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bacterial contamination of lake powell waters: an assessment of the problem

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BACTERIAL CONTAMINATION OF LAKE POWELL WATERS: AN ASSESSMENT OF THE PROBLEM

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LAKE POWELL RESEARCH PROJECT

The Lake Powell Research Project (formally known as Collaborative Research on Assessment of Man's Activities in the Lake Powell Region) is a consortium of university groups funded by the Division of Advanced Environmental Research and Technology in RANN (Research Applied to National Needs) in the National Science Foundation.

Researchers in the consortium bring a wide range of expertise in natural and social sciences to bear on the general problem of the effects and ramifications of water resource management in the Lake Powell region. The region currently is experiencing converging demands for water and energy resource development, preservation of nationally unique scenic features, expansion of recreation facilities, and economic growth and modernization in previously isolated rural areas.

The Project comprises interdisciplinary studies centered on the following topics: (1) level and distribution of income and wealth generated by resources development; (2) institutional framework for environmental assessment and planning; (3) institutional decision-making and resource allocation; (4) implications for federal Indian policies of accelerated economic development of the Navajo Indian Reservation; (5) impact of development on demographic structure; (6) consumptive water use in the Upper Colorado River Basin; (7) prediction of future significant changes in the Lake Powell ecosystem; (8) recreational carrying capacity and utilization of the Glen Canyon National Recreational Area; (9) impact of energy development around Lake Powell; and (10) consequences of variability in the lake level of Lake Powell.

One of the major missions of RANN projects is to communicate research results directly to user groups of the region, which include government agencies, Native American Tribes, legislative bodies, and interested civic groups. The Lake Powell Research Project Bulletins are intended to make timely research results readily accessible to user Groups. The Bulletins supplement technical articles published by Project members in scholarly journals.

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ABSTRACT

The results of analyses for total coliform, fecal coliform, fecal streptococci, and Salmonella lead to the conclusion that Lake Powell waters are not safe to drink, but are safe for body-contact recreational use. A linear regression model for estimating safe and hazardous water conditions is presented.

BACTERIAL CONTAMINATION OF LAKE POWELL WATERS: AN ASSESSMENT OF THE PROBLEM

INTRODUCTION

The presence of fecal bacteria in recreational waters is of serious concern to individuals participating in water-oriented activities because of the possibility of health hazards being imparted. Monitoring the levels of various fecal group contaminants in natural waters provides a basis for determining the suitability of those waters for use by man as drinking, contact, or non-contact sources.

Lake Powell, a reservoir on the Colorado River, is the major focus of activity in the Glen Canyon National Recreation Area and has been examined for bacterial contamination on several occasions since it began filling behind Glen Canyon Dam in 1963. The Colorado River, on which the reservoir is located, also has been examined both above Lake Powell and below the dam.

An investigation made by Walther (1971) between 17 August 1970 and 15 August 1971 at 15 widely scattered locations in an area extending from below Bass Rapids, in Grand Canyon, through Lake Powell and up to the Animas River (north of Durango, Colorado) provided evidence of fecal contamination in that area. A pertinent conclusion from this report is that "...the National Park Service sewage treatment facility at Rainbow Bridge Marina is not releasing appreciable numbers of viable coliform organisms (based on total coliform determinations)...the community at Hall's Crossing may be an appreciable source of coliform." Walther's data are presented in Table 1 and should be evaluated in regard to the U.S. Public Health Service (USPHS) recommendation of remedial action when three or more sample tubes are found to have a positive confirmation of coliform bacteria and when the most probable number (MPN) per 100 milliliters equals or exceeds 9.2 (Department of Health, Education and Welfare, 1962). Examination of these data indicates that only two locations on Lake Powell had water which was safe to drink. Most sites registered 9.2 or higher.

Another event that focuses attention on possible water quality problems at Lake Powell and vicinity is the finding of Shigella sonni in the stools of raft passengers below Lake Powell and the finding of "...coliform contamination...at high levels at many locations along the river and in most of the major tributaries: the water was found to be unsafe for drinking purposes" (Department of Health, Education and Welfare, 1972). These observations resulted from an inquiry into outbreaks of dysentary in boatmen and passengers that occurred between 23 May and 31 July 1972. The region in question includes Lee's Ferry, Arizona (28 kilometers below Lake Powell) to Temple Bar Marina on Lake Mead. This health problem may have been due to the improper handling of food and water supplies rather than to contaminated drinking water from the river.

Slawson and Everett (1974) investigated total and fecal coliform and fecal streptococcus levels in areas of the Grand Canyon during the summer of 1972 and found total coliform levels of 900 and 3,560 at Lee's Ferry.

Table 1: Coliform Concentrations in the Colorado River System Based on the Most Probable Number (MPN) Total Coliform Test Procedure

Location	Date	Total Coliform Concentration (MPN) per 100 Milliliters of Water
Colorado River below Bass Rapids	17 Aug 70	>16
Bright Angel Creek at Colorado River	22 Nov 70	920
Little Colorado River at Grand Falls	15 Aug 71	>1600
Colorado River above Paria River	13 Mar 71	>1600
Colorado River above Lee's Ferry	1 Nov 70	>1600
Lake Powell at Wahweap Marina	13 Mar 71	>16
Lake Powell between Gunsight and Tower Buttes	13 Mar 71	5.1
Lake Powell near Forbidden Canyon	13 Mar 71	16
Lake Powell at Rainbow Bridge Marina	13 Mar 71	5.1
Spring under Rainbow Bridge	13 Mar 71	>16
Bridge Creek above Rainbow Bridge	13 Mar 71	9.2
San Juan River at Route 666	27 Sep 70	>1600
Lake Powell at Hall's Crossing Ramp	19 Dec 70	>160
Animas River south of Durango, Colorado	7 Oct 70	>1600
Animas River north of Durango, Colorado	7 Oct 70	16<C<220

Source: Walther, 1971

There still is no really definitive conclusion concerning the seriousness and sources of bacterial contamination in Lake Powell and in the greater Grand Canyon area.

The purpose of this Bulletin is to attempt to define whether a bacterial contamination problem exists at Lake Powell, and if one is found to exist, to identify probable sources of the contamination. The benefit of this investigation is that it provides direction for management of reservoir water quality.

MEANING OF TESTS AND STANDARDS

Each type of bacterial test has a specific purpose, limitation, and strength of inference. It is important to understand what types of organisms constitute the coliform group, which are of sanitary significance, and what the different tests actually measure. The coliform group includes forms such as Escherichia, Aerobacter, Enterobacter, Serratia, Salmonella, Shigella, Klebsiella, and Aeromonas. The presence of coliform bacteria may indicate fecal contamination (either human or animal)

of water. Humans could become infected by ingesting such water. Intestinal diseases in man are commonly caused by Salmonella or Shigella, which are transmitted primarily by fecal contamination of water, food, and milk (Stainer et al., 1963). An idea of typical symptom severity is indicated in Table 2 which lists symptoms experienced in 1972 by passengers on the Colorado River below Lake Powell.

Bacteriologists commonly rely on a general test which measures total coliform present in the sample. Included in this test is detection of fecal coliform organisms as well as other types of coliform, such as Escherichia coli which is of little sanitary significance, and some non-fecal forms. The assumption made is that the general test--total coliform--reflects fecal contamination. In order to prove that there is fecal contamination, a more specific test for fecal coliform must be made. The presence of fecal coliform and other fecal forms (such as fecal streptococci) does not necessarily indicate that pathogenic forms are present. A positive fecal coliform test only confirms that fecal pollution is occurring. In summary, "coliforms in a water sample are considered indicators of the possible presence of pathogenic Enterobacteriaceae (Salmonella and Shigella) plus other enteric pathogenic bacteria and enteric viruses" (Millipore Corp., 1972).

A common misconception is that fecal coliforms only represent a potential danger

Table 2: Symptoms of 115 Ill Passengers on 13 Colorado River Trips Taken During May through July 1972

Symptom	Number	Percent
Diarrhea	105	91
Weakness	82	71
Abdominal Pain	74	64
Fever	65	57
Chills	64	57
Tenesmus	60	54
Nausea	54	47
Headache	49	43
Vomiting	24	21
Mucous in Stool	22	19
Blood in Stool	13	11
Mucous in Blood in Stool	9	8

Source: Department of Health, Education and Welfare, 1972

when they come from human feces. This idea has led to proposals that concern should be limited only to fecal contamination from humans. However, these proposals are invalid because pathogens harmful to man can come from animals as well (Geldreich, 1970).

Coliform values already cited for Lake Powell and the Colorado River system only suggest the possibility that pathogens are present. The pertinent point is to discuss whether the levels recorded imply a high probability of the presence of pathogens.

In Table 3 are summarized the types of tests, inferences, and/or tentative standards that have been suggested for determining safe bacterial levels. Although the state-of-the-art concerning such standards is still under debate, much evidence is available to support their validity, and they can serve as general guidelines for decision-making.

DESCRIPTION OF THE LAKE POWELL RESERVOIR

Glen Canyon Dam was built on the Colorado River near Page, Arizona, by the Bureau of Reclamation, between 1956 and 1963. Lake Powell, which formed behind the dam, is part of the Colorado River Storage Project and is located on the Arizona-Utah border approximately 190 kilometers north of

Table 3: Tentative Standards for Bacterial Levels

Test	Acceptable Levels		Inference
	Drinking Water	Recreational Body Contact	
Total Coliform	1/100 milliliter[a] average monthly count	50-3000/100 milliliters[b] safe bathing areas 1,000/100 milliliters[a] mean monthly density	Fecal contamination possible; pathogens may be present
Fecal Coliform	None	200/100 milliliters[a]; not more than 10 percent of total samples in a 30-day period exceed 400/100 milliliters	Warm-blooded animal fecal contamination; pathogens may be present
Fecal Streptococcus	None	>100/100 milliliters[b]	Fecal contamination, absence suggests little or no warm-blooded animal contamination; pathogens could be present
Salmonella	None	None	Direct health hazard

[a] McKee and Wolf (1963)
[b] Geldreich (1970)

Flagstaff and 8 kilometers northwest of Page, Arizona. It is a multiple-use impoundment with power generation and recreation being of major importance. Recreation activities presently are concentrated at the lower end of the reservoir; however, marinas are located at approximately 80-kilometer intervals along the shoreline, and these areas are heavily used during the summer months (June to October). Total visitations at Wahweap Bay (near Page, Arizona) far exceed visitations at locations further up the reservoir (see Table 4). Wahweap Bay also received the heaviest use of all areas, as evidenced by the special categories listed in Table 5.

Table 4: Total Visitations During 1973 at Specific Areas of Lake Powell

Location	Total Visits
Wahweap Bay	436,796
Bullfrog Bay	58,644
Hall's Crossing	12,686
Hite	12,070

Source: National Park Service, 1974

Soils in the area surrounding the reservoir are derived from sandstone and are of such quality that the land is relatively barren of vegetation. Both wind and water erosion have played a significant role in the development of the surrounding landscape, which includes dissected canyons, sandstone arches, mesas, and buttes. Strong winds are common from February to May, while gusty winds and rain storms of short duration are common in the summer. Calm days are characteristic from September to February.

When filled, Lake Powell will be 300 kilometers long with a shoreline of 3,155 kilometers. Maximum water storage capacity will be $33,304.5 \times 10^6$ cubic meters at 1,128 meters in elevation. This elevation has not been attained during the study period of this Bulletin, but ranged from 1,095 meters in April to 1,111 meters in August.

Table 5: Special-Use Categories by Area at Lake Powell During August 1971 (Information in Terms of Visitation Records)

Location	Boat-Days	Fishermen	Beach	Campground	Remote Camping	Picnickers
Wahweap Bay	8,788	10,123	12,270	23,533	25,924	1,600
Hall's Crossing	542	501	NA[a]	870	848	NA
Bullfrog Bay	3,907	1,836	411	2,372	3,539	1,145
Hite	94	160	NA	913	27	NA

[a]Data not available

Source: National Park Service, 1971

In Table 6 are summarized various water quality parameters. On the basis of the primary productivity values, the reservoir has been classified as mesotrophic. Wetzel (1975) has categorized lakes having mean daily productions of about 250 to 1,000 milligrams of carbon-12 per square meter as mesotrophic. Annual means observed at Lake Powell generally fall within this range.

METHODS

Total Coliform

Water samples were taken from the surface and were processed according to the Millipore recommended procedure described in Circular MRP-3 (Millipore Corp., 1967). Colonies on the filter were ennumerated, and counts of organisms were expressed as coliform organisms per 100 milliliters of lake water.

In those cases where colonies were too dense for convenient counting, an estimation procedure was used. The estimation formula was derived by computing an expansion factor:

$$\text{Constant} = \frac{\text{Total Usable Filter Surface Area}}{\text{Surface Area Counted}}$$

For example, the area of usable filter surface was 690.927 square millimeters. Eight grid blocks in the center of the filter had an area of 85.543 square millimeters; this yielded a constant of 8.077. The number of colonies in eight consecutive grids were counted and multiplied by the constant which gives an estimate of the number of colonies on the filter. This value was multiplied by the dilution factor used, usually 4 (25 milliliters of filtered lake water) to give the number of organisms per 100 milliliters of water.

Fecal Streptococci

Water samples taken from the surface were filtered and cultured according to Millipore Corp. Application Manual AM 302. Typical fecal streptococcus colonies were enumerated, and results were expressed as organisms per 100 milliliters of water.

Fecal Coliform

Aliquots of surface water were filtered and processed according to Millipore Corp. Application Manual AM 302. Results were expressed as organisms per 100 milliliters of water.

Salmonella

During the bacterial investigation of 1973, surface water samples were collected and refrigerated, and were transported to the University of New Mexico at Albuquerque. The water was transported in tetrathionate broth. Samples were incubated for 12 to 24 hours and then aliquots were streaked on bismuth sulfite agar, Salmonella-Shigella agar, and xylos lysine decarboxycholate (XLD) agar. These plates were incubated for 24 hours at 37°C. Suspected Salmonella colonies were then subcultured on lysine decarboxylase slants, CTA Mannitol agar, dulcitol fermentation agar, and TSI slants. Suspected colonies only confirmed the possibility of Salmonella being present (presumptive test). No confirmed tests were made.

In the summer of 1974, tampons were placed in the water at various lake sites, were collected after 5 days, and then were placed in jars containing tetrathionate broth. They were incubated for 2 days at 37° C. Aliquots were streaked on BS agar. Suspected colonies were subcultured on TSI and LIA tube slants. These tubes were

Table 6: Annual Grand Means of Selected Parameters for Each Collecting Site at Lake Powell (At each site a mean was computed for data collected at each depth--usually the surface, 1, 2, 6, and 8 meters--and then a grand mean was calculated for each site.)

	Sites								
	1	2	3	4	5	6	7	8	9
Distance Above the Dam (Kilometers)	5.4	4.8	0.1	20.9	80	92.8	142.4	152	224
Specific Conductance (Microhos per Centimeter at 25°C)	810.00	828.00	837.00	838.00	702.00	608.00	616.00	634.00	628.00
pH	8.23	8.26	8.16	8.27	8.34	8.37	8.11	8.16	8.09
Turbidity (JTU)	13.73	10.83	6.64	7.99	9.12	10.74	20.97	26.65	98.99
Temperature (°C)	19.60	19.60	17.90	19.80	19.50	20.00	19.70	19.30	21.90
Dissolved Carbon (Milligrams per Liter)	28.17	28.90	29.89	29.04	29.00	27.51	28.50	28.32	30.73
Primary Productivity (Milligrams of Carbon-12 per Square Meter per Day)	374.00	590.00	535.00	506.00	626.00	640.00	621.00	508.00	717.00
Zooplankton Density (Individuals per Liter)	719.00	799.00	710.00	733.00	1118.00	1173.00	1704.00	2068.00	2988.00
Phytoplankton Density (Individuals per Milliliter)	1599.00	1769.00	1483.00	1200.00	1832.00	2669.00	2638.00	2738.00	1858.00

delivered to the New Mexico State Health Laboratory for final identification of bacteria on the tube slants. Two water samples were used for all determinations except Salmonella and the total coliform work during the 1972-1973 period.

RESULTS AND DISCUSSION

The first question addressed by the research in this Bulletin is whether fecal contamination of Lake Powell waters is a significant problem.

From August 1972 through July 1973 nine main channel sites (see Figure 1) were sampled for total coliform. As shown in Table 7, all counts were found to exceed the drinking water standard of 1 total coliform per 100 milliliters of surface water. Using a range count of 50 to 3,000 total coliform per 100 milliliters as a safe condition of water for body contact, only 6 percent of the 1972-1973 observations were found to exceed the acceptable maximum of 3,000 per 100 milliliters. However, using an alternate general criterion of 1,000 total coliform per 100 milliliters of surface water, 20 percent of the observations were found to exceed the standard. Sites of particular man-impact are Site 1 (near the Wahweap Swimming Beach), Site 2 (near the Wahweap Marina), Site 5 (at the sewage

Table 7: Observed Total Coliform (Numerator) and Expected Fecal Coliform (Denominator) for Each Site, August 1972 through July 1973 (Counts are expressed as organisms per 100 Milliliters of lake water.)

Site	1972: Aug 1-4	Aug 7-10	Aug 14-17	Sept 11	Oct 9-12	Nov 6-9	Dec 4-7
1 Wahweap Swim Area	16/3	542/108	790/158	452/90	520/104	590/118	740/148
2 Wahweap Marina	80/16	1184/237	428/86	554/111	862/172	754/151	-
3 Dam	-	-	-	-	280/56	1222/244	-
4 Warm Creek	3292/658	712/142	130/26	366/73	244/49	578/116	646/129
5 Rainbow Marina	5640/1128	632/126	352/70	-	400/80	400/80	-
6 San Juan	88/18	664/133	380/76	-	290/58	400/80	-
7 Buoy 89	210/42	440/88	584/117	-	444/89	512/102	190/38
8 Buoy 95	204/41	774/155	332/66	-	320/64	322/64	360/72
9 Hite	524/105	124/25	924/185	-	546/109	472/94	410/82

discharge buoy in front of Rainbow Bridge Marina), and Site 7 (below Hall's Crossing-Bullfrog Marina centers).

In Table 8 are shown the annual median and range of total coliform counts for each sampling site on Lake Powell. The median total coliform counts at Sites 1 and 2 were higher than at any other site. Sites which might be expected to show higher counts if there were human impact in the area would be Sites 1, 2, 5, and 7. Median counts were found to be higher at Sites 1, 2, and 7 (located at Wahweap Swim Beach, Wahweap Marina, and below Hall's Crossing, respectively). The data suggest that human inputs of fecal material are occurring in the reservoir. Input of fecal material from animals does not seem to be a significant factor at any of the locations, since we have observed few livestock in the region.

The low median count at Site 5 (Rainbow Marina) suggests that the National Park Service (NPS) facility at this location is not allowing much fecal material to circulate into surface waters (the sewage discharge is on the lake bottom, at a depth of about 60 meters). This finding supports Walther's 1971 conclusion.

In view of the fact that a total coliform count only suggests the possibility of fecal contamination and the presence of pathogens, in January 1973 we began to monitor for Salmonella and fecal streptococci. We were unable to measure fecal coliform, but we did estimate its abundance based on the fact that 10 to 30 percent of total coliform is composed of fecal coliform. (A figure of 20 percent was used as an average.) The 10-to-30 percent range was derived from an investigation of concentrations in a stream below effluents

Table 7 (Continued)

1973: Site	Jan 1-4	Jan 29-31	Feb 26-28	Mar 26-27	Apr 23-26	May 21-24	Jun 4-7	Jun 18-21	Jul 2-5
1 Wahweap Swim Area	332/66	2680/536	4000/800	1936/387	994/199	668/134	1184/237	362/72	1536/307
2 Wahweap Marina	328/66	1650/330	1440/288	224/45	1366/273	800/160	-	592/118	1158/232
3 Dam	522/104	836/167	450/90	652/130	486/97	506/101	330/68	410/82	174/35
4 Warm Creek	-	200/40	508/102	-	390/78	190/38	216/43	270/54	1622/324
5 Rainbow Marina	944/189	320/64	3150/630	4300/860	106/21	28/6	24/5	206/41	310/62
6 San Juan	452/90	376/75	840/168	2476/495	112/22	34/7	726/145	102/20	828/166
7 Buoy 89	630/126	520/104	5000/1000	-	84/17	36/7	-	1740/348	782/156
8 Buoy 95	472/94	276/55	4200/840	-	1996/399	-	-	1572/314	1800/360
9 Hite	-	-	-	-	204/41	106/21	-	180/36	-

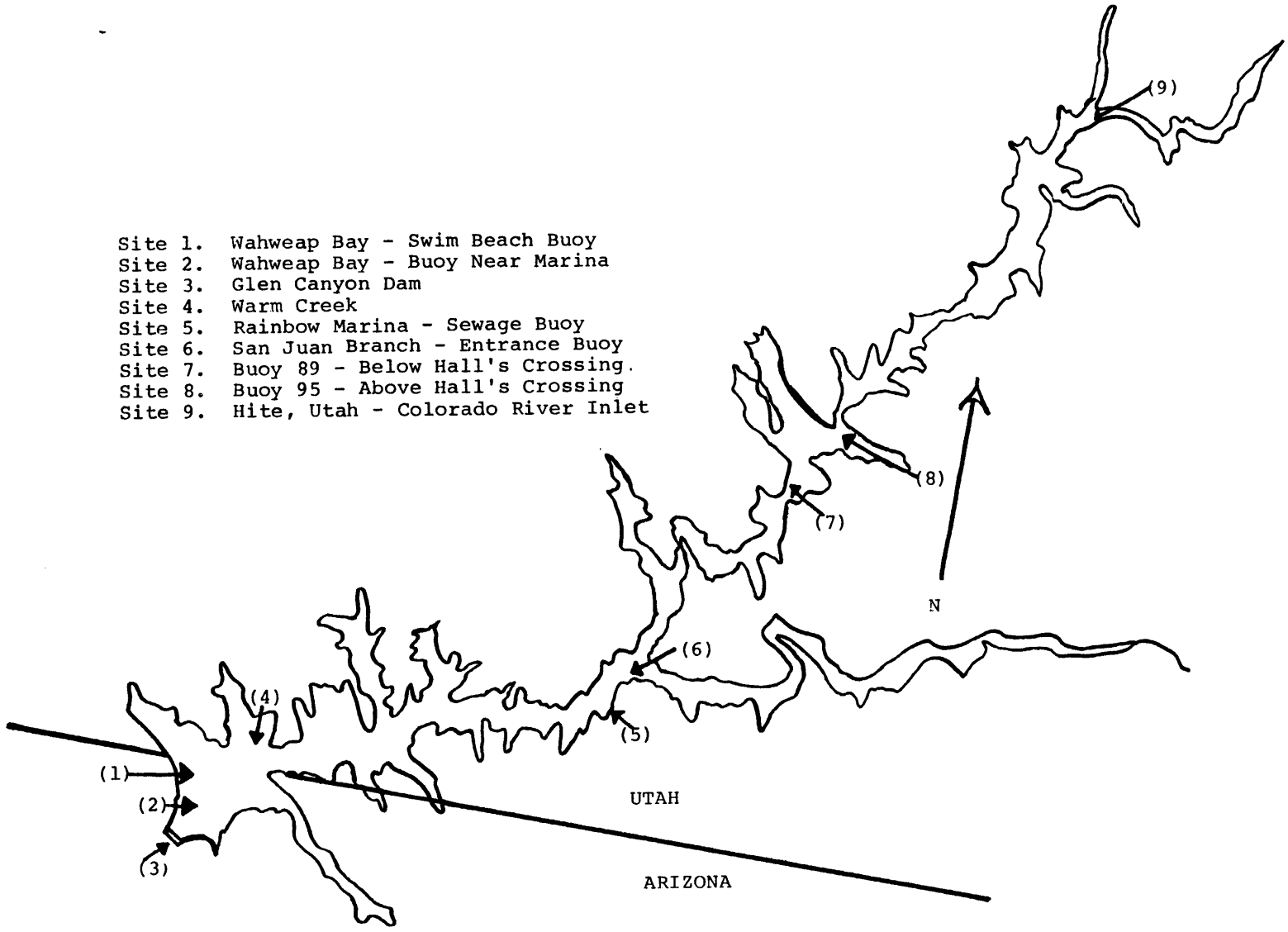

Figure 1: Location of Sampling Sites, 1972-1973.

Table 8: Annual Median and Range for Total Coliform Counts per 100 Milliliters of Surface Water at Lake Powell, 1972-1973.

Site	Number of Collections	Median	Range
1	16	704	16-4000
2	14	777	80-1650
3	11	486	174-1222
4	14	378	130-3292
5	14	376	24-5640
6	14	390	34-2476
7	13	512	36-5000
8	12	416	204-4200
9	9	412	106- 924

of raw sewage (Bullentine et al., in Geldreich, 1970). In Table 7 the estimated fecal coliform counts are indicated. Twenty-seven percent of these counts were found to be above the level of 200 fecal coliform per 100 milliliters of surface water. On an annual basis, the lake water was found to be safe for recreational body contact, but estimated fecal coliform counts were found to be relatively high (200 per 100 milliliters) at both Site 1 (Wahweap Swim Beach) and Site 2 (Wahweap Marina buoy) at times during the summer. It should be noted again that areas of human impact display more frequent occurrences of estimated higher fecal coliform counts than do more isolated areas. We suggest that the fecal coliform estimation method not be used as a standard procedure for assessing water quality at Lake Powell since it is based on the extreme condition of raw sewage effluents.

The potential problems in human impact areas become more evident when the presence of fecal streptococci (Table 9) in the reservoir is examined. Site 3 (Glen Canyon Dam) and Site 4 (Warm Creek) did not indicate the presence of fecal streptococci. These two sites are more remote from man's activities than are Sites 1 and 2 in Wahweap Bay. Presumption of the presence of Salmonella was detected at a few sites (Table 9) in the reservoir, and more frequently in the Wahweap Bay area.

Table 9: Presence of Fecal Streptococci (Numerator) and Salmonella (Denominator) Measured in Lake Powell from February to July 1973

Station	Feb 26-28	Mar 26-27	Apr 23-26	May 21-24	Jun 4-7	Jun 18-21	Jul 2-5
1			+ / —	+ / —	+ / +	+ / +	+ / +
2				+ / —	+ / —		+ / +
3							
4							
5				+ / —	+ / —		— / +
6					+ / —	+ / +	+ / +
7					+ / —	+ / —	
8							
9						+ / —	

Major conclusions from the 1972-1973 study were as follows:

- Water in the lake was not safe to drink.
- Waters were generally safe for human body contact.
- Wahweap Bay definitely was contaminated with fecal material from warm-blooded animals (probably humans) during the warmer months, coincident with higher recreational activity.
- There is a high probability that pathogens existed in the waters in the vicinity of the Wahweap Marina and swimming beach at certain times of the year. Salmonella (presumptive test) was isolated at certain sites, particularly in Wahweap Bay during the warmer months.

BACTERIAL INVESTIGATIONS, SUMMER 1974

The sampling process was increased during the summer of 1974 to include additional areas of high recreational use, while selected main channel sites were maintained for comparative purposes. Tests were made for Salmonella, total coliform, fecal coliform, and fecal streptococcus. The water level of the reservoir rose during the spring and summer of 1974, and we were interested to note whether inundating waters would bring more human fecal material from camping areas and more animal wastes (as evidenced by a comparison of 1973 and 1974 total coliform counts).

Total Coliform

Two total coliform surveys were made during the summer of 1974 (Table 10). At the first collection period, June 22-29, 84 percent of the counts were above the standard of 1,000 total coliform per 100 milliliters, and 58 percent were above the more liberal suggested standard of 3,000 per 100 milliliters. At the second collection period, July 10-14, 96 percent of the counts were above 1,000 per 100 milliliters and 61 percent were above 3,000 per 100 milliliters. Both standards indicated that the water was unsafe for human body contact at a substantial number of the sites examined.

To provide a little better grasp of the problem, the results of a USPHS investigation (McKee and Wolf, 1963) are presented. They found a significant increase in illness frequency among swimmers in the Ohio River when the median coliform density was 27,000 per 100 milliliters. Illnesses were of a gastrointestinal variety. Among swimmers, there were usually eye, ear, nose, and throat ailments as well as gastrointestinal disturbances. The median values of counts for the two sampling periods at Lake Powell were 3,780 and 7,430 respectively. Since these median values are considerably lower than the Ohio River example, the values for Lake Powell may indicate a less severe potential health problem.

When the data from both collecting periods were combined and evaluated (Table 11), some interesting relationships emerged. Higher median counts were found at the dockside discharge units and at the Wahweap swimming beach. When man-use impact areas such as marinas and the swimming beach were compared to mid-channel sites, which were the standards for comparison, the man-use impact areas clearly had higher median counts of total coliform. Some tributaries may be sources of unusual levels of coliform. Counts at Aztec Creek (near Rainbow Bridge), Hall's Creek, and Dirty Devel were high (Table 11).

Table 10: Total Coliform Counts per 100 Milliliters Surface Water at 32 Locations on Lake Powell

	June 22-29	July 10-14
Bridge, Colorado River	447	1,865
Site 9	3,425	1,200
Hite Dockside Discharge	10,500	
Hite Marina Store		9,100
Dirty Devil River	5,040	8,239
Site 8	7,528	1,100
Site 7	2,617	8,885
Bullfrog Marina Store		1,512
Bullfrog Marina	8,174	2,085
Bullfrog Dockside Discharge	13,117	6,353
Hall's Creek	2,084	1,732
Hall's Marina	9,175	
Hall's Marina (North)		1,465
Hall's Marina (South)		1,898
Hall's Dockside Discharge		2,664
Hall's Drinking Water		110
Site 6	3,780	4,800
Aztec Creek		6,620
Rainbow Marina		8,970
Escalante		1,900
Site 4		13,080
Site 3	540	12,500
Site 2	1,600	16,230
Site 1	1,140	
Wahweap Marina (Southwest)	1,800	13,170
Wahweap Swim Beach (North)	5,815	22,530
Wahweap Swim Beach (South)	5,371	19,060
Wahweap Swim Beach (Middle)		20,270
Wahweap Marina (Northeast)	1,000	16,070
Wahweap Dockside Discharge	9,778	23,750
Wahweap Drainage Ditch		21,650

Table 11: Total Coliform Median and Range Statistics for Two Sampling Periods During the Summer of 1974 at Lake Powell

	Number of Collections	Median	Range
Tributaries	6	3,562	1,900- 8,239
Midchannel Sites	16	3,021	447-16,230
Midchannel Sites, Exclusive of Wahweap Bay	13	3,425	447-13,080
Marinas	12	5,130	1,000-16,070
Dockside Discharge Units	6	10,139	2,664-23,750
Marinas plus Dockside Discharge Units	18	8,572	1,000-23,750
Wahweap Swim Beach	5	19,060	5,371-22,530

The data gathered on total coliform indicated that bacterial contamination of the lake was greatest near marinas and swimming areas, i.e., from humans.

Additional problems were found in marina areas (Table 10). Drinking water at Hall's Crossing Marina was contaminated (110 total coliform per 100 milliliters), and a ditch near the Wahweap boat-launching ramp, which was draining into the lake, had a count of 21,650 total coliform per 100 milliliters of water. Counts at mid-channel sites were considerably higher than were counts for the same period in 1973.

Fecal Streptococci

Fecal streptococci counts generally supported the conclusion of fecal contamination in man-use impact areas (Table 12). All but one of the counts was below 100 fecal streptococci per 100 milliliters of water. Counts were very low at the mid-channel sites. Values at two sites are of special interest. During the regular sampling (July 9-14) no fecal streptococci were recorded at the Hall's Crossing discharge unit; however, we noted that the NPS emptied the unit and took a sample while pumping was in progress. A high count of 78 fecal streptococci was recorded. This may mean that these discharge units are more likely to pollute while they are being used or serviced. Leaks and flooding of the barge holding the unit were observed periodically during the summer. Other possible sources of contamination at the discharge units are hosing down of the dock and accidental releases while boats are discharging.

Fecal Coliform

Fecal coliform counts were all below a level of 200 per 100 milliliters (Table 12). On this basis we determined that

Table 12: Fecal Streptococcus (FS) and Fecal Coliform (FC) Counts per 100 Milliliters of Surface Water During the Summer of 1974 at Lake Powell

	June 9		June 20-29		July 9	
	FS	FC	FS	FC	FS	FC
Bridge, Colorado River			9	0	0	0
Site 9			3	0	1	0
Hite Dockside Discharge			5	8	2	0
Hite Marina Store			4	1	0	0
Dirty Devil River			2	0	0	0
Site 8	3	1	0		0	0
Site 7	0	0	0		0	0
Bullfrog Marina Store					1	
Bullfrog Marina Dock	66				1	
Bullfrog Dockside Discharge					1	2
Hall's Creek		11	35		0	0
Hall's Marina (North)					108	1
Hall's Marina (South)					0	0
Hall's Dockside Discharge	12	8	11		0	0
Hall's Dockside Discharge (special sample when NPS pumping out sewage)					78	2
Hall's Crossing Sign Buoy	3					
Site 6			1	2	0	0
Aztec Creek					0	0
Escalante					3	0
Site 5			32	70	2	4
Site 4					0	15
Site 3			1	23	0	0
Site 2			2	28	0	0
Site 1			1	12	0	0
Wahweap Marina (Southwest)			0	28	0	1
Wahweap Marina (Northeast)			11	22	1	1
Wahweap Swim Beach (North)			22	75	0	0
Wahweap Swim Beach (South)				33	1	4
Wahweap Swim Beach (Middle)			13	101	2	3
Wahweap Marina (Southeast)			1			
Wahweap Marina Store			97	96	2	0
Wahweap Dockside Discharge			40	TNTC[a]	3	0
Wahweap Drainage Ditch					8	63

[a]Too numerous to count

the reservoir waters are safe for body contact. At a level of about 200 fecal coliform per 100 milliliters there is an 80-percent chance of Salmonella being present (Geldreich, 1970). On the basis of these relatively low counts there is little probability of finding Salmonella. At no time in the summer of 1974 was the presence of Salmonella confirmed.

Although total coliform counts were generally above accepted standards, the fecal coliform test indicated that the reservoir waters may be safe for swimming. However, higher fecal coliform counts do occur in man-use impact areas. The drainage ditch at Wahweap did not have too high a fecal coliform count (it was 63 per 100 milliliters). Higher counts did occur at the Wahweap swimming beach and marina store during the June 20-28 sampling period.

Fecal Coliform - Fecal Streptococci Ratios (FC/FS)

Ratios of the various counts can be used to aid in interpretation of the source of bacterial contamination.

The following ratios have been suggested by Millipore Corp. (1972):

$\frac{FC}{FS} \geq 4.0$	Contamination from human wastes
$\frac{FC}{FS} \leq 0.7$	Contamination from livestock or poultry
$2 < \frac{FC}{FS} < 4$	Human wastes predominate
$0.7 < \frac{FC}{FS} < 1.0$	Animal wastes predominate
$1 \leq \frac{FC}{FS} \leq 2$	Uncertain interpretation

Examination of Table 13 indicates that most ratios reflect human contamination.

DETAILED ANALYSIS OF A REGION

In order to determine whether marina areas are likely sources of fecal contamination, a special sampling program was designed for the Hall's Crossing-Bullfrog area. Nine sites were selected for analysis on a 5-day basis at about the same time each day (Table 14). Surface water was analyzed for total and fecal coliform, fecal streptococci, and Salmonella.

Fifty-five percent of the values were found to exceed the standard of 1,000 total coliform per 100 milliliters, whereas 31 percent were found to exceed the more liberal standard of 3,000 per 100 milliliters. Fecal coliform and fecal streptococci values were generally found to be low. On the basis of these data we concluded that the water in Lake Powell is safe for human body contact. Mean values for total coliform (Table 14) were higher at some marina sites than at other sites. The two highest means were 8,946 at Bullfrog Marina dock and 8,946 at Hall's Crossing Marina dock. Some of the average marina values were below the two main channel sites. For example, the discharge units have lower mean values than did Site 8. There was no visual indication that discharge units were leaking fecal matter into the lake during this period although certainly boaters used the units during this period.

Fecal Coliform

Fifteen percent of the fecal coliform counts were found to exceed the suggested standard of 200 per 100 milliliters. The highest mean fecal coliform count (Table 15) was obtained at Hall's Crossing dock. Only one count at a discharge unit was high.

Table 13: Fecal Coliform (FC)/Fecal Streptococcus (FS) Ratios for a Variety of Sites at Lake Powell During the Summer of 1974

Location	Date	Ratio	Interpretation
Hite Discharge	Jun 8	1.6	Uncertain
Hite Marina Store	Jun 8	0.25	Animal contamination
Site 5	Jun	2.2	Human-predominately
Site 6	Jun	2	Human-predominately
Wahweap Marina (Northeast)	Jun	2	Human-predominately
Site 1	Jun	12	Human contamination
Site 2	Jun	14	Human contamination
Site 3	Jun	23	Human contamination
Swim Beach	Jun	3.4	Human-predominately
Swim Beach	Jun	7.8	Human contamination
Wahweap Marina Store	Jun	0.98	Animal contamination
Hite Discharge	Jul 9	0.80	Animal
Bullfrog Discharge	Jul	2	Human-predominately
Hall's Marina (North)	Jul	0.09	Animal
Site 5	Jul	2	Human-predominately
Wahweap Marina (Northeast)	Jul	1	Uncertain
Wahweap Swim Beach	Jul	1.5	Uncertain
Wahweap Swim Beach	Jul	4	Human
Special Sample	Jul	0.02	Animal
Wahweap Drainage Ditch	Jul	7.9	Human
Hall's Marina (South)	Aug 3	17	Human
Hall's Marina (North)	Aug 7	26	Human
Hall's Discharge	Aug 4	8	Human
Hall's Discharge	Aug 5	75	Human
Hall's Discharge	Aug 6	46	Human
Bullfrog Marina Store	Aug 3	11	Human
Bullfrog Marina Store	Aug 4	3.6	Human
Bullfrog Marina Store	Aug 5	7	Human
Bullfrog Marina Store	Aug 6	17	Human
Bullfrog Marina Store	Aug 7	4.6	Human
Bullfrog Marina Dock	Aug 4	15.5	Human
Bullfrog Marina Dock	Aug 5	80	Human
Bullfrog Discharge Unit	Aug 3	30	Human
Bullfrog Discharge	Aug 4	14.5	Human
Site 8	Aug 7	8	Human

Fecal Streptococci

Counts of fecal streptococci were very low at all sites. The highest count was 30 per 100 milliliters of surface water at the Bullfrog discharge unit on 6 August 1974. Fecal streptococci were detected only at marina sites.

Detailed analyses of this region over a 5-day period point up the great variability of bacterial counts. This variability makes it very difficult to set up standards. We feel that the previous investigations discussed in this Bulletin for Lake Powell and the Grand Canyon region cannot be used to make inferences about water quality because too few samples and collections were taken at too few points in time. The approach we used in this study at Hall's Crossing-Bullfrog Bay led to the conclusion that the water in Lake Powell is safe for human body contact. The small amounts of fecal contamination found to occur in the area most likely come from warm-blooded animals, probably humans. Activity at marina areas does contribute small amounts of fecal matter to the water.

Isolated Bacteria of Fecal Origin

Attempts by this study to isolate Salmonella from presumptive cultures have

Table 14: Total Coliform Counts for Nine Sites, August 3-6, 1974, in the Hall's Crossing-Bullfrog Bay Area at Lake Powell (Based on 100 Milliliters of Lake Water)

Site	Aug 3	Aug 4	Aug 5	Aug 6	$\bar{X}$[a]
Hall's Marina Dock, South End	5000	33	567	0	1400
Hall's Marina Dock, North End	1400	6000	133	TNTC[b]	7821
Hall's Discharge Unit	2200	1067	333	40	910
Bullfrog Marina Dock, Near Store	10166	1733	133	TNTC	8946
Bullfrog Marina Dock	5766	2067	500	0	2083
Bullfrog Discharge Unit	4033	2366	0	0	1600
Hall's Creek Confluence with Main Channel	3333	8333	2500	1000	3792
Site 7	1734	2266	267	500	1192
Site 8	4333	5799	0	0	2533

[a] Sample Mean

[b] Too numerous to count, used an estimated count of 23,700 for TNTC

resulted in confirmation of the presence of several other forms of bacteria known to be of fecal origin (Table 17). It would seem that the isolation of these bacteria at the sites listed in Table 17 indicates there is at least a potential health hazard associated with Lake Powell waters in certain instances. These bacteria are of fecal origin, and their presence supports the contention that fecal material reaches Lake Powell waters in the vicinity of marinas. None of the forms isolated indicate that the water is a direct health hazard. The presence of Salmonella in Lake Powell has not been confirmed.

PRELIMINARY MANAGEMENT MODEL

Management of the Glen Canyon region by government agencies has as one of its goals the preservation of water quality at Lake Powell. One part of this goal is the maintenance of safe water conditions for recreational purposes--boating, swimming, and other activities. The problem from the management aspect is that, with regard to bacterial problems, it is not practical to establish a laboratory with qualified technicians to perform the various specialized tests to determine whether the waters represent a direct health hazard.

Table 15: Fecal Coliform Counts for Nine Sites, August 3-7, 1974, in the Hall's Crossing-Bullfrog Bay Area at Lake Powell (Based on 100 Milliliters of Lake Water)

Site	Aug 3	Aug 4	Aug 5	Aug 6	Aug 7	$\bar{X}$[a]
Hall's Marina Dock, South End	109[b]	TNTC[c]	TNTC	6	18	227
Hall's Marina Dock, North End	14	0	350	1	18	77
Hall's Discharge Unit	20	6	53	64	76	44
Bullfrog Marina Dock, Near Store	85	31	15	24	10	33
Bullfrog Marina Dock	38	43	112	35	1	46
Bullfrog Discharge Unit	21	82	11	TNTC	0	123
Hall's Creek Confluence with Main Channel	0	0	0	18	0	4
Site 7	73	TNTC	0	210	78	172
Site 8	0	0	TNTC	0	6	101

[a]Sample Mean

[b]Average of five counts

[c]Too numerous to count, used an estimated count of 500 for TNTC

Therefore, an estimation of health risk is required. This estimation can be accomplished at the lake by using a model. The total coliform test is one which can be easily made at the lake by unskilled personnel. Once a mean total coliform value has been determined for an area such as at the Wahweap swimming beach during, say, a 1-week or 1-day period, then the potential health hazard can be assessed. This health potential may be evaluated by using the mean total coliform count to predict a particular level of fecal coliform. If the predicted fecal coliform level is 200 per 100 milliliters, then the water is a potential hazard because there is an 80-percent probability that Salmonella is present. The following model enables prediction of the fecal coliform level from mean total coliform count. The model is empirical and is derived from selected data obtained by this study during the summer of 1974. To enable complete validation, the model should be tested for the next two summers. Until this is accomplished the model must be considered provisional or preliminary.

Regression of fecal coliform counts on total coliform counts showed a product-moment correlation coefficient of 0.546, which is significant at the 0.05 critical value. The F-value for the regression is also significant ($F_{16,17} = 6.795$). Total coliform versus fecal coliform counts are graphed in Figure 2. A regression line was fitted to the data. A decision regarding the number of fecal coliform expected, given a particular total coliform value, can be determined from the graph.

Table 16: Fecal Streptococci Counts for Nine Sites, August 3-7, 1974, in the Hall's Crossing-Bullfrog Bay Area at Lake Powell (Based on 100 Milliliters of Lake Water)

Site	Aug 3	Aug 4	Aug 5	Aug 6	Aug 7	$\bar{X}^a$
Hall's Marina Dock, South End	6	0	0	0	0	1.2
Hall's Marina Dock, North End	0	0	0	0	1	0.2
Hall's Discharge Unit	0	1	1	1	0	0.6
Bullfrog Marina Dock, Near Store	8	8	2	1	2	4.2
Bullfrog Marina Dock	0	3	1	1	0	1.0
Bullfrog Discharge Unit	1	6	0	30	1	7.6
Hall's Creek Confluence with Main Channel	0	0	0	0	0	0
Site 7	0	0	0	0	0	0
Site 8	0	0	0	0	0	0

[a]Sample Mean

However, the predicted values for Y are subject to some uncertainty; therefore, confidence intervals have been fitted to the regression line. The basic computations for the regression line are given in Table 18. Details of the procedure and its following computations are given in Weber (1973). The regression line is used to predict a particular fecal coliform level (X) from the mean of a number of representative total coliform counts (Y) taken at a particular Lake Powell location. Confidence intervals about the line are a statement of the uncertainty of the total coliform count mean. The equation for computing these interval estimates is arrived at by computing the variance of deviations about the regression line:

$$S^2_{y \cdot x} = \frac{\Sigma Y^2 - CT_y - \frac{(\Sigma XY - CT_{xy})^2}{(\Sigma X^2 - CT_x)}}{N - 2}$$

The square root of the above statistic is then determined:

$$S_{y \cdot x} = \sqrt{S^2_{y \cdot x}}$$

Confidence intervals are calculated as follows for an expected mean:

$$CL(\hat{\bar{Y}}) = a + bXp \pm (t\alpha)(Sy \cdot x)\sqrt{\frac{1}{N} + \frac{(Xp - \bar{X})^2}{(\Sigma X^2 - CT_x)}}$$

Table 17: Bacterial Taxa Isolated from Salmonella Presumptive Test Cultures

Proteus mirabilis[a,b,c,d,e]
Proteus vulgaris[b]
Proteus morganii[d]
Enterobacter agglomerans[d,e,f]
Aeromanas hydrophila[e]
Klebsiella pneumoniae[d]
Citrobacter freundii[b,c,d,e]
Edwardsiella tarda[e]
Escherichia coli[a]
Seratia liqueficeans[g]

[a] Bullfrog Marina
[b] Hall's Crossing Boat Discharge Unit
[c] Wahweap Marina Boat Discharge Unit
[d] Wahweap Marina Dock Area
[e] Hall's Crossing Marina Dock Area
[f] Site 7
[g] Hall's Crossing Sign Buoy

Table 18: Computed Values of Fecal Coliform (X) and Total Coliform (Y) for the Regression Equation, Y = a + bx

Quantity	Value
n	18
ΣX	941
ΣY	55544
ΣX^2	92019
ΣY^2	332608822
ΣXY	4338288
$(\Sigma X)^2$	885481
$(\Sigma Y)^2$	3085135936
$(\Sigma X)(\Sigma Y)$	52266904
CT_x	49193.4
CT_y	171396440.9
CT_{xy}	2903716.9

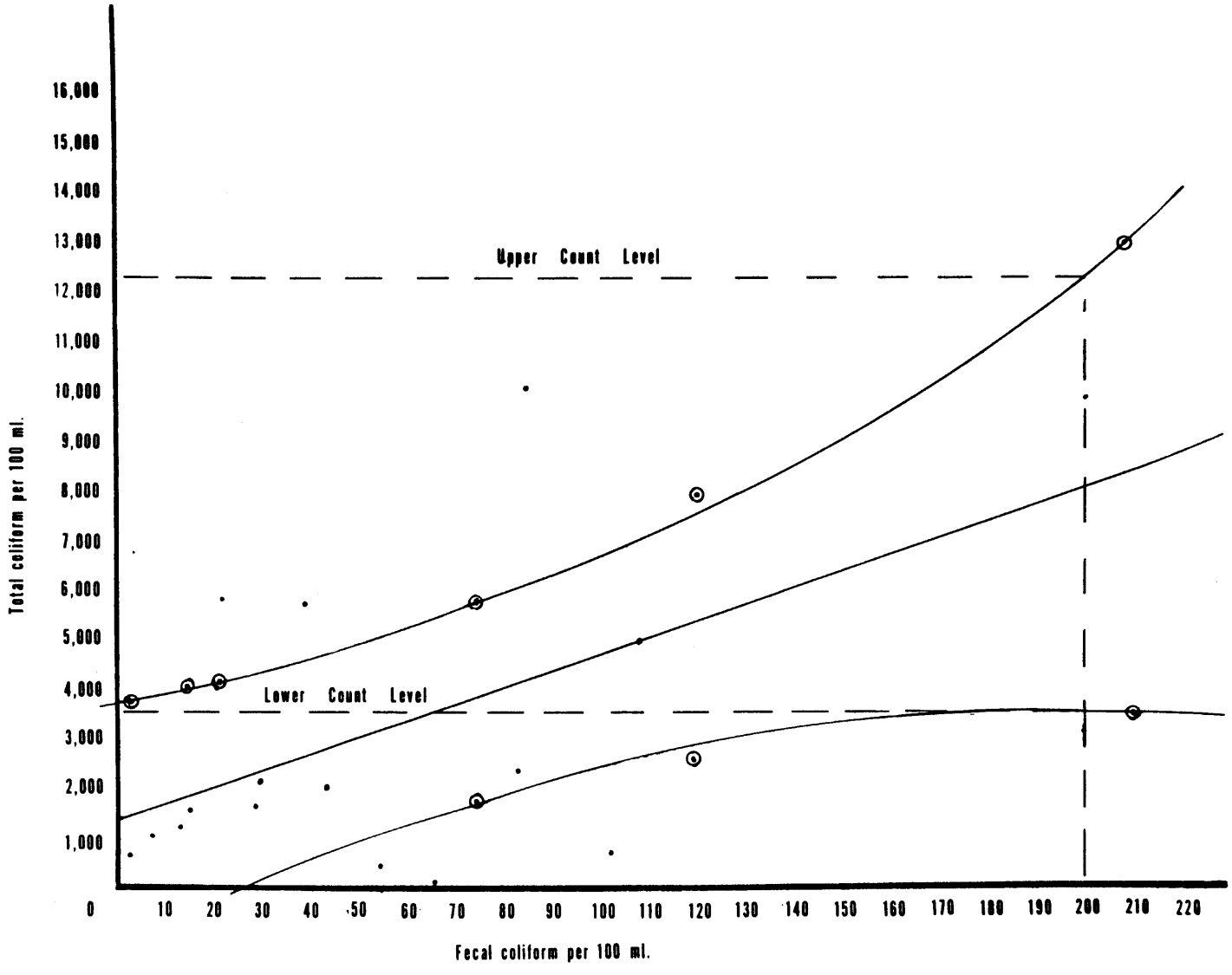

Figure 2: Preliminary Management Model for the Range of Total Coliform Counts per 100 Ml of Water Which Might Be Expected To Predict a Count of 200 Fecal Coliform.

Interpretation of the model is as follows. As an example, ten samples taken at the Wahweap swimming beach may provide a mean total coliform count of 8,000. The expected fecal coliform level is 200. Since a potential problem could exist, more sampling is indicated, and if mean total coliform counts which indicate counts of 200 or more fecal coliform are consistently obtained, then the water is a potential health hazard for human body contact, and corrective action should be anticipated.

CONCLUSIONS

The data presented in this Bulletin support earlier contentions that Lake Powell water is unsafe to drink, but is safe for recreational use. The NPS provides adequate sanitary facilities and boat dockside discharge units; however, small amounts of fecal material are reaching Lake Powell waters, particularly in the vicinity of marinas. This fecal material does not represent a health hazard as of this writing; however, there is concern that increased recreational activity in the future will mean increased fecal contamination at Lake Powell in the vicinity of marinas. Sources of fecal material at Lake Powell seem to come from accidental spillage at discharge units and perhaps from the cleaning process at these facilities.

RECOMMENDATION

Total coliform, fecal coliform, and Salmonella should continue to be analyzed for at least one more summer in order to identify problem areas and to test the linear regression model. Once the model is tested and/or modified, total coliform should be monitored weekly during the summer at the locations given in Table 10. Corrective action should be taken when mean total coliform counts consistently exceed 8,000 per 100 milliliters of lake water.

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GLOSSARY

Aerobacter aerogenes	a common representative of a group of non-encapsulated coliforms that is characterized by butylene glycol fermentation; they exist in the soil and on plants; their presence in a water sample does not indicate fecal contamination
Aeromonas	a genus of gram-negative, motile, freeliving, anaerobic bacteria
aliquot	a fractional portion of a sample
bismuth sulfite agar	a selective medium for the isolation of Salmonella
coliform	a group of gram-negative, rod-shaped bacteria dwelling in the animal gut; their presence in a water sample indicates the possibility of fecal contamination of a water supply by pathogenic organisms
CTA Mannitol agar slants	a selective medium for the isolation of Staphylococci
dulcitol fermentation agar slant	selective medium for isolation of suspected pathogens such as Salmonella
enteric pathogen	a gut-dwelling, disease-causing organism
Enterobacter	a genus of bacteria belonging to the family Enterobacteriaceae, which is either free-living or found in the intestinal tract
enterobacteriaceae	a family of lactose-fermenting bacteria, some of which are pathogenic to man and animals
Escherichia coli	a common coliform bacterial inhabitant of the animal gut
F-value	a ratio of variances for two samples of n_1 n_2 items whose significance is tested by

	comparison to a theoretical probability distribution, the F-distribution
fecal coliform	a group of coliform bacteria whose presence in a water supply definitely indicates (a) fecal contamination by warm-blooded animals and (b) the possible presence of pathogens
fecal streptococci	a group of coccoid gram-positive bacteria that is numerous in the gut of humans and animals; their presence in a water sample indicates fecal contamination by warm-blooded animals and the possibility of enteric pathogens in the water supply
Klebsiella	a genus of encapsulated coliform bacteria which are parasitic in the respiratory tract and can cause infection
lysine decarboxylase slants	hot media placed in culture tubes which are left in a leaning position until the medium sets so as to produce a larger surface for innoculation
meso-oligotrophic	a lake characterized by a relatively low level of nutrient enrichment
Salmonella	a genus of gram-negative non-spore-forming bacteria which are pathogenic to man and animals via oral ingestion
Salmonella-Shigella agar	a selective medium for the isolation of the enteric pathogens Salmonella and Shigella
Serratia	a genus of coliform bacteria characterized by the production of the red pigment prodigiosin; they occur in soil and water
Shigella	a genus of bacteria infecting the lower intestinal tract in humans and other higher mammals such as monkeys and chimpanzees; the infection and resultant symptoms are called Shigellosis
Shigella sonni	a species of the genus Shigella which infects the lower intestinal tract of some animals; in humans, symptoms include bloody diarrhea and weakness
tetrathionate broth	a selective enrichment medium for the isolation of

	Salmonella from materials of sanitary significance	xylos lysine decarboxycholate	a selective medium for the isolation of enteric pathogens, particularly Shigella forms
TSI slants	triple sugar iron agar prepared in culture tubes for isolation of certain enteric pathogenic bacteria		

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