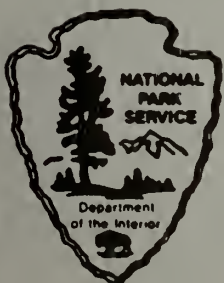


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WATER QUALITY MONITORING ALTERNATIVES FOR THE GLEN CANYON NATIONAL RECREATION AREA WATER RESOURCES MANAGEMENT PLAN



WATER RESOURCES REPORT NO. 86-3



WATER RESOURCES DIVISION
NATIONAL PARK SERVICE
COLORADO STATE UNIVERSITY
FORT COLLINS, COLORADO 80523

This report presents the results of a study conducted by the National Park Service Water Resources Division. It is intended primarily for use by the particular Park Service area or areas that are addressed in the report but may be of interest to other persons working in water resources management. Requests for copies of this report should be addressed to:

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WATER QUALITY MONITORING ALTERNATIVES
FOR THE GLEN CANYON NATIONAL RECREATION AREA
WATER RESOURCES MANAGEMENT PLAN

Water Resources Report No. 86-3

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June 1986



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TABLE OF CONTENTS

	<u>Page</u>
LIST OF FIGURES	iv
LIST OF TABLES	v
ACKNOWLEDGMENTS	vii
INTRODUCTION	1
I. LAKE POWELL WATER CHEMISTRY AND PRODUCTIVITY	3
Major Ion Chemistry and Physical Limnology	8
Major Inflow Tributaries: Discharge and Water Chemistry	10
Lake Primary and Secondary Productivity	13
II. RECREATIONAL WATER QUALITY AND PUBLIC HEALTH	17
Shoreline Contact Recreation	18
Backcountry and River Contact Recreation and Drinking Water	21
Heavy Metal Bioaccumulation in Gamefish	25
"Gray Water" Contamination	28
III. SPECIAL RESOURCE MANAGEMENT ISSUES	30
Minor Tributary Water Quality and Native Fish Habitat	30
Baseline Inventory of Springs, Seeps, and Waterpockets	31
Water Quality Impact of Tar Sands Development	35
Power Plant and Uranium Mine Waste Disposal	36
Water Contamination by Grazing Activities	44
CONCLUSIONS	46
LITERATURE CITED	49

LIST OF FIGURES

<u>Figure</u>	<u>Page</u>
1. Map of Glen Canyon National Recreation Area	4

LIST OF TABLES

<u>Table</u>	<u>Page</u>
1. Water quality monitoring and research issues identified in the GLCA Water Resources Management Plan . . .	2
2. History of the Bureau of Reclamation major ion chemistry and physical limnology monitoring program in Lake Powell	9
3. Water quality information from long-term USGS monitoring stations on the major inflow tributaries of Lake Powell	12
4. Study design for proposed primary and secondary productivity studies for Lake Powell	16
5. Proposed shoreline bacterial monitoring approaches for Glen Canyon National Recreation Area	20
6. Estimated program costs to implement Approaches 1 and 2 for shoreline bacterial monitoring in GLCA . . .	22
7. Parameters measured in fish collected at Station 93, Colorado River at Lake Powell, Arizona . .	27
8. Hydrological parameters determined in a reconnaissance of springs and seeps in the Bown's Canyon, Wilson Mesa, and Orange cliffs areas of GLCA	33
9. Recommended surface water quality monitoring program for streams, springs, and seeps located in the vicinity of tar sands development	37
10. Suggested ground water quality monitoring program for aquifer sites located in the vicinity of tar sand development	39
11. USGS analytical laboratory costs for surface- and ground-water monitoring constituents associated with tar sand development	40
12. Recommended chemical constituents for a ground-water monitoring program at coal-fired power plants	43

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INTRODUCTION

The Water Resources Management Plan currently being developed for Glen Canyon National Recreation Area (GLCA) contains a number of problem statements for which water quality studies or monitoring activities are identified within the prescribed management alternatives. The purpose of this paper is 1) to investigate those issues requiring monitoring in order to summarize the status of what is currently being accomplished, and 2) to recommend cost-effective monitoring plans and research alternatives that will aid in water resources management.

The list of problem statements requiring water quality monitoring or research activity is long and diverse. However, the types of monitoring and research activities necessary to provide data relating to these issues can be consolidated into three general categories:

1. Lake Powell water chemistry and productivity
2. recreational water quality and public health
3. special resource management issues

A listing of the issues relating to each of these categories is presented in Table 1.

This paper will address monitoring activities or research needs for each identified problem and present general study plans and approximate implementation costs for each program. It is hoped that this information will be of assistance to park

Table 1. Water quality monitoring and research issues identified in the GLCA Water Resources Management Plan.

I. LAKE POWELL WATER CHEMISTRY AND PRODUCTIVITY

- a. major ion chemistry and physical limnology
- b. water chemistry of the major inflow tributaries (Colorado River, Green River, and San Juan River)
- c. lake primary and secondary productivity

II. RECREATIONAL WATER QUALITY AND PUBLIC HEALTH

- a. shoreline water quality (contact recreation)
- b. backcountry and river recreational water quality (drinking water and contact recreation)
- c. heavy metals bioaccumulation (sport fishery)
- d. "gray water" contamination from houseboating

III. SPECIAL RESOURCE MANAGEMENT ISSUES

- a. minor tributary water quality and fishery habitat
 - b. baseline inventory of springs and seeps
 - c. tar sands development
 - d. power plant and uranium mine waste disposal
 - e. water contamination by grazing activities
-

resource managers in the planning and prioritization of water quality activities.

It should be noted that the costs and level of effort for implementing these alternatives vary widely. In several instances, data requirements are being provided by past and present programs of a number of agencies including the National Park Service, Bureau of Reclamation, U. S. Geological Survey, Utah Division of Wildlife Resources, U. S. Fish and Wildlife Service, and the Salt River Project. In some instances, successful program management may be attained by the development or continuation of effective liaison. In the remaining cases, expansion or initiation of new monitoring or research activities may be required. I have attempted in the following sections to identify the agencies for which acquired data would enhance management decision-making, in order that the possibility of cooperative monitoring or research efforts may be explored.

I. LAKE POWELL WATER CHEMISTRY AND PRODUCTIVITY

Lake Powell (Figure 1), the major water feature of Glen Canyon National Recreation Area, was created in 1963 with the completion of the Glen Canyon Dam. During the next few years a 260 km (160 mi) stretch of the Colorado River was transformed into the United States' second largest reservoir. At a maximum operating level of 1128 m (3700 ft), Lake Powell has a mean depth of 51 m (167 ft) and a maximum depth of 171 m (561 ft). It covers a surface area of 653 km² (317 mi²) and stores a volume of 33,000,000,000 m³ (26,753,000 acre feet) (Paulson and Baker, 1980; Water and Power Resources Service, 1981).

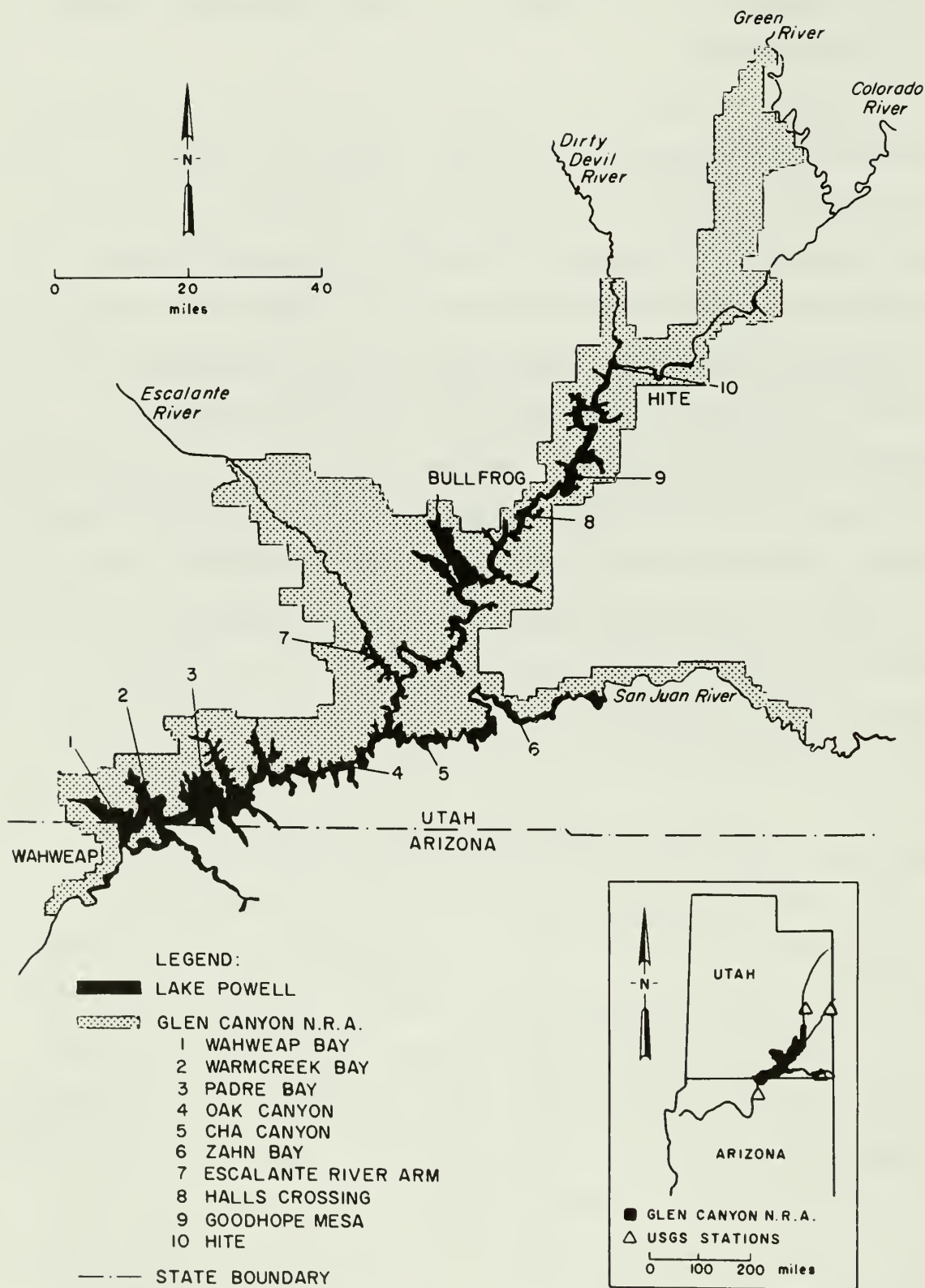


Figure 1. Map of Glen Canyon National Recreation Area.

The major sources of inflow to Lake Powell are the Colorado, Green, and San Juan Rivers. To some degree, the major ion chemistry is determined by the relative inflow of each of these tributaries, since Colorado River water is sulfate-chloride rich, Green River water is sulfate-carbonate rich, and San Juan River water is sulfate rich (Reynolds and Johnson, 1974).

The waters of Lake Powell itself are moderately saline (TDS = 500 mg/l). Major ion concentrations within the lake occur in the proportions sulfate > calcium $\approx$ sodium > alkalinity > magnesium > chloride >> potassium (Reynolds and Johnson, 1974). Of the major dissolved species, calcium carbonate and silica have been found to be nonconservative in their passage through the lake. Calcium carbonate precipitates inorganically as a result of high pH, caused by algal photosynthesis, and silica precipitates as a result of incorporation into diatom frustules (Mayer, 1976).

Nutrient dynamics within Lake Powell are characterized by the high removal of phosphorus, which results from the sedimentation of phosphorus bound to silt and clays close to the tributary inflow points. Paulson and Baker (1984) estimate that Lake Powell traps 98 percent of the total phosphorus and 46 percent of the total nitrogen entering from the tributaries. Thus, with the exception of certain areas near the inflow of the tributaries, nutrient concentrations are low, with mean soluble reactive phosphorus ranging from 0.002 - 0.003 mg/l and mean total phosphorus concentrations ranging from 0.008 - 0.010 mg/l in 1981 and 1982 (Paulson and Baker, 1984). While extensive data are not available, the low nutrient concentrations found in Lake

Powell indicate that primary productivity may be limited, except in areas close to the source of nutrient inflow. Such a situation may ultimately affect fisheries and should be understood for effective fisheries management.

The physical limnology of Lake Powell is complex but reasonably well studied (Johnson and Merritt, 1979; Gloss et al., 1980; U. S. Department of the Interior, 1983). The lake has been described as "warm monomictic" which indicates that convective mixing occurs only once a year, during the winter cool-down period. However, Johnson and Merritt (1979) report that advective circulation is significant, and that during a typical year the lake will receive two distinctive types of inflow: a lower-density water associated with the spring flood, and a higher-density water during the winter.

The impact of the advective circulation is important in the functioning of the lake at all levels of trophic organization. The influx of warm, lower-density water (spring overflow current) largely sets the thickness of the summer thermal equilibrium, especially in the upper reaches of the lake. Johnson and Merritt (1979) report that years with a large spring flood are associated with a deeper, more diffused metalimnion than are years with a small spring flood.

As the summer progresses, the total dissolved solids content of the inflow water increases, eventually closing off the overflow current. By early winter, the water is sufficiently dense to become an underflow current (the winter underflow current) (Johnson and Merritt, 1979). This current contains cold, saline water with a high initial dissolved oxygen concentration and

flows into the deeper areas of the lake, replenishing the deep-water dissolved oxygen concentrations.

Although the winter underflow current helps to maintain desirable dissolved oxygen concentrations in some of the deep waters of Lake Powell, the dissolved oxygen in hypolimnion waters over 77 m (250 ft.) deep sags to less than 4 mg/l (Jerry Miller, Bureau of Reclamation, personal communication). In addition, dissolved oxygen depletion may develop in the metalimnion in late summer. This is due to the decomposition of algae and other organic materials trapped by the density gradient in a layer typically 12-20 m (40-65 ft) below the surface (Johnson and Page, 1980). This layer may extend the full length of the lake and could possibly present a barrier to vertical fish migration during the late summer and early fall (Johnson and Page, 1980).

Finally, it should be noted that Lake Powell functions both as a lake and as a "deep river." Record high flows along the mainstem of the Colorado River in 1983 caused severe flood damage throughout parts of the Colorado River Basin (Vandivere and Vorstor, 1984). Large discharges through the Glen Canyon Dam resulted in the release of large amounts of more saline water from the depths of the lake. These releases in turn reduced the total dissolved solids concentration in hypolimnetic deep waters of Lake Powell. Overall, the total dissolved solids concentration in Lake Powell is at an all-time low due to heavy runoff since water year 1983. It is anticipated that this will reduce salinity in the lower Colorado River for the next two to four years (Jerry Miller, Bureau of Reclamation, personal communication).

To properly understand and manage Lake Powell, a certain amount of long-term trend information is required for the lake as well as its inflow tributaries. Presently, long-term monitoring activities are being conducted by the Bureau of Reclamation and the U. S. Geological Survey to maintain baseline information for both the major tributary inflow chemistry and the major ion chemistry and physical limnology of the lake itself. Specifics of these programs will be presented later in this paper. While the Utah Division of Wildlife Resources is responsible for fisheries management research, information pertaining to primary and secondary productivity in Lake Powell is limited. A description of present monitoring activities and a recommendation for a proposed lake productivity study by the Utah Division of Wildlife Resources, National Park Service, and Bureau of Reclamation will also be discussed.

Major Ion Chemistry and Physical Limnology

Beginning in 1965, the Bureau of Reclamation initiated a major ion chemistry and physical limnology monitoring program in Lake Powell. The purpose of this program was to create a comprehensive data base relating to the salinity and major ion changes brought about in the Colorado Basin by the closing of the Glen Canyon Dam. Sampling locations, frequencies, and parameters measured have been modified slightly over the years (Table 2). While this data collection program has focused primarily on salinity management questions, the long-term, consistent nature of this program has proved invaluable in providing baseline and trend information utilized in a number of short-term intensive

Table 2. History of the Bureau of Reclamation major ion chemistry and physical limnology monitoring program in Lake Powell.

Period	Program Description
1965-1971	Six stations (Wahweap Bay, Padre Bay, Oak Canyon, Cha Canyon, Hall's Crossing, and Hite) were monitored quarterly at 50' depth intervals (top to bottom) for physical parameters including temperature and dissolved oxygen, and chemical parameters including specific conductance, TDS, pH, and common ions (Jerry Miller, U.S. Bureau of Reclamation, personal communication).
1971-1984	Seven stations (Wahweap Bay, Padre Bay, Oak Canyon, Cha Canyon, Hall's Crossing, Good Hope Mesa, and Hite) were monitored monthly at 50' depth intervals for physical parameters including temperature and dissolved oxygen, and chemical parameters including specific conductance, TDS, pH, and common ions (calcium, sodium, magnesium, potassium, chloride, sulfate, alkalinity, and bicarbonate) (Jerry Miller, U. S. Bureau of Reclamation, personal communication). In addition, a special two-year study occurred in 1981-82 that focused on nutrients and productivity (Paulson and Baker, 1984).
1984-present (86)	With an extensive data base established from 1965-1984, the Bureau of Reclamation elected to reduce sampling to a quarterly basis. An eighth site (Cataract Canyon) was added to the seven sites previously listed. Parameters sampled remained the same except for the addition of silica to the parameter list. In addition, continuous recording (at 2 hour intervals) at three depths for temperature and specific conductance has been attempted at two sites (Cataract Canyon and Clear Water Canyon). Because of instrumentation problems, only intermittent data are available (Jerry Miller, U. S. Bureau of Reclamation, personal communication).

studies.

While a reduction in sampling frequency in 1984 from monthly to quarterly was necessary, quarterly sampling should be adequate to detect any major changes that could occur, especially in response to changes in water management practice within the Colorado River basin.

Information gained from this monitoring program is a direct benefit to the National Park Service in several ways. First, although the parameters monitored focus on salinity-related issues, the data obtained are an important baseline and can be used in other studies. Second, the data provide important information on the physical processes within the lake, which are of importance in understanding many of the biological processes. Third, the monitoring is sufficient to detect some of the impacts that could result from changes in water management or from watershed development. Continued cooperation and regular liaison between NPS and the Bureau of Reclamation is recommended.

Major Inflow Tributaries: Discharge and Water Chemistry

Approximately 96 percent of the total surface water inflow into Lake Powell enters from the three major tributaries: the Colorado River, the Green River, and the San Juan River (Iorns et al., 1965).

The Colorado River begins in Rocky Mountain National Park, Colorado, and flows approximately 740 km (460 mi) before entering Lake Powell near Hite, Utah. Two major tributaries of the upper Colorado River - the Green River and the San Juan River - also influence Lake Powell. The Green River begins in western Wyoming

and enters the Colorado River in Canyonlands National Park just above Lake Powell; the San Juan River flows directly into Lake Powell.

Three long-term discharge and water quality stations maintained cooperatively by the U.S. Geological Survey and the Bureau of Reclamation monitor water quality of the major tributary inflow into Lake Powell (Table 3). Data presently collected at these stations include:

- discharge
- water chemistry
 - specific conductance, pH, turbidity, dissolved oxygen, major cations, major anions (monthly)
 - nutrients, heavy metals and trace elements (quarterly)
- bacteriological data (quarterly)
- water temperature, specific conductance, and suspended sediment load (daily)
- particle size distribution (quarterly) (ReMillard et al., 1984)

The locations of these stations (Figure 1), while not ideal because of the long distances to the lake, are adequate for NPS requirements. The Colorado River station near Cisco, Utah, lies approximately 255 km (160 mi) above the upper reaches of Lake Powell. The town of Moab, Utah, and some uranium mining and milling operations are located between this station and the lake. The Green River station is located in Green River, Utah, approximately 185 km (117 mi) upstream from its confluence with the Colorado River. Much of the watershed between the Green River Station and the confluence of the Colorado and Green Rivers is within Canyonlands National Park, and human disturbances are negligible. The San Juan River station, located southwest of

Table 3. Water quality information from long-term USGS monitoring stations on the major inflow tributaries of Lake Powell (ReMillard et al., 1984).

USGS #	Station Name	Period of Record	1984 Water Quality Parameters
09180500	Colorado River near Cisco, UT	DSX 1895-present WQ 1928-present	D, C, B, T, S
09315000	Green River at Green River, UT	DSX 1894-1899 1904-present WQ 1928-present	D, C, B, T, S
09379500	San Juan River near Bluff, UT	DSX 1914-present WQ 1929-present	D, C, B, T, S

LEGEND:

DSX = discharge

WQ = water quality

D Daily discharge

C Monthly water chemistry (nutrients and metals quarterly)

specific conductance

pH

turbidity

dissolved oxygen

hardness (carbonate and non-carbonate)

major cations (Ca, Na, Mg, K)

major anions (alkalinity, Cl, SO₄, F)

silica

total dissolved solids

nutrients (ammonia,

nitrate and nitrite,

organic nitrogen, total

nitrogen, dissolved

phosphorus, dissolved

orthophosphorus and

total phosphorus)

heavy metals and trace

elements (Al, As, Ba,

Be, Cd, Cr, Co, Cu, Fe,

Pb, Li, Mn, Mo, Hg, Ni,

Se, Ag, Sr, V, Zn, Bo)

B Bacteriological data (quarterly), including fecal coliform bacteria and fecal streptococcus bacteria

T Daily water temperature and specific conductance

S Suspended sediment (daily) and particle size (monthly)

Bluff, Utah, is approximately 60 km (38 mi) from the upper reaches of the San Juan Arm of Lake Powell and may be slightly impacted by uranium mill tailings development and small oil fields around Mexican Hat, Utah. In addition to these long-term stations, the U.S. Bureau of Reclamation has recently begun to monitor continuous water temperature and specific conductance at three depths in Cataract Canyon. When an adequate data base has been developed, these data will be correlated with data from the upstream U.S.G.S. stations.

The monitoring program now in operation for the major tributaries is very good and is also adequate for the anticipated long-term needs for the management of Lake Powell. Data from this program are published annually by the U. S. Geological Survey in a report entitled Utah Water Resources Data, Water Year 19--. The NPS should effect proper liaison with the U.S. Geological Survey so that Glen Canyon National Recreation Area is informed of any significant program changes proposed for these three stations. Major program reductions would threaten the long-term integrity of this data base.

Currently, no routine water quality monitoring occurs on the minor tributaries of Lake Powell that would be useful in resource decision-making for Glen Canyon National Recreation Area. Possible needs for water quality information from the minor tributaries will be addressed in a later section of this paper.

Lake Primary and Secondary Productivity

The overall "health" and fisheries potential of a reservoir

system depends largely on a complex interaction between nutrient concentration, primary productivity (phytoplankton), secondary productivity (zooplankton), and the various trophic-level interactions of the fish community.

Gloss et al. (1980) report that phosphorus is the limiting nutrient in Lake Powell, and they suggest a model in which phosphorus-rich overflow from the Colorado River creates a highly productive epilimnion in the upper reservoir. This is decreased substantially as the available nutrients settle out and are lost to the sediments between Hite and Bullfrog. Lake Powell retention coefficients for phosphorus are extreme, ranging from about 74 percent for dissolved phosphorus to about 96 percent for total phosphorus. Gloss et al. (1980) assert that these are among the highest retention coefficients reported in the scientific literature, reflecting the important interrelationship between phosphorus and associated suspended sediments in the Colorado River.

Studies by Paulson and Baker (1984) support this earlier work and indicate that while highly productive areas exist near the inflows of both the Colorado and San Juan Rivers, the lower reaches of Lake Powell, especially in the mainstream of the lake below the Escalante Arm, are characterized by low nutrient concentrations and primary productivity. Additionally, Paulson and Baker (1983) surmise that a relationship may exist between chlorophyll a concentration, zooplankton densities, and the abundance of threadfin shad in the Lake Mead Reservoir, which is located downstream from Lake Powell.

Presently, the monitoring programs in Lake Powell do not

routinely address nutrient concentrations, primary productivity, or zooplankton abundance. A limited-duration study in 1981-82 (Paulson and Baker, 1984) addressed nutrient concentrations and chlorophyll a distribution, but did not provide data on either primary productivity or zooplankton. Because of the importance of this information to the long-term health and fisheries potential of the lake, it is recommended that a 15-month nutrient, primary productivity, and zooplankton study be completed in Lake Powell once every six to eight years. A suggested study design providing station location, sampling frequency, and parameters to be measured is presented in Table 4. At the request of Glen Canyon National Recreation Area, Dr. Larry Paulson of the University of Nevada at Las Vegas prepared a list of approximate costs associated with this type of study. While the \$65,000 cost of the program would be difficult for one agency to absorb, the information gathered from this type of study will benefit the Utah Division of Wildlife Resources, the Bureau of Reclamation, and the National Park Service. It is recommended that discussion be initiated by the National Park Service with the other agencies to see if a cooperative study could be funded.

Table 4. Study design for proposed primary and secondary productivity studies for Lake Powell.

Sampling frequency: Study to last 15 months and consist of nine sampling trips including:

<u>Year 1</u>	<u>Year 2</u>
June	January
July	March
August	June
November	July
	August

Stations:	Warm Creek Bay	Hall's Crossing
	Padre Bay	Hite
	Escalante River Arm	Zahn Bay (San Juan Arm)

Physical parameters: Profile of water temperature, pH, specific conductance, dissolved oxygen, and photo-synthetically available radiation.

Nutrients: Two samples will be taken at each site. One will be an integrated sample from 0-2.5 m, the second an integrated sample from 1-5 m. Nutrient determination will include:

<u>dissolved species</u>	<u>total (unfiltered)</u>
NH ₄ -N	total nitrogen
NO ₂ and NO ₃ -N	total phosphorus
Si	
soluble reactive phosphate	

Phytoplankton: Chlorophyll a biomass and ¹⁴C primary productivity determined at surface, 1 m, 3 m, 5 m, 7 m, 10 m, 15 m, 20 m, and 25 m at shallow stations; and at surface, 1 m, 3 m, 7 m, 10 m, 25 m, and 70 m at deep stations.

Zooplankton: Zooplankton identification and enumeration from integrated plankton tows at depths determined appropriate by the Utah Division of Wildlife Resources.

II. RECREATIONAL WATER QUALITY AND PUBLIC HEALTH

The formation of Lake Powell created a multi-purpose water resource that greatly increased water-based recreational activities in northern Arizona and southern Utah. Today, Lake Powell is heavily used for swimming, boating, fishing, boat camping, and house boating. Glen Canyon National Recreation Area also offers opportunities for river rafting in the Colorado River above and below Lake Powell, as well as in the San Juan and Escalante Rivers. Further, several areas of GLCA are heavily used for wilderness hiking and backcountry camping. Springs, seeps, and streams in these areas are frequently used for both drinking and swimming.

The draft Water Resources Management Plan for Glen Canyon National Recreation Area lists four issues specifically related to recreational water quality and public health. These include:

- shoreline water quality (contact recreation)
- backcountry and river recreational water quality (drinking water and contact recreation)
- heavy metals bioaccumulation (sport fishery)
- "gray water" contamination from houseboating

A review of previous studies, present monitoring activities, and proposed monitoring or research designs for each of these issues are addressed below.

Shoreline Contact Recreation

With the continued development of shoreline recreational facilities along Lake Powell, the use of the lake for swimming and wading activities is expected to continue to increase. Presently, heavily used beaches are located at Wahweap, Lone Rock, and Bullfrog Bay, and popular boat-in beaches are found in Oak Canyon, Farley Canyon, and Moqui Canyon. Initial investigations into the bacterial water quality at popular swimming areas were conducted by Walther (1971) and Kidd (1975). These short-term, intensive studies were undertaken in the early years after Lake Powell was formed. Both studies concluded that while the waters were not safe to drink without adequate treatment, they did generally meet applicable state standards for both primary and secondary contact recreation. However, Kidd (1975) found that contact recreation standards were occasionally exceeded near the Wahweap swimming beach and marina, at the sewage discharge buoy (no longer in operation) in front of the Rainbow Bridge marina, and at a site below the Hall's Crossing - Bullfrog marina areas.

In a follow-up study, Cudney (1977) measured fecal coliform and total coliform bacteria several times during the summer of 1976 at 15 popular swimming beaches or boat-in campsites. As in the previous studies, results indicated that while the water of Lake Powell was not suitable for drinking, standards were usually met for full-body contact recreation.

A recent study again surveyed bacterial indicators in Lake Powell (Fitzgerald et al., 1985). Five three-day sampling trips were conducted throughout the lake during the summer of 1985.

Fecal coliform and fecal streptococcus bacterial levels were determined at all popular beaches and boat-in locations. Although bacterial levels at most locations were acceptable for contact recreation, the authors found several areas, including Farley Canyon, Moqui Canyon, White Horse Mesa, Lone Rock, Davis Gulch, and White Canyon, that frequently exceeded desirable bacterial concentrations.

Sufficient information is now available to conclude that while the bacterial water quality of Lake Powell is generally very good, popular swimming beaches and boat-in campsites do exceed acceptable bacterial levels during periods of heavy use. For this reason, continued bacterial monitoring is warranted. Two complementary approaches for further monitoring are presented for consideration by Glen Canyon National Recreation Area (Table 5).

Approach 1 would implement a routine bacterial monitoring program at the primary swimming beach and marina areas. Multiple samples would be taken every second week, preferably during periods of heavy use. The objective of this program would be compliance with recommended monitoring procedures for contact recreation, although the resulting data could also be compared with beach usage trends or used to assess the frequency of violations.

Programs similar to this are currently being used by Indiana Dunes National Lakeshore, Fire Island National Seashore, and Golden Gate National Recreation Area. Urban influences in each of these areas create short-duration, bacterial contamination problems that are much more severe than those encountered in Lake Powell. In these cases, monitoring data are frequently used by

Table 5. Proposed shoreline bacterial monitoring approaches for Glen Canyon National Recreation Area.*

Objective	Frequency	Sites (# of samples)	Parameters
Approach 1 Routine monitoring of popular beach areas for compliance with contact recreation standards	Every two weeks Memorial Day to Labor Day	Wahweap Swim Beach (3) Wahweap Marina (2) Wahweap at sewage pumpout (1) Lone Rock Beach (3) Antelope Point (2) Bullfrog Marina (2) Bullfrog Swim Beach (3)	fecal coliform bacteria (water) water temperature pH turbidity specific conductance
Approach 2 Limited duration intensive transect study of bacterial distribution patterns of heavily used beach areas	4-6 sampling trips: 1-2 during periods of light beach use, 3-4 during periods of heavy beach use	Lone Rock Beach (15) Moqui Canyon (15) One of the following: Farley Canyon (15) Oak Canyon (15) Bullfrog Creek (15)	fecal coliform bacteria (water) fecal coliform bacteria (sediment, 2 times only) fecal streptococcus bacteria (water) (every third sample) total coliform bacteria (water) (every third sample) water temperature pH turbidity specific conductance

* Bacterial sampling, handling, and analysis procedures should follow recommendations listed in Microbiological Methods for Monitoring the Environment: Water and Wastes, U.S. EPA, 1978.

park management to identify areas where a temporary health hazard may exist so that warning signs can be posted.

The implementation of this program at Glen Canyon National Recreation Area would not be difficult. Equipment presently available in Glen Canyon National Recreation Area includes a Hydrolab 4000, which could be used to collect water temperature, specific conductance, pH, and dissolved oxygen data, and Millipore microbiological apparatus sufficient to determine total and fecal coliform bacterial contamination.

Approach 2 would provide a more thorough study on areas already identified as bacterial "hot spots." This study would incorporate transect sampling at three popular contact recreation locations 4-6 times during the summer season. Sampling times would be selected according to usage patterns with an attempt made to sample 1-2 times during low-use periods and 3-4 times during high-use periods.

The implementation of both programs is appropriate to address resource management needs. Approach 1 provides the coverage of a broad geographic area and meets accepted monitoring practices currently employed in many shoreline areas for routine contact recreation. Approach 2 employs a stronger study design, though limited in geographical area, which would allow a more thorough investigation into the possible causes of high bacterial levels. Projected costs for implementing the two programs are given in Table 6.

Backcountry and River Contact Recreation and Drinking Water

The bacterial water quality of recreational waters used for

Table 6. Estimated program costs to implement Approaches 1 and 2 for shoreline bacterial monitoring in Glen Canyon National Recreation Area.

Approach 1: Routine monitoring of beach areas during swimming season (annual program).

Personnel: GS-5 summer seasonal, 25% of time from May 15 - September 15	\$1250
Expendable bacterial monitoring supplies (media, petri dishes, filters etc.)	1250
Expendable field equipment supplies	200
Logistics (truck, etc.)	500
Personnel training (Fort Collins or Rocky Mountain National Park)	<u>1000</u> \$4200

Approach 2: Intensive transect study of heavily-used contact recreation areas (one-time study).

Personnel: Graduate student assistant, three months at \$600/month	\$1800
Expendable monitoring supplies	1200
Laboratory expenses (bacterial analysis of sediments)	1000
Logistics (truck, boat)	<u>500</u> \$4500

river-running activities in the Colorado River below the Glen Canyon Dam and in the San Juan River above Lake Powell has been the subject of several well-executed studies (Brickler and Tunnicliff, 1980; Tunnicliff and Brickler, 1984; Doyle, Tunnicliff, and Brickler, 1985). These studies conclude that both rivers are generally acceptable for primary contact, though not suitable for drinking without prior treatment. However, these studies further report that the resuspension of sediments pose a potential water quality hazard because of the suspected accumulation of bacteria in the bottom material. Based on the consistent nature of the available data, it would seem appropriate to implement the recommendations of these studies in similar areas in the contact recreation areas of the Escalante and Dirty Devil Rivers that have not already been studied.

In many hydrological situations, elevated bacterial concentrations correlate strongly with storm runoff from the surrounding watershed (Kunkle, 1970). The previous studies have all been conducted during low to normal flow conditions. If resource management concerns dictate that a further study is warranted, a study should be conducted during a period of maximum tributary inflow, when higher levels of bacteria may enter the aquatic system in runoff from land surfaces supporting grazing activities.

Few data are available concerning water usage (drinking water and contact recreation) and bacterial or other contamination of backcountry waters of Glen Canyon National Recreation Area. While NPS recommendations state that no water in the backcountry should be consumed without proper treatment, a

recent survey in Rocky Mountain National Park revealed that untreated water is consumed by approximately 15% of backcountry users (Cowdin, in press). In many instances the users are unaware of the potential health problems that can result from drinking untreated backcountry water. Moderately high concentrations of magnesium sulfate found in waters throughout the southwest can act as a very effective laxative, creating temporary discomfort in humans unaccustomed to high sulfate waters. Additionally, it is possible to contract giardiasis or other gastrointestinal illnesses from consuming improperly treated water.

As it is likely that use of untreated water occurs in Glen Canyon National Recreation Area, a reconnaissance survey may be warranted that examines ion concentration, bacterial contamination, and the presence of Giardia spp. in a heavily used backcountry area in Glen Canyon National Recreation Area. A survey consisting of five chemical/bacterial sampling trips (major ions, total coliform bacteria, fecal coliform bacteria, and fecal streptococci bacteria) and three Giardia spp. sampling trips at selected areas could provide resource managers with enough initial information to devise a course of action. Costs of such a reconnaissance program are difficult to estimate without considering the specific logistical situation (e.g., necessity for helicopter transportation, personnel, etc.). Generally, bacterial samples must be analyzed within six hours of collection, and Giardia filters must reach a laboratory with specially trained personnel who can analyze for Giardia within 36 hours. Assuming the availability of a bacterial laboratory in Glen Canyon National Recreation Area, and without considering logistics, this

reconnaissance program could probably be implemented for approximately \$2500.

Heavy Metal Bioaccumulation in Gamefish

Lake Powell, because of its influence on flow dynamics and its location as the first major reservoir along the mainstem of the Colorado River, functions as an efficient trap for river sediments. Graf (1985) states that the weathering of natural source rocks in the lake's 279,000 km² (108,700 mi²) watershed is responsible for most of the estimated 2200 kg (4840 lb) of mercury annually delivered to the lake in fluvial sediments. It might also be expected that erosional processes could be a source of other heavy metals and trace elements associated with the sediments.

Of all the heavy metals that could be deposited in the lake, mercury has received the most attention because of its tendency to bioaccumulate. Standiford et al. (1973) monitored mercury accumulation throughout the trophic system and found that mercury concentration increased from 30 ppb (parts per billion) in the bottom sediments to more than 400 ppb in walleye. They concluded that larger fish of a given species and fish of higher trophic levels have a tendency to contain higher mercury concentrations, and that the muscle of large walleye and largemouth bass may exceed 500 ppb (Standiford et al., 1973). The maximum concentration of mercury in fish flesh destined for human consumption has been set at 500 ppb wet weight, and the daily intake of mercury should be less than 30 ug for adults.

Bussey et al. (1976) surveyed the concentrations of five

additional heavy metals (cadmium, chromium, lead, arsenic, and selenium) in Lake Powell gamefish that included largemouth bass, black crappie, walleye, and rainbow trout. At that time, the selenium levels found in fish flesh were high enough to be considered a possible health hazard (Bussey et al., 1976).

The National Contaminant Biomonitoring Program of the U.S. Fish and Wildlife Service has been monitoring heavy metal and organochlorine pesticide contamination in Lake Powell since 1970. The protocol of this national sampling program requires that metal and pesticide concentrations be determined from whole fish composite samples of five individuals of each species. Each site in the national network is sampled once every other year, with the attempt made at each site to sample at least one bottom-feeding species and one species near the top of the trophic structure. The Lake Powell sampling currently consists of two composite samples of the common carp (Cyprinus carpio) and one composite sample of the largemouth bass (Micropterus salmoides) (Bill Kepner, U.S. Fish and Wildlife Service, personal communication). A listing of parameters monitored is presented in Table 7.

Mercury concentrations reported from this program in 1978 and 1980 range from 80-110 ppb for largemouth bass (Lowe et al., 1985), which is considerably lower than that reported for bass (314 ppb) by Standiford et al., (1973).

Since Lake Powell serves as a natural sink for sediments, it is important to continue monitoring for heavy metals accumulation. The present program of the U.S. Fish and Wildlife

Table 7. Parameters measured in fish collected at Station 93, Colorado River at Lake Powell, Arizona. (All samples monitored were whole fish concentrations from a composite of 5 fish per sample [Schmitt et al., 1983; Lowe et al., 1985].)

Period of Record	Species	Parameters
1970-present (alternate years)	common carp	Metals: cadmium arsenic
		mercury lead
	largemouth bass	copper zinc
		selenium
	rainbow trout (partial record)	DDT homologs:
		DDT DDD DDE
		PCB's:
		Arochlor 1242
		1248
		1254
		1260
		Cyclodiene
		Insecticides:
		dielddrin
		cis nonachlor
		trans nonachlor
		endrin
		heptachlor
		cis chlordane
		trans chlordane
		oxychlordane
		Miscellaneous
		pesticides:
		toxaphene
		dacthal
		a-BHC
		g-BHC
		HCB

Service will provide important long-term trend data of contaminant accumulation in two important indicator species. In addition, minor expansion of the present monitoring program is recommended in which lead, cadmium, mercury, arsenic, selenium, copper, and zinc concentrations are determined in a composite of five fillets of mature striped bass (Morone saxatilis), presently the major game species in Lake Powell. This expansion could be implemented for an additional cost of less than \$300 every other year.

"Gray Water" Contamination

While the discharge of sewage from houseboats and pleasure craft is prohibited on Lake Powell, the problem of "gray water" discharge has long been debated by park managers. "Gray water" is defined as the non-sewage discharge from houseboats which includes wastewater from the kitchen sink, shower, and bathroom sink. During peak season, up to 300 houseboat rental units may be in use on Lake Powell at any one time.

A literature search of the subject showed that little information is published regarding either the composition or the effect of gray water discharge. Only one study (Brandes, 1978) characterized the chemical and bacterial composition from a household system where sewage and gray water were isolated into separate systems. This study revealed that kitchen wastewater contains large amounts of organic matter that have undergone little breakdown, as well as rather high concentrations of total and fecal coliform bacteria.

The houseboat rentals at Lake Powell contain a closed sewage

system that generally would not be tampered with by the renter. Water for the shower, the kitchen sink, and the bathroom sink (not for drinking) is obtained directly from the lake via a small pump. The gray water is then returned directly to the lake.

With the small amount of information available, it is difficult to judge if a problem does exist. The concessionaire has demonstrated responsible behavior by furnishing each boat with a bottle of phosphate-free detergent. In addition, literature should be provided requesting that houseboaters refrain from using strong organic cleaning solutions. Problems resulting from gray water discharge would appear to be primarily aesthetic, but if the small amount of data from the earlier study are extrapolated, the problems could also be bacterial.

At this time, it is not believed that gray water discharge presents enough of a problem to warrant a special study. However, if routine shoreline bacterial monitoring were to be implemented as a resource management function, it is suggested that an occasional transect be run for fecal and total coliform bacteria in a popular houseboat anchorage. If a problem were found, a more comprehensive study should be considered.

III. SPECIAL RESOURCE MANAGEMENT ISSUES

The draft Water Resources Management Plan identifies a number of resource management issues that focus on specific activities having potential impact on the water quality within Glen Canyon National Recreation Area. The specific scope of many of these activities will place lead agency responsibility, in many cases, with the National Park Service. However, in several instances, implementation costs and responsibilities might be cooperatively shared or borne entirely by the entity responsible for the impact.

Issues addressed in this category include:

- o minor tributary water quality and native fishery habitat
- o baseline inventory of springs, seeps, and waterpockets
- o water quality impact of tar sands development
- o power plant and uranium mine waste disposal
- o water contamination by grazing activities

Minor Tributary Water Quality and Native Fish Habitat

While the contributions of several minor tributaries of Lake Powell are too small to significantly influence the water chemistry of the lake, certain resource management issues relate to the tributaries themselves. These include the resource importance of the Dirty Devil River as habitat to native fish populations and the value of the Escalante River both for native fisheries and as a unique natural resource.

The importance of these two rivers as native fish habitat suggests the need for a fisheries habitat suitability study that is multidisciplinary in nature. Components of this study would include instream flow (quantity) questions, interspecies competition issues, food base availability, and water quality assessment. A fisheries biologist should be consulted to devise the proper study design. However, the water quality component would include periodic determination of such field parameters as water temperature, dissolved oxygen, pH, and specific conductance. These could be measured by the Hydrolab 4000 presently available to the NPS. Occasional determinations of discharge, turbidity, and ammonia, chloride, and sulfate concentrations would also be made. While a fisheries biologist should be consulted concerning project design, much of the field work for this type of study could be accomplished in-house by a seasonal employee with a background in fisheries biology.

Baseline Inventory of Springs, Seeps, and Waterpockets

The springs, seeps, and "waterpockets" of Glen Canyon National Recreation Area, which are the natural water features of the canyons and uplands, have received limited study. Laity and Malin (1985) have described a ground-water sapping process from the highly transmissive Navajo Sandstone, which is the source of many springs and seeps. This process is also important in the geomorphic development of the theater-headed valley networks common to the Colorado Plateau.

A limited amount of information is available regarding the chemical composition of the springs and seeps in Glen Canyon

National Recreation Area from Hand (1979), who studied the springs in the Orange Cliffs area, and from a recent reconnaissance study by Williamson (in preparation). Williamson characterized the flow rate and chemical composition of a number of springs in the Bown's Canyon, Wilson Mesa, and Orange Cliffs area. The hydrological parameters determined in this study are listed in Table 8.

In addition to natural springs and seeps, a number of man-induced springs and seeps appear to have been created below the Glen Canyon Dam due to the increase of hydraulic head attributed to the formation of Lake Powell. The discharge and environmental impact of these newly created water resources are yet to be determined.

While the overall quantity of water associated with springs, seeps, and waterpockets in Glen Canyon National Recreation Area is small, their ecological significance is great. The seeps not only influence the geology (Laity and Malin, 1985), but they also support a specialized vegetation known as "hanging gardens." Further, it is not uncommon to find diverse assemblages of invertebrate and vertebrate fauna associated with springs and waterpockets in otherwise arid areas. Springs, seeps, and waterpockets within Glen Canyon National Recreation Area potentially could be affected by two activities. The quantity and quality of springs and seeps could be greatly altered by nearby mineral development or the utilization of aquifer recharge water for development. Water pockets, while not threatened by subsurface development, can be severely polluted by grazing cattle.

Table 8. Hydrological parameters determined in a reconnaissance of springs and seeps in the Bown's Canyon, Wilson Mesa, and Orange Cliffs areas of GLCA (adapted from Williamson [in preparation]).

discharge (estimated)	trace elements:
water temperature	iron
pH	copper
	zinc
	chromium
specific conductance	barium
	selenium
	arsenic
alkalinity	cadmium
major cations:	major anions:
calcium	bicarbonate
magnesium	nitrate
sodium	chloride
potassium	sulfate

Because of these threats, three specific water resources baseline reconnaissance studies should be considered. The first would be an extension of the studies of Hand (1979) and Williamson (in preparation) and would continue the inventory of the discharge and chemical characterization of these resources. The methods and chemical parameters chosen by Williamson are proper, and a geographical extension of this study design should be undertaken. While it is important that springs, seeps, and waterpockets throughout Glen Canyon National Recreation Area be inventoried and that this inventory be periodically updated, priority should be given to those areas most likely to be influenced by mineral development (e.g. tar sands areas).

At least one new spring has been identified in the river corridor below the Glen Canyon Dam since the filling of Lake Powell (Larry Belli, NPS, personal communication). As mentioned before, this and other yet unidentified springs may have resulted from ground-water flow around the dam induced by the increased hydraulic head of the lake. A cooperative investigation between the Bureau of Reclamation and the National Park Service is recommended in order to identify and quantify discharge from the springs and to establish an ecological monitoring effort for assessing biological changes that may result from these springs.

A third effort deserving consideration is a biological inventory of the springs, seeps, and waterpockets in Glen Canyon National Recreation Area. Williamson (in preparation) includes a vegetation inventory for each of the springs and seeps she studied. However, an inventory of invertebrate and vertebrate aquatic life would be useful for interpretive as well as resource

management activities.

Costs for the completion of spring, seep, and waterpocket inventories would depend upon both the study design and the geographical area to be covered. While an accurate total cost estimate would require more information than is presently available, significant continuing progress probably could be made on this issue for a cost of \$6000 - \$8000 per year if the work could be conducted as a graduate training program with a local university.

Water Quality Impact of Tar Sands Development

Tar sand development in areas within and adjacent to Glen Canyon National Recreation Area could potentially affect the quality and quantity of surface and ground waters. Cleave et al. (1980) have suggested that leachate from spent oil shale piles in the vicinity of Glen Canyon National Recreation Area could contaminate local water resources by increasing salinity as well as increasing the risk of contamination by both organic compounds and heavy metals.

In an assessment of monitoring needs, Flug (1985) suggested the implementation of an 11-station monitoring program in order to evaluate the impact of tar sand development on water resources in Glen Canyon National Recreation Area. While station-siting criteria and parameter selection in this design are appropriate, program implementation is likely to be expensive.

A similar approach in baseline water quality monitoring in areas of surface coal mine development has been adopted by the State of Colorado (1982). In the Colorado program, monitoring

costs are the responsibility of the mine developer. Suggested parameters for water quality monitoring activities required in response to tar sand development are presented in Table 9 (surface-water resources) and Table 10 (ground-water resources). The recommendations of both Flug (1985) and the State of Colorado (1982) were utilized in compiling these tables.

Table 11 lists analytical costs associated with implementing the tar sands monitoring recommendation. Implementation costs for water quality monitoring associated with a particular tar sand development plan would depend upon site-specific design criteria. However, it is not unreasonable to expect that initial monitoring well and platform installation would be costly and the annual recurring labor and analytical costs significant. Because of the high costs of baseline monitoring required at each operation, it is recommended that NPS require this monitoring to be done by the operator of any mineral development.

Power Plant and Uranium Mine Waste Disposal

In 1980, the electric power industry in the U.S. produced more than 75 million tons of solid wastes from coal-fired generation stations (EPRI, 1981). Included in these wastes are vast quantities of flue gas-desulfurization wastes, fly ash, bottom ash, and other combustion products that are often treated, stored, and disposed of on-site and close to the generating facility.

The Salt River Project Agricultural and Improvement District (SRP) operates the 2250 megawatt Navajo Generating Station just east of Page, Arizona. Ash emissions from the plant are

Table 9. Suggested surface water quality monitoring program for streams, springs, and seeps located in the vicinity of tar sands development (adapted from Flug, 1985 and State of Colorado, 1982).

Field measurements

flow	pH
specific conductance	water temperature
dissolved oxygen ¹	

Chemical constituents²

total suspended solids	chloride
total dissolved solids	magnesium
oil and grease	total nitrogen
dissolved organic carbon (DOC)	nitrogen composition ⁴
DOC analysis by fraction ³	total phosphorus
alkalinity	sulfate
sodium	boron
calcium	fluoride

Suggested metals package^{2 5}

aluminum	manganese
arsenic ⁶	molybdenum
cadmium	mercury ⁶
copper	selenium
iron	zinc
lead ⁶	

Frequency

1. Perennial streams⁷
 - a. Measure field water quality parameters monthly.
 - b. Sample water for complete chemical analysis quarterly, especially during high and low flow periods. Record flow at time of sampling.
 - c. Install a continuous recording device to monitor flow. Report monthly minimum, maximum, and mean flows.
2. Intermittent streams
 - a. Sample frequency will be figured on an individual basis. Consult the Water Resources Division before initiating baseline studies. Record flow at time of sampling.
 - b. Determine duration of flow season and seasonal peak flow.

Table 9. Continued.

3. Springs and seeps

- a. Measure field water-quality parameters monthly (pH, conductivity, and temperature). Record flow at time of sampling.
 - b. Sample water for complete chemical analysis quarterly. Record flow at time of sampling.
-

¹Not needed for springs and seeps.

²Dissolved concentration preferred (when applicable).

³Infrequent fraction analysis to determine carbon make-up.

⁴Initial separation of nitrogen compounds to determine make-up, i.e., ammonia (NH₃) and other organics versus NO₂ and NO₃.

⁵Generally an ICP lab package is most economical for metals analysis and includes a varying list of elements, from one lab to another. This list is a typical example and costs from \$40 to \$75; other individual laboratory procedures are acceptable but probably cost much more.

⁶Separate sampling also suggested to achieve necessary detection limits at a cost of about \$20 each.

⁷Monitoring locations will be dealt with on an individual basis.

Table 10. Suggested ground water quality monitoring program for aquifer sites located in the vicinity of tar sands development (adapted from State of Colorado, 1982, and Flug, 1985).

Parameters¹

water temperature	ammonia
specific conductance	nitrate-nitrite
pH	phosphate
total dissolved solids	arsenic
calcium	cadmium
sodium	iron
magnesium	manganese
alkalinity	mercury
chloride	selenium
dissolved organic carbon (DOC)	sulfate
DOC analysis by fraction ²	zinc

Frequency

Measure field water quality parameters (water temperature, pH, and specific conductance) monthly. Record elevation of water level in the well at the time of sampling. Sample water for complete chemical analysis two times per year.

¹Dissolved species preferred (when applicable).

²Infrequent fraction analysis to determine carbon make-up.

Table 11. USGS analytical laboratory costs for surface- and ground-water monitoring constituents associated with tar sands development (USGS, 1985).

Inorganic analysis

sodium	\$ 4.80	aluminum	\$10.65
calcium	5.75	arsenic	20.60
magnesium	5.75	mercury	20.60
alkalinity	5.00	selenium	20.60
chloride	4.15	nitrogen, ammonia	4.80
sulfate	7.10	nitrogen, ammonia and organic	12.60
fluoride	7.40	nitrogen, nitrate and nitrite	7.50
boron	10.90	total phosphorus	13.45
total suspended solids	12.60	ICP metals package including:	
total dissolved solids	12.60	cadmium, copper, iron, lead, manganese, molybdenum, selenium, and zinc	72.35

Organic analysis

dissolved organic carbon	\$31.25
DOC by fraction *	
oil and grease	34.20

*Organic analysis by fraction will depend on the composition of the organics in the tar sand. Assuming no knowledge, an initial full scan would cost \$508. With information available, these costs could be reduced.

controlled by means of electrostatic precipitators, and dewatered bottom ash slurry is trucked from the plant to a disposal area approximately 3.5 miles east of the plant. The disposal area is located in an ephemeral tributary to Lake Powell. In addition, the Navajo Power Plant maintains a number of cooling water ponds in close proximity to the facility.

Approximately 65 ground-water wells are periodically sampled by the staff of the Salt River Project at the Navajo Generating Station (R. Candelaria, SRP, personal communication). The majority of these wells are shallow (less than 100 feet) and do not reach regional ground water. These wells are monitored for moisture on a schedule that has varied from monthly to quarterly for the purpose of locating any areas that may contain a perched water table. Three deep wells (1200-1500 feet) intersect the Navajo Aquifer. These are sampled quarterly for water-level elevation and chemical quality including specific conductance, total dissolved solids, major cations, and major anions (L. Watts, SRP, personal communication). Approximately 15-16 of the wells are in the vicinity of the ash disposal area, and four are designated for quarterly chemical water-quality monitoring. However, water has never been found in these wells (L. Watts, SRP, personal communication).

Data from the Salt River Project monitoring program have not been made available to the National Park Service. However, the study design presently utilized may not be optimal for providing an "early warning system" for leachate escaping from disposal containment facilities. A more effective monitoring program should be considered in which pressure vacuum lysimeters are

utilized to monitor fluid movement in the unsaturated zone. The advantages and design suggestions for this type of study are discussed in EPRI (1981).

Thus far, the primary focus of the Salt River Project ground water quality monitoring has been on dissolved salts. While these are important, potential contamination from a number of trace elements associated with coal-fired power plant wastes (EPRI, 1981) should not be ignored. A recommended list of chemical constituents that should be included in the ground-water program at the Navajo Power Plant is presented in Table 12.

It is strongly recommended that a cooperative program be initiated between the National Park Service and the Salt River Project to review the present ground-water monitoring program. Data already obtained by the SRP could be used to evaluate the present study design and, if appropriate, modifications to the present program considered.

Plateau Resources Limited has developed a uranium mining and milling operation approximately 10 miles north of Bullfrog at Ticaboo, Utah. Uranium mine waste and mill tailings have been stored adjacent to Shootering Creek, a tributary of Hansen Creek which flows into Lake Powell just north of Bullfrog. The draft environmental statement for the project (NRC, 1979) provides background information regarding surface-water quality in Hansen and Shootering Creek, and ground-water quality in the vicinity of the mine. Sizeable clay-lined mine dewatering and mill tailing ponds have been developed. Since these are total containment ponds relying on evaporation for water removal, discharge

Table 12. Recommended chemical constituents for a ground-water monitoring program at coal-fired power plants.

water temperature	trace elements:
specific conductance	arsenic
total solids	lead
total dissolved solids	molybdenum
nitrate	barium
ammonia	boron
major cations:	chromium
sodium	zinc
calcium	selenium
magnesium	major anions:
potassium	alkalinity
	chloride
	sulfate

permits have not been required (Utah Bureau of Water Pollution Control, personal communication). However, an evaluation should be undertaken to determine the hydrologic conditions during which these ponds could overflow because of an extreme rainfall event.

The mining and milling operations have been closed down due to the current depressed state of the uranium industry. Plateau Resources, however, did continue to keep the mine dewatered, at least until the middle of 1985.

It is recommended that liaison be developed between NPS and the Utah Bureau of Water Pollution Control so that Glen Canyon National Recreation Area would receive copies of semi-annual operations reports submitted by Plateau Resources to the state. This would help assure that the Glen Canyon National Recreation Area's hydrologic monitoring activities could be modified to address hydrologic concerns associated with the uranium mining and milling operations, should they once again become active.

Water Contamination by Grazing Activities

Cattle that are grazing in an arid environment will have a tendency to congregate in the vicinity of natural or man-made water sources. Heavy use of natural springs, seeps, and waterpockets by range cattle may result in the damage of fragile vegetation and the bacterial contamination of the water source. Kunkle (1979) utilized fecal coliform bacteria, total coliform bacteria, and fecal streptococcus bacteria in order to monitor the influences of cattle wastes on water quality.

The influence of cattle grazing upon the natural resources of Glen Canyon National Recreation Area is most properly a range

management issue. However, a comparison of bacterial contamination in springs, seeps, and waterpockets on heavily used cattle range versus control sites would complement any range management research. This type of reconnaissance activity could be implemented by monitoring fecal coliform bacteria, total coliform bacteria, and fecal streptococcus bacteria concentrations from range and control sites on a regular basis for one year. By selecting sites in one geographical area, each survey could probably be conducted in one day's time if adequate facilities are developed within Glen Canyon National Recreation Area for bacterial analysis. In addition to the bacterial analysis, water temperature, specific conductance, and turbidity should also be measured.

CONCLUSIONS

With the few exceptions already noted, the present quality of the water resources in Glen Canyon National Recreation Area is generally good. However, changes in water management practices in the upper Colorado River basin, increased mineral development in or adjacent to Glen Canyon National Recreation Area, or increased grazing activities in the vicinity of springs, seeps, and waterpockets could all adversely influence the present situation.

Although it exhibits good water quality overall, Lake Powell frequently exceeds primary contact recreation standards for bacterial contamination at popular swimming areas. Additionally, the lake serves as a sink for both nutrients and naturally eroding heavy metals. Some of the heavy metals appear to be incorporated into the food chain and are bioaccumulating in species near the top of the trophic structure. The rapid depletion of nutrients available for primary productivity is well documented, but the impact of long-term fisheries management is not understood. Baseline monitoring activities related to lake water management being conducted by the Bureau of Reclamation, the U.S. Geological Survey, and the Utah Division of Wildlife Resources will yield much useful data. Still, information linking nutrient dynamics to productivity and fisheries management is limited, and one of the recommended study designs should be implemented.

Similarly, backcountry recreational waters occasionally exceed contact recreation standards, and the water must be treated prior to consumption. For these waters also, an additional short-term study may be warranted. Of the special resource management issues discussed, several require further assessment and the establishment of a more thorough data base.

Because of the potential for adverse water quality impacts and the need for additional data on some existing problems, proper management of Glen Canyon National Recreation Area's water resources dictates the consideration and implementation of a number of water quality related studies and monitoring programs as part of research, resource management, and public health monitoring activities. Recommended activities include:

- continued liaison among the Bureau of Reclamation, U.S. Geological Survey, and Glen Canyon National Recreation Area to discuss any changes in the long-term lake water quality or major tributary monitoring program.
- implementation of a cooperative study sponsored by the Bureau of Reclamation, Glen Canyon National Recreation Area, and the Utah Division of Wildlife Resources to obtain data relating to Lake Powell primary and secondary productivity and the relationship between nutrient input and fisheries management.
- development of a routine bacterial water quality monitoring program focused on shoreline contact recreation.
- implementation of a limited duration reconnaissance assessment of backcountry bacterial water quality and gray water contamination.
- establishment of liaison with the U.S. Fish and Wildlife Service's resource contaminant specialists (Arizona and Utah) to assure the continuation of effective heavy metal and pesticide contaminant monitoring activities.
- development and sponsorship of proposals for the continued assessment and inventory of waterpockets, springs, and seeps, and of fisheries habitat of significant minor tributaries.

- establishment of liasion with the Salt River Project and Utah Bureau of Water Pollution Control to discuss monitoring activities related to power plant waste disposal and mining and milling activities.

A phased approach to the activities recommended in this report could yield important information in the next five years which may prove invaluable in management decision-making.

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