipboard (CLP) format which can be imported and/or edited in most Windows-based word processors and graphics packages. The names of the files included in this compressed file combine the site identification codes for the two sites whose plots appear in the file. For example, AP1AP2.CLP is the file containing the box-and-whiskers plots for sites AP1 and AP2. Some of the site identification codes were abbreviated when they were more than four characters long.

(5) GLCAGEOM.ZIP

This compressed file contains all of the geometric mean plots which appear in this report. These files are in Computer Graphic Metafile (CGM) format which can be imported and/or edited in most word processors and graphics packages, including WordPerfect. The names of the files included in this compressed file have the prefix GEOM followed by two numbers indicating the sites whose plots appear in the file. For example, GEOM0102.CGM is the file containing the geometric mean plots for sites AP1 and AP2. The files are numbered in alphabetical order by site identification code. Sites with insufficient data do not have geometric mean plots.

(6) GLCAREG.ZIP

This compressed file contains the linear regression plots associated with the Pearson correlations. These files are in Windows Metafile (WMF) format which can be imported and/or edited in most Windows-based word processing and graphics packages. These files include:

(a) REGE&T.WMF - Linear regression plots of average fecal coliform versus water surface elevation and turbidity.

(b) REGW&A.WMF - Linear regression plots of average fecal coliform versus water temperature and air temperature.

(7) GLCAREPT.ZIP

This compressed file contains all narrative portions of this report in WordPerfect Version 5.1 format files. These files include:

(a) GLCAREP.WP - Report text.

(b) AP_ABCD.WP - Appendices A, B, C, and D.

(c) AP_EFC.WP - Fecal coliform summary statistics table contained in Appendix E.

(d) AP_EFS.WP - Fecal streptococci summary statistics table contained in Appendix E.

(e) AP_EFCFS.WP - Fecal coliform/fecal streptococci ratio table contained in Appendix E.

(f) AP_F.WP - Pearson correlation matrix contained in Appendix F.

(g) AP_G.WP - Geometric mean table contained in Appendix G.

(h) AP_H.WP - Appendix H.

Appendix C

Water Quality Database File Structures

The following table provides the DBASE III+ database field structure for all the water quality data contained in ARCHIVE.DBF. These data will allow parks or other interested parties to replicate the statistical analyses and graphics contained in this report; perform more sophisticated analyses; or to establish a baseline park water quality database. Values equalling -9 in the database represent missing data.

ARCHIVE.DBF				
Field Name	**Field Type**	**Width/ # Decimal places**	**Parameter STORET No.**	**Field Description**
SITE_ID	Character	8		Identification code for sample location
DATE	Date	8		Date sample taken [mm/dd/yy]
TIME	Numeric	4		Time sample taken [hhmm]
TIMEPROC	Numeric	4		Time sample processed in lab [hhmm]
SITE_NAME	Character	25		Name of sample location
WEATHER	Character	6		Weather conditions at time of sampling
AIRTEMP	Numeric	3	00020	Temperature, air: °F
WIND	Numeric	2		Wind speed at time of sampling
CLARITY	Logical	1		Water clear or turbid
CHOPPY	Logical	1		Water choppy or not
BOATS	Numeric	3		Number of boats at time of sampling
VEHICLES	Numeric	3		Number of vehicles at time of sampling
PEOPLE	Numeric	3		Number of people at time of sampling
USE	Numeric	2		Number indicating degree of use at sample site

ARCHIVE.DBF				
Field Name	**Field Type**	**Width/ # Decimal places**	**Parameter STORET No.**	**Field Description**
SANIST	Numeric	3		Sanitation present or absent on boats
CONDITIONS	Character	80		Other conditions related to sampling
ELEVATION	Numeric	7/2	50040	Elevation of water to MSL: feet
WATERTEMP	Numeric	2	00010	Temperature, water: °C
TURBIDITY	Numeric	4	82078	Turbidity, field: Nephelometric Turbidity Units (NTU)
COLCOUNT	Numeric	4	31616	Fecal Coliform, M-FC BROTH, 0.45 mm filter: cfu/100 mL
ST_REMARK1	Character	1		STORET remark codes for Fecal Coliform data
FSCOUNT	Numeric	4	31673	Fecal Streptococci, MF, AGAR at 35 °C: cfu/100 mL
ST_REMARK2	Character	1		STORET remark codes for Fecal Streptococci data
FCFSRATIO	Numeric	7/3	00111	Ratio of Fecal Coliform to Fecal Streptococci

The following table provides the DBASE III+ database field structure for ANALYSIS.DBF, the data file used for SAS analyses. These data will allow parks or other interested parties to replicate the statistical analyses and graphics contained in this report; perform more sophisticated analyses; or to establish a baseline park water quality database. Values equalling -9 in the database represent missing data.

ANALYSIS.DBF				
Field Name	**Field Type**	**Width/ # Decimal places**	**Parameter STORET No.**	**Field Description**
SITE_ID	Character	8		Identification code for sample location
DATE	Date	8		Date sample taken [mm/dd/yy]
TIME	Numeric	4		Time sample taken [hhmm]
AIRTEMP	Numeric	3	00020	Temperature, air: °F
WIND	Numeric	2		Wind speed at time of sampling
BOATS	Numeric	3		Number of boats at time of sampling
VEHICLES	Numeric	3		Number of vehicles at time of sampling
PEOPLE	Numeric	3		Number of people at time of sampling
USE	Numeric	2		Number indicating degree of use at sample site
SANIST	Numeric	3		Sanitation present or absent on boats
ELEV	Numeric	7/2	50040	Elevation of water to MSL: feet
H2OTEMP	Numeric	2	00010	Temperature, water: °C
TURBID	Numeric	4	82078	Turbidity, field: Nephelometric Turbidity Units (NTU)

ANALYSIS.DBF				
Field Name	**Field Type**	**Width/ # Decimal places**	**Parameter STORET No.**	**Field Description**
AVGFCOL	Numeric	4	31616	Fecal Coliform, M-FC BROTH, 0.45 mm filter: cfu/100 mL
REMARK1	Character	1		STORET remark codes for Fecal Coliform data
AVGFS	Numeric	4	31673	Fecal Streptococci, MF, AGAR at 35 °C: cfu/100 mL
REMARK2	Character	1		STORET remark codes for Fecal Streptococci data
AVGCSRAT	Numeric	7/3	00111	Ratio of Fecal Coliform to Fecal Streptococci

The following table provides the DBASE III+ database field structure for ANALGEOM.DBF, the data file used for the geometric mean analysis. These data will allow parks or other interested parties to replicate the geometric mean tables and plots contained in this report. The file ANALGEOM.TXT has the same field structure as ANALGEOM.DBF.

ANALGEOM.DBF				
Field Name	**Field Type**	**Width/ # Decimal places**	**Parameter STORET No.**	**Field Description**
SITE_ID	Character	8		Identification code for sample location
DATE	Date	8		Date sample taken [mm/dd/yy]
COLCOUNT	Numeric	4	31616	Fecal Coliform, M-FC BROTH, 0.45 mm filter: cfu/100 mL

Appendix D

STORET Remark Codes

The following is a list of STORET remark codes. These codes are found in the files ARCHIVE.DBF and ANALYSIS.DBF in the fields named ST_REMARK1 (or REMARK1) and ST_REMARK2 (or REMARK2).

STORET Remark Codes	
A	Value reported is the mean of two or more determinations
B	Results based upon colony counts outside the acceptable range
C	Value calculated
D	Indicates field measurement
E	Indicates extra samples taken at composite stations
F	In the case of species, F indicates female sex
G	Value reported is the maximum of two or more determinations
H	Value based on field kit determination; results may not be accurate
J	Estimated value; value not accurate
K	Actual value is known to be less than value given
L	Actual value is known to be greater than value given
M	Presence of material verified, negative value, or male sex
N	Presumptive evidence of presence of material
O	Sampled, but analysis lost or not performed
P	Too numerous to count
Q	Exceeded normal holding time
R	Significant rain in last 48 hours
S	Laboratory test
T	Value reported is less than criteria of detection
U	Indicates material was analyzed for but not detected, or undet. sex
V	Analyte was detected in sample and method blank
W	Value observed is less than lowest value reportable under "T" code
X	Value is quasi vertically-integrated sample
Y	Analysis of unpreserved sample
Z	Too many colonies were present; numeric value is filtration volume