CHEMICAL AND BIOLOGICAL PROBLEMS

IN THE GRAND CANYON

by

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ABSTRACT

A survey of chemical and bacteriological water quality in the Grand Canyon was undertaken to assess possible health hazards to river travelers. The water quality of the main Colorado River channel is relatively stable with only slight increases in ionic concentration and bacteriological load with respect to distance from Lee Ferry and time over the summer season. The tributary streams show extreme temporal variability in chemical water quality and bacteriological contamination as a result of the summer rain and flood patterns in the tributary canyons. These side streams pose a definite health hazard to unwary river travelers. More extensive sampling is called for to determine the sources of this contamination and to protect the quality of the Grand Canyon experience.

INTRODUCTION

In recent years, the recreational use of the Grand Canyon National Park has increased fantastically. It has become necessary for the National Park Service to limit the number of individuals that can travel on the Colorado River through the park in order to avoid deterioration of the area and the experience. One aspect of this preservation effort is to monitor the water quality of the main river channel, tributary streams and springs in which river travelers drink, swim and bathe.

During the summer of 1972, outbreaks of acute gastroenteritis were reported among the boatmen and passengers of the river raft trips in the Grand Canyon. The cause of some of the illness has been identified as Shigella sonnei and it is strongly suspected that this organism was the predominant agent in the outbreak. The mode of transmission of the disease, whether by contaminated food and water sources or person-to-person contact, is still a matter of conjecture.

These events support the conclusions of the authors and others who conducted a series of water quality surveys of the Colorado River in the Grand Canyon during 1971 and 1972 (Slawson and Everett, 1972a,b; Everett et al., 1971). These studies indicate the existence of potential health hazards in this section of the Grand Canyon National Park. This is a report of the 1972 chemical and biological investigations of the Grand Canyon from Lee Ferry to Diamond Creek (see Figure 1).

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The location of sampling stations will be given as river miles with Lee Ferry at mile 0 and Diamond Creek at mile 226. Samples taken in tributary streams were taken upstream from the confluence to eliminate the influence of the river water. Three surveys were conducted during the summer of 1972. In the report, the individual trips will be referred to as the June, July and August surveys. Actual survey days are given below:

Survey	Dates
June	June 13-19, 1972
July	July 25-29, 1972
August	August 28, 1972

Because of the infrequency of the sampling, the occurrence of rapid changes in the character of the system during the summer rainy season, and the technical difficulties of performing bacteriological analysis in the field, it is difficult to make specific conclusions concerning the chemical and bacteriological quality of the main channel and side streams. But it is possible to draw general inferences concerning the general spatial and temporal pattern of these water quality parameters.

CHEMICAL WATER QUALITY

Water chemistry samples were taken in the main river channel and in many of the streams and springs entering the river. Chemistry samples were collected and stored in prewashed one-liter polyethylene bottles. Chemical analysis was performed by the Soil and Water Testing Laboratory of the University of Arizona using the techniques outlined in Standard Methods. The results of this analysis are given in Table 1.

Table 1
Chemical Standards for Drinking Water (WHO, 1963).

Ion	Permissible Level (mg/l)	Excessive Level (mg/l)
Ca	75	200
Mg	50	150
SO_4	200	400
Cl	200	600
pH	7.0-8.5	<6.5 or >9.2

In order to evaluate the chemical water quality in the main river channel, tributary streams, and spring sampled, the concentrations shown in Table 1 were used as the standards for surface waters to be used as a public water supply: these standards have been set by the World Health Organization (1963). The "permissible" concentrations listed indicate levels that are generally acceptable for human consumption. The "excessive" concentrations indicate levels at which the potability of the water has become markedly impaired.

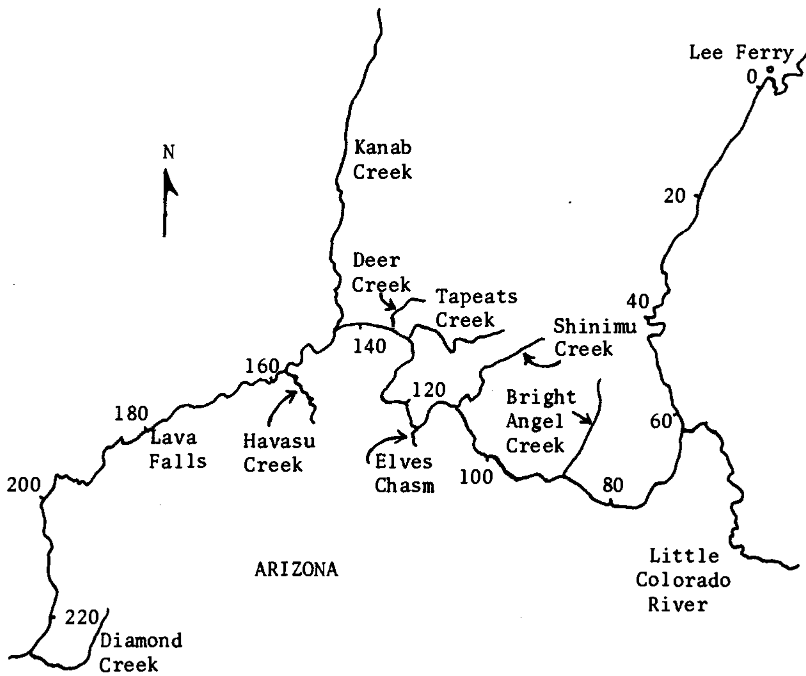

Figure 1. Main Colorado River channel and principle tributaries in the Grand Canyon area between Lee Ferry and Diamond Creek. Numbers indicate river miles from Lee Ferry.

In addition, the following standards are recommended by the U. S. Public Health Service (1962). The level listed for fluoride concentration is for a maximum daily air temperature in the range of 70-90°F.

Table 2
Chemical Standards for Drinking Water (PHS, 1962)

Ion	Recommended Limit (mg/l)
Total Dissolved Solids (TDS)	500
Fl	0.8-1.0
NO_3	2.0-4.0

Table 3 summarizes the results of the chemical analysis of samples taken in the main Colorado River channel. Table 4 summarizes the chemical analysis of tributary stream water.

Table 3
Summary of Chemical Water Quality Surveys of the Main Colorado River Channel. -- Samples taken at tributary streams were taken in main channel above the confluence.

Ion			TDS	Ca	Mg	Cl	SO_4	Fl	NO_3	PO_4
Permissible Level (mg/l)			500	75	50	200	200	1	2-4	-
Location	River Mile	Survey								
Lee Ferry	0	June	585	80	24	16	235	<.2	1.8	-
		July	641	90	28	54	230	.21	2.3	0.0
		August	639	84	27	54	240	.23	2.6	0.02
Mile 41	41	July	654	92	28	54	240	<.2	2.6	0.0
Little Colorado	60	June	572	76	24	16	220	<.2	1.8	-
		August	645	94	24	56	230	<.2	2.4	0.01
Hance Rapid	78	July	629	78	28	28	240	.21	3.2	0.02
Bright Angel Creek	89	August	683	84	27	80	230	.21	2.4	0.07
Elves Chasm	115	August	665	84	27	72	230	.20	2.4	0.05
Deer Creek	136	June	672	74	27	76	240	.20	1.8	-
Kanab Creek	140	August	675	88	26	64	250	.21	2.6	0.04
Lava Falls	180	June	677	78	28	80	235	.20	1.8	-
Diamond Creek	226	June	611	78	26	34	230	.26	2.4	-
		July	655	78	22	64	240	.30	2.3	0.05

Table 4
Comparison of Chemical Analysis of Selected Ions at Lee Ferry and Main Tributaries in Grand Canyon, Summer, 1972.

Location	Survey	TDS	Ca	Mg	Cl	SO_4	NO_3	PO_4
Lee Ferry	June	585	80	24	16	235	1.8	-
	July	641	90	28	54	230	2.3	0.0
	August	639	84	27	54	240	2.6	0.02
Little Colorado River	June	2787	120	80	1214	180	3.8	-
	July	2731	154	41	1060	250	1.5	0.10
	August	1207	104	17	48	200	4.6	0.19
Bright Angel Creek	June	302	38	21	14	18	0.0	-
	July	315	40	21	14	12	0.1	0.01
	August	305	45	24	12	8	0.2	0.0
Elves Chasm	June	521	70	45	28	205	2.2	-
	July	545	76	40	28	200	2.8	0.06
	August	525	98	29	24	200	3.3	0.05
Tapeats Creek	June	247	19	22	12	15	0.2	-
	July	270	40	15	8	10	0.0	0.01
	August	341	59	19	8	40	0.4	0.06
Deer Creek	June	385	42	21	10	90	0.0	-
	July	335	44	22	12	20	0.1	0.01
	August	382	55	22	12	40	1.0	0.16
Kanab Creek	June	1123	176	80	28	680	0.2	-
	July	1142	196	69	40	650	0.5	0.01
	August	1007	228	45	20	570	3.2	0.05
Havasu Creek	June	528	38	44	52	60	0.6	-
	July	500	40	45	56	70	1.0	0.02
	August	500	50	49	52	55	0.8	0.01

An examination of Table 3 shows that the chemical quality in the main river channel is relatively uniform with respect to both time and distance during the summer season. The general spatial pattern is a nearly constant concentration from Lee Ferry (mile 0) to the confluence of the Colorado River and the Little Colorado River (mile 60). At this point, due to the inflow of the Little Colorado River, the salinity (TDS) increases by 50-70 mg/l. The high sodium and chloride concentrations in the Little Colorado River cause this increase. There was also an increase of about 60 mg/l from June to August at Lee Ferry. This reflects the seasonal fluctuations in water quality in the Colorado River. The spatial and temporal water chemistry variations result predominantly from variations in the chloride and sodium ion concentrations.

The chemical quality of the tributary streams (Table 4) is capable of more significant changes throughout the summer season. These changes are due to the cyclic patterns in salinity caused by the periodic storms in the side canyons. These rains have two effects on the water chemistries of the tributary streams. Decreases in the concentration of some ions can be caused by the dilution effect of the rain water. Such changes are usually noted in the concentrations of sodium (Na), chloride (Cl) and total dissolved solids (TDS).

The second effects of the summer rains and resultant floods in the tributary canyons is due to the washing or leaching effect of the rains on the watersheds of the tributary basins. This effect is to increase the concentrations of certain ions by increasing the salt load carried by the streams. Such increases are most notable in the concentrations of nitrate (NO_3) and orthophosphate (PO_4) ions. These concentrations can be related to increases in bacteriological activity which have been noted during periods of flooding in the side streams (Slawson and Everett, 1972a,b,c; Everett et al., 1971). Flooding in the tributary basins would increase the organic matter content of the stream waters. The biological decomposition of this organic matter leads to an increase in microbiological populations and the release of nitrates and phosphates into solution.

The recommended limit for nitrate concentration is related to the danger of infantile methanemoglobinaemia if the water is consumed by infants. Thus, nitrates present no health problem to river travelers in the Grand Canyon. The impact of increases in the nitrate and phosphate concentrations may be important downstream in Lake Mead. Here, this nutrient input, accompanied by increases in water temperature, result in significant and possibly deliterious increases in alge populations.

The recommended salinity (TDS) level of 500 mg/l for drinking water is exceeded at all river locations sampled, as well as several tributary streams. Since waters of the concentrations found in the main channel are commonly used for domestic purposes in the Lower Colorado River Basin, there is probably no health hazard caused by the salinity levels in the main river channel and most of the tributary streams. Extremely high TDS concentrations have been noted in the Little Colorado River, Kanab Creek, and several small streams and spring not listed in Table 4 (Crystal Creek, about 2000 mg/l; Pumpkin Bowl, about 7000 mg/l). These locations pose potential health problems to river travelers who should be warned against drinking from these sources.

In the main river channel, and most of the tributary streams, concentrations of calcium (Ca), magnesium (Mg), chloride (Cl), and sulphate (SO_4) ions are generally below or slightly above the permissible levels listed in Table 1. It is difficult to determine the significance of those samples which showed concentrations slightly above the permissible level because different individuals will show varying sensitivity to these ions. In general, these ions probably present no great danger to river travelers in most of the side streams and in the main river channel within the Grand Canyon. Notable exceptions include the Little Colorado River with respect to chloride, calcium and possibly magnesium ion concentrations; Elves Chasm with respect to calcium concentration; and Kanab Creek with respect to calcium, magnesium, and sulphate ion concentrations. Drinking from these streams should be limited.

Fluoride (Fl) ion concentrations were generally found to be at or below 0.25 mg/l in the main channel and tributary streams. Concentrations in excess of 2.0 mg/l were found in the Pumpkin Bowl spring and concentrations of about 0.9 mg/l were noted in Diamond Creek (mile 226). Because of the limited exposure time, there is probably no danger to river travelers at these two locations.

BACTERIAL ANALYSIS

The presence of coliform bacteria is commonly used to indicate the presence of pollution. Members of the coliform group are associated with the excretia of warm-blooded animals. The possible presence of pathogenic organisms such as those known to cause typhoid fever, cholera, and various types of dysentery, is shown by the presence of these indicator organisms.

There are millions of coliforms for every enteric pathogen, but both types of organisms exist under similar environmental conditions. The isolating and culturing of pathogenic bacteris is expensive, time-consuming, difficult and dangerous. For these reasons, indicator organisms are used. Routine procedures have been developed for the culturing and enumeration of coliform bacteria.

Bacteriological analysis was undertaken using the membrane filtration techniques described by Standard Methods. Bacteria were collected on 0.45 micron membrane filters. Because of the difficulty of culturing fecal coliforms in the field during the June and July surveys, total coliform counts (i.e., including both fecal and soil groups) were made. Measured volumes of water samples were aspirated through the filters which were then placed on blotters containing 2 cubic centimeters of Difco-M-Endo MF media. The media contained a 95% ethanol solution to suppress the growth of non-coliform groups. The plates were then incubated at 35 $\pm$ 1°C for 48 hours.

The August samples were collected, kept cool and driven the same day to Phoenix, Arizona. Here, at the U. S. Public Health Service laboratories, the water samples were filtered as above and placed on specific media used to culture fecal coliforms and fecal streptococci. An effort was also made to detect the presence of Shigella by first placing filtered samples in GN (gram negative) broth to stimulate growth and then steak-plating these samples on differential growth media.

The results of the June and July surveys are summarized in Table 5. It should be noted that only one main channel sample location is listed in this table. As with the chemical quality, the bacteriological quality of the main Colorado River channel in the Grand Canyon is relatively uniform. The several other samples taken in the main channel during the June and July surveys yielded colony counts similar to or less than the Lee Ferry samples.

The desired quality criteria for surface waters to be used for drinking is that there be less than 100 total coliforms (TC) per 100 ml (milliliter) and less than 20 fecal coliforms (FC) per 100 ml. The maximum permissible level is 10,000 TC per 100 ml and 2000 FC per 100 ml (Clark, Viessman and Hammer, 1971). These criteria were issued by the Federal Water Pollution Control Administration (FWPCA) in 1968. The levels were set as the quality of surface waters that could be made potable using available technology. The Arizona water quality standard for primary contact (recreation) is a mean fecal coliform count of less than 200 per 100 ml with 10% of the samples having less than 400 per 100 ml sample. Nevada has set the upper limit at 100 fecal coliforms per 100 ml for recreational use. Using the rule-of-thumb ratio of 20 total coliforms per fecal coliform, the following criteria were

Table 5
Summary of Bacteriological Analysis for June and July Surveys.

Location	River Mile	Survey	Sample Size (ml)	Colony Count or Description
Lee Ferry[1]	0	June	50	TNTC[2]
			25	190
			10	100
		July	10	428
			5	142
Little Colorado River	60	June	25	49
			10	21
Bright Angel Creek	89	June	20	TNTC
			10	Colonies spread by excess water
		July	5	Packed[3]
			10	Packed
Pipe Creek	90	June	10	TNTC
		July	10	Packed
Elves Chasm	118	June	25	Packed
			10	TNTC
		July	10	Packed
Deer Creek	136	June	20	Colonies spread by excess water
			10	120
		July	10	15
			5	36
Kanab Creek	140	June	20	226
			10	118
			5	49
		July	5	Packed
			10	Packed
Havasu Creek	155	June	20	Packed
			10	Packed
			5	Packed
		July	10	Packed
Diamond Creek	226	June	20	TNTC
			10	TNTC

[1] Main Colorado River channel sample; other samples taken in tributary streams.

[2] Too numerous to count.

[3] Colonies overgrowing one another with no clear definition of colonies.

used to evaluate the bacteriological quality (with respect to TC) of the samples taken during the June and July surveys.

Use	Desired Criteria	Maximum Permissible Criteria
Drinking	100/100 ml	10,000/100 ml
Recreational		
Arizona		4,000/100 ml
Nevada		2,000/100 ml

In general, the colony counts were less in the main Colorado River channel than in the side streams. It should be noted that it is in these tributary streams that most of the drinking and recreational activity of river travelers occurs. Thus, these sites are of predominant importance in assessing the health hazards to the river runners.

The bacteriological contamination in the main river channel is normally at or below the criteria for primary contact and is below the maximum permissible level for drinking water. This does not preclude the necessity of treating water taken from the main channel for drinking purposes. It is indicated that proper chlorination or other treatment should make the water quite safe for drinking.

Many of the side streams present quite another picture, at least with respect to primary contact. With the possible exception of Deer Creek, the bacteriological contamination in most of the popular streams and swimming pools is in excess of the levels recommended for primary contact. Because of the failure to obtain countable plates with even 5-ml samples in some cases, it is difficult to make a quantitative evaluation. But the evidence is strong enough to indicate the presence of a very real hazard.

From Table 5 it is also evident that great variations can occur in the bacteriological water quality of the tributary streams and the main river channel within the Grand Canyon. The variations in the side streams appear to be related to summer storm and flooding cycles in the side canyons of the Grand Canyon. The impact of this flooding with respect to water chemistry was discussed earlier. The variations in the main channel may be related to the slight warming of the water observed as the summer progressed.

Because of the sporatic nature of these summer storms and the incomplete knowledge of the effect of these storms on water quality in the tributary streams, it is difficult to quantitatively predict the water quality status of these streams. Qualitatively, it is shown that flooding in the side canyons causes a tremendous increase in the bacterial population of the waters entering the Colorado River. Such contamination poses a definite health hazard to river travelers.

The results of the August bacteriological survey are shown in Table 6. Analysis for fecal coliforms in the main river channel showed much greater variability than had been observed for total coliforms in the earlier surveys. Some of this variability may be due to local effects as the samples were taken near the shoreline in all cases. Of the main channel samples, only the Lee Ferry sample showed a reasonable possibility of human fecal contamination. This possibilty is shown by the fecal coliform (FC) to fecal streptococci (FS) ratio. Ratios less than unity indicate contamination from non-human sources.

Ratios from 2 to 4 indicate human contamination. The FC/FS ratio is not an exact indication of the source of fecal contamination. Therefore, it is necessary to consider all fecal coliform organisms as indicative of dangerous contamination.

Table 6
Fecal Coliform Counts from August Survey.

Location	River Mile	Fecal Coliforms (per 100 ml)	FC/FS Ratio
Lee Ferry[1]	0	20	2
Above Little Colorado River[1]	60	60	0.5
Little Colorado River	60	30	0.2
Bright Angel Creek[2]	89	10	0.1
Bright Angel Creek[3]	89	40	0.1
Above Elves Chasm[1]	118	10	1
Elves Chasm	118	200	0.1
Deer Creek	136	0	0.0
Above Kanab Creek	136	60	1
Kanab Creek	140	1600	4
Havasu	155	50	2

[1]Main Colorado River channel sample; other samples were taken in tributary streams.

[2]Above Phantom Ranch.

[3]Below Phantom Ranch.

As was the case with the total coliform analysis of the June and July surveys, all of the tributary streams samples, except for Deer Creek, showed signs of contamination. The FC/FS ratios indicate the possibility of human fecal contamination in Kanab Creek and in Havasu Creek. The State of Utah requires that Kanab Creek have a total coliform monthly arithmetic mean of 5000 per 100-ml sample "with exceptions." These "exceptions" are ill-defined but apparently August must be one of them.

Another factor which should be mentioned with this bacteriological analysis is sediment. The July and August surveys were conducted after the commencement of the summer rains. Therefore, most of the tributary streams and the main channel below the Little Colorado River were carrying considerable amounts of sediment. Sediment hinders the membrane filter technique by masking the presence of growing colonies and clogging the filters. Sediment in the samples taken by the U. S. Public Health Service (in August) was allowed to settle out to some degree before the samples for analysis were extracted. Obviously there was opportunity for bacteria to settle out with the sediment. The general effect of sediment was to reduce the numbers of colonies observed and any contamination level observed is minimized. Thus, where any fecal contamination was observed there is a great possibility of the actual presence of significantly greater levels of contamination.

The effort to culture and detect Shigella yielded negative results. This fact by itself does not, however, eliminate water as the source of the epidemic. There are several reasons why Shigella may not have been found:

1. The samples may have been taken at a low point in the cyclic pattern of water quality in the side streams.

2. The initial source of contamination may have been transient with the ensuing epidemic being spread by person-to-person contact among river travelers and boatmen.

3. The difficulties in analysis caused by large amounts of sediment in the water samples may have rendered undetectable any Shigella present. Most of the tributary streams were flooding and filled with sediment when the August survey was made.

Even though Shigella organisms could not be isolated in the water samples, Salmonella were found at several sites: in the swimming pool at Elves Chasm, below Deer Creek falls, in Kanab Creek, in the Colorado River below Kanab Creek and Havasu Creek. Salmonella groups B, C, and D were detected. This is further evidence of potentially hazardous fecal pollution within the Grand Canyon.

DISCUSSION

From the data presented in the previous sections, it is evident that the water quality in the Grand Canyon reach of the Colorado River is a function of both time and location. In general, the chemical and bacteriological quality of the main Colorado River channel appears to be within acceptable limits. Potential health hazards to river travelers have been noted in several tributary streams and springs within the canyon. The infrequency of the sampling program followed in these studies makes it virtually impossible to reach quantitative and specific conclusions about the chemical and biological quality of the main channel and side streams. The summer rains can cause rapid and significant changes in water quality. It is evident that a more intense monitoring program is required to assure the accurate characterization of this water quality system and the enumeration of natural and man-caused pollution sources.

REFERENCES CITED

Clark, J. W., W. Viessman, Jr., and M. J. Hammer. 1971. Water Supply and Pollution Control. 2nd edition. International Textbook Company, Scranton.