

A BACTERIAL WATER QUALITY INVESTIGATION
OF CANYON LAKE, ARIZONA

by

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The use of Millipore filters and Hach equipment does not signify an endorsement of these products.

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ABSTRACT

A study was made on Canyon Lake to determine the source of fecal contamination and to learn how best to control the contributing sources. Of all the water samples taken from the Acacia swimming area, 5.5% exceeded the recommended standard of 200 fecal coliforms per 100 ml water. Bacterial levels determined for 24 sediment samples from the Acacia area were mostly in the thousands per 100 ml range. Fecal coliform-fecal streptococci ratios for both the water and sediment samples were predominately in the range where animal waste is the presumed source. A hypothesis is presented which implicates sediment-stored bacteria as the major immediate source of water pollution with human users and dogs as the ultimate sources. Bacterial survival data are presented showing how the fecal coliform-fecal streptococci ratio will shift with storage until, after one week, a ratio typical of human pollution will decrease to one indicative of contamination by animal wastes.

Multiple regression analysis was employed to define the relationships between bacterial levels and site conditions and area use. User load index (car count) and/or turbidity were significantly correlated with fecal coliform count in most of the various regressions. This correlation over all data was about 50 percent.

INTRODUCTION

Water-based outdoor recreation is extremely popular in the United States. Swimming, boating, and fishing are some of America's favorite outdoor activities (Mackenthum and Ingram, 1967). This popularity bestowed upon our rivers and lakes is commonly manifest in high concentrations of people at public recreation sites over much of the summer recreation season. Where concentrations of water users are found so also is the likelihood of water pollution in some degree. Such pollution can assume many forms, but perhaps the most ominous of these is bacterial pollution. If present in water and ingested by swimmers in sufficient quantities, many types of bacteria are capable of inducing infections ranging from minor skin irritations to serious or fatal diseases.

For obvious reasons it is desirable to monitor bacterial levels in recreation areas. The detection of bacterial and viral pathogens at concentrations normally found in natural waters is, unfortunately, impractical at the present time. Procedures are complicated, costly, and excessively time consuming. However, included in the same family as most water-borne bacterial pathogens (Enterobacteriaceae) are some species of bacteria always found in the intestines of warm-blooded animals. A group of these bacteria, collectively

known as the coliform group*, possess these convenient characteristics which make them well suited as indicators of bacterial pollution:

- 1) they are constantly present in the intestines of warm-blooded animals and humans and are excreted in feces by the millions per gram,
- 2) the survival times of these organisms closely approximate (or slightly exceed) the survival times of pathogens in water,
- 3) identification and enumeration procedures are relatively fast and simple, and
- 4) most coliform strains are harmless to man and so are safe to handle.

Thus, the coliform group, by virtue of its presence in a water body, is well suited to warn of potentially dangerous pollution (Pelczar and Reid, 1965).

In order to minimize the risk to recreationists of exposure to pathogenic bacteria, most states now have either total or fecal coliform standards for recreational waters. These standards range from 5000/100 ml to 50/100 ml for total coliforms (the majority are 1000/100 ml) and 1000/100 ml to 70/100 ml for fecal coliforms (the majority are 200/100 ml) (Mechalas et al., 1972). In 1968, the National

*The coliform group of bacteria are defined as all aerobic and facultative, gram-negative, nonsporulating bacilli that produce acid and gas from the fermentation of lactose within 48 hours incubation at 35° C. (Pelczar and Reid, 1965).

Technical Advisory Committee of the Federal Water Pollution Control Administration (FWPCA) recommended a geometric mean of 200 fecal coliforms per 100 ml as a limit for bathing beaches* (FWPCA, 1968). This criteria has been adopted by federal agencies charged with the management of water recreation areas.

To comply with the intent of the state and federal regulations, recreational waters should at least be sampled during periods of heaviest use and those samples assayed for the appropriate coliform bacteria. Should any sample be found to contain coliforms in excess of the lawful standard, regulations generally dictate that confirmatory samples be taken immediately. If the standard is again exceeded, normal procedure is to close the contaminated recreation area until such time that daily sampling demonstrates that compliance with standards has resumed.

Personnel of the Tonto National Forest regularly perform bacterial analyses on samples of water from the major recreation areas on the Salt River reservoir system. The analyses have indicated the periodic occurrence of fecal coliform counts in excess of the 200 counts per 100 ml standard.

*Because total coliforms are present in the natural environment in the absence of fecal contamination, the fecal coliform subgroup is now generally preferred as the bacteriological indicator of natural water quality. Fecal coliform densities are more directly indicative of the probable presence of associated enteric pathogens inasmuch as they both result from pollution by man and other warm-blooded animals (Geldreich, 1967, and Mechals et al., 1972).

Concern over the possibility of health hazards accompanying the high bacterial counts prompted the Forest Service, in conjunction with The University of Arizona, to initiate an intensive study of the fecal contamination problem.

Canyon Lake was chosen as the study site because of its accessibility and because sampling during the summer of 1972 had occasionally revealed excessive bacterial concentrations.

The objectives of the study were:

- 1) to ascertain the dominant source of contamination and to learn how best to control the contributing sources, and
- 2) to determine what relationships, if any, exist between the observed bacterial levels and site conditions and area use.

Related Studies

Few studies have been made of the relationship between recreational water quality and the incidence of illness among bathers swimming in water of a particular quality. An investigation of this type was undertaken by Stevenson (1953) in which he and his colleagues observed the health records of selected population groups over a period of time when each group swam in a different body of water of known bacterial quality. The results indicated that a higher overall incidence of illness may be expected in swimmers than

among nonswimmers regardless of the bathing water quality. It was found that among swimmers, eye, ear, nose, and throat ailments represented more than half of all the illnesses recorded, gastrointestinal disturbances up to 20 percent, and skin irritations the remainder.

Stevenson (1953) discovered in two instances a significantly higher incidence of illness among bathers swimming in relatively poor quality water over that of bathers who swam in water of good quality. The mean total coliform concentrations associated with the higher illness occurrences were 2,300 and 2,700 per 100 ml.

Extensive bacteriological and epidemiological studies conducted in England and Wales over a period of five years involving some 40 coastal bathing beaches are reported by Moore (1959). Total coliform counts varied from 40 to 25,000 per 100 ml with as many as 40 percent of the samples containing over 10,000 coliforms per 100 ml. The frequency of illness among swimmers was such that the investigators concluded that bathing in sewage polluted water carries only a negligible risk to health, and, where the risk is significant, it is probably associated with chance contact with intact aggregates of infected fecal material.

American investigators and public health authorities do not subscribe to the extreme view of the British workers. They maintain that any water subject to fecal pollution is susceptible to contamination by pathogens. Traditionally,

the pathogens which have received most of the attention of workers in the water quality field have been the organisms of the genus Salmonella. Gallagher and Spino (1968) reviewed available data from various studies throughout the country in which coliform concentrations were determined for water samples containing at least one Salmonella isolate. They concluded that there was little apparent correlation between quantities of total or fecal coliforms and the probable isolation of Salmonella. Their data indicate that waters containing fecal coliform concentrations as high as 16,000 per 100 ml need not necessarily yield Salmonella isolates while waters with fecal coliform counts as low as two per 100 ml have borne Salmonella organisms.

Recent studies, though they have not refuted the variability of the coliform to Salmonella isolation relationship cited by Gallagher and Spino (1968), have shown compatible results in regard to the probability of occurrence of Salmonella in water samples with a given coliform count. Investigations by Van Donsel and Geldreich (1971), Davis (1969), Dutka and Bell (1973), and Smith, Twedt, and Flanigan (1973) show Salmonella occur with frequencies ranging from 28 to 50 percent in water samples containing fecal coliform concentrations of 200 per 100 ml or less. Dutka and Bell (1973) were able to isolate Salmonella from approximately 25 percent of the samples from waters that contained fecal coliform and fecal streptococcus densities

of nine or less per 100 ml. Apparently the indicator-pathogen relationship, Smith et al. (1973) state, "... is tempered by such important factors as the nature of seasonal pollution and the numbers of Salmonella excretors among the human and animal populations in the drainage basin. High fecal coliform levels can occur in conjunction with low Salmonella densities and conversely."

Claims have been made discrediting the value of the fecal coliform test in view of the little apparent correlation with the occurrence of Salmonella. Since new techniques have simplified the identification of Salmonella from polluted waters, it has been suggested that the fecal coliform test be supplanted by Salmonella determinations as this would give a direct indication of the health hazard of the water. Geldreich (1970) challenges this claim stating that the inability to detect Salmonella in waters containing high fecal coliform levels does not imply poor correlation with the fecal coliform test, but that it demonstrates the variability of the occurrence of Salmonella in polluted water since that occurrence is related to the incidence of salmonellosis in a given population. He states that, even though Salmonella may not be excreted by any member of a small population over a given period of time, other pathogens might be prevalent in the population at that time. Thus, the absence of Salmonella in a polluted water is no assurance that other pathogens will not be there.

Geldreich (1970) has noted that, "The idealistic aim in establishing microbiological standards for recreational water has been to develop the 'magic number' of organisms that will denote no health risk to the people using the water. Conversely, this implies a health risk will exist if the number is exceeded." This thesis was expanded upon by a comprehensive study sponsored by the U.S. Environmental Protection Agency (Mechalás et al., 1972). The first phase of the study was a review of all published literature which in any way was related to the field of recreational water quality. After completion of the review its authors are of the opinion that current fecal coliform standards bear little relationship to the level of risk of exposure to pathogens undergone by recreationists who come in contact with the water. The report advocates the adoption of a method for setting bacteriological standards based on a mathematical treatment of medical dose-response data in conjunction with the probability of exposure over a period of time to a given level of pathogens such that a quantitative risk can be assigned to the recreational activity. This method would require that the relative levels of pathogens to indicator organisms be established for each water of interest. It also requires a knowledge of pathogen dosages necessary for the contraction of infections and diseases. The technique is largely untried and has not as yet stood the test of close scrutiny by public health scientists and practitioners.

It is noteworthy that Mechalias et al. (1972) declare that, "... it is the risk of virus infection that will pertain in the establishment of 'safe' coliform levels. In contradiction to traditionally held views, the probability of a virus infection increases more rapidly than does the risk from Salmonella (p. 105)."

The majority of bacterial water quality studies reported in the literature are concerned with the pros and cons of allowing recreational use of water supply reservoirs. Five such studies are reviewed by Carswell, Symons, and Robeck (1969). Conclusions reached in these studies are consistent in that little or no deterioration in bacterial water quality occurred at the water supply intakes when recreation was permitted in or around public water supply reservoirs. When moderate rises in indicator organism densities did occur, the elevated counts were localized within the high recreational use area. As the concern of the studies was for the quality of water drawn from the impoundments for public consumption, no mention was made of the duration or probable source of the high bacterial concentrations within the recreational areas. The authors concluded that the protection afforded by natural dilution, die-off, and disinfection following complete water treatment would seem to indicate that safe water can be produced from a source in which water-based recreation is permitted.

A study of recreation areas on a large reservoir in central Mississippi showed that both fecal coliform and fecal streptococci densities were significantly higher at most sampling stations during a heavy use weekend than during a weekend of normal recreational activity (Barbaro et al., 1969). Also, concentrations of these two indicator organisms were generally higher at the marina areas than at non-marina sites. The authors cite the inability of the total coliform test to show significant concentration differences between the two weekends when such variations were evident for both fecal coliforms and fecal streptococci. This observation leads to their conclusion that the latter two groups are better indicators of significant bacteriological pollution.

Research was conducted on three mountain watersheds in Washington and Oregon in an attempt to demonstrate the influence of the level of human use on bacterial water quality (Lee, Symons, and Robeck, 1970). The data showed no influence of increase in human use on bacterial indicator densities on any of the watersheds. It was hypothesized that the non-existence of such a relationship was due to the very low levels of human usage. Discernible indicator organism densities in remote areas of each of the watersheds were attributed to large wild animal populations. The source of enteric pathogens detected at these remote stations was also believed to be animal contamination. Indeed, numerous

studies cited in literature reviews by Summers (1967) and Geldreich (1972) provide evidence that virtually all warm-blooded animals are susceptible to infection by enteric pathogens or may at least serve as natural carriers. Contamination from wild and domestic animal waste, therefore, should be of public health concern.

An investigation reported by Geldreich (1972) examined the bacterial water quality of a multiple-purpose reservoir in the Texas Panhandle. Source water for the reservoir was derived from a drainage basin supporting a large cattle population. It was found that serious water quality degradation occurred at the inlet end of the impoundment following heavy rainfalls. This degradation progressed to the middle of the five-mile-long lake before rapid diffusion, dilution, and sedimentation offset any further water quality deterioration resulting from the stormwater inflow. It was recommended that a buffer zone be maintained between the swimming areas and a wildlife refuge located at the upper end of the lake. It was also recommended that swimming be temporarily suspended following rains of sufficient intensity to produce a specified volume of stormwater inflow.

METHODS

Study Area Design

The study plan for this project, as originally drafted, called for nine sampling stations at various locations throughout the lake (Figure 1). However, data gathered during the initial sampling period (Friday, June 29 through Wednesday, July 4, 1973) during a very heavy-use weekend indicated that only in the immediate vicinity of the Acacia swimming area was there a likelihood of significant bacterial pollution. It was, therefore, decided to delete all other locations from the sampling network and add two more in the Acacia area so that efforts could be concentrated where the probability of pollution is greatest. Figure 1 shows the positioning of the four sampling stations relative to the Acacia swimming area. As the prevailing wind in the area is nearly always out of the west or northwest, station 7 borders the beach on the upwind side. Contamination at this point should be the result of recreational use of the beach and near shore waters west of and including the west edge of the swimming area. Station 6, at the downwind, easterly extreme of the swimming area should receive bacteria not only from users in the immediate area, but also from the entire upwind swimming area. Stations 10

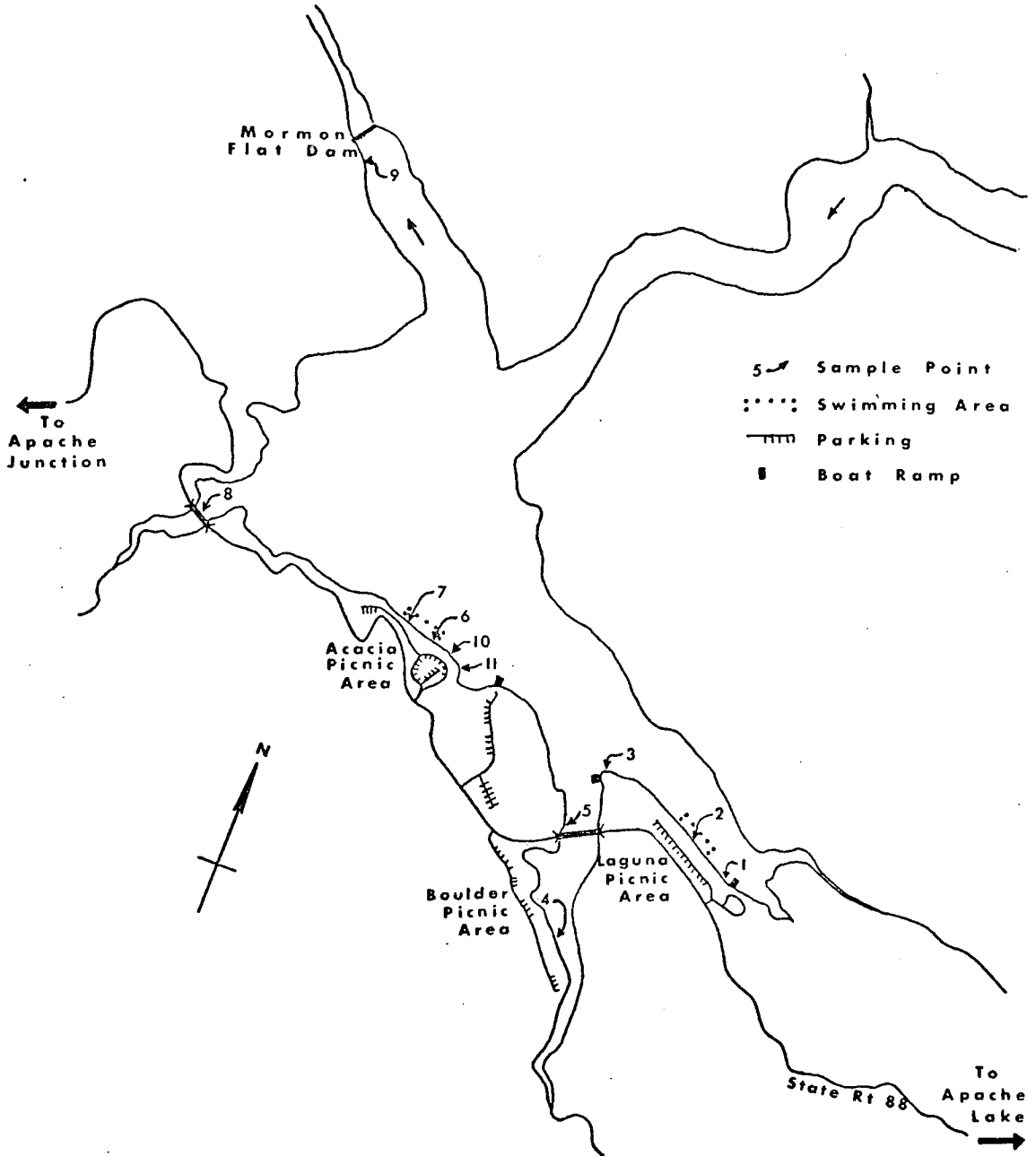


Figure 1. Canyon Lake, Tonto National Forest, Arizona

and 11 were so located in order to monitor the eastward migration of bacteria under the influence of the prevailing westerly winds. Also, possible leakage from the vault privy near the east end of Acacia beach, which could have contributed to contamination, could be detected at these stations.

Sediment samples were collected from eight stations within and adjacent to the Acacia swimming area (Figure 2).

Field Procedures

The water sampling periods for this study were: June 29 through July 4, 1973; Friday, August 10 through Tuesday, August 14, 1973; Saturday, September 1 through Monday, September 3, 1973; Friday, May 24 through Tuesday, May 28, 1974; Thursday, July 4 and Sunday, July 7, 1974. Additionally, lake bottom sediment samples were collected on three occasions in order to assess the relative contribution from the benthic zone to the bacterial load in overlying waters. These samples were taken at approximately 9:00 a.m. on alternating Tuesdays (June 11, June 25, and July 9, 1974).

Generally, water samples were collected four times daily (7 and 11 a.m., 3 and 7 p.m.) from each of the sampling stations. These times were chosen in order that samples might be taken prior to, during, and subsequent to maximum daily use periods.

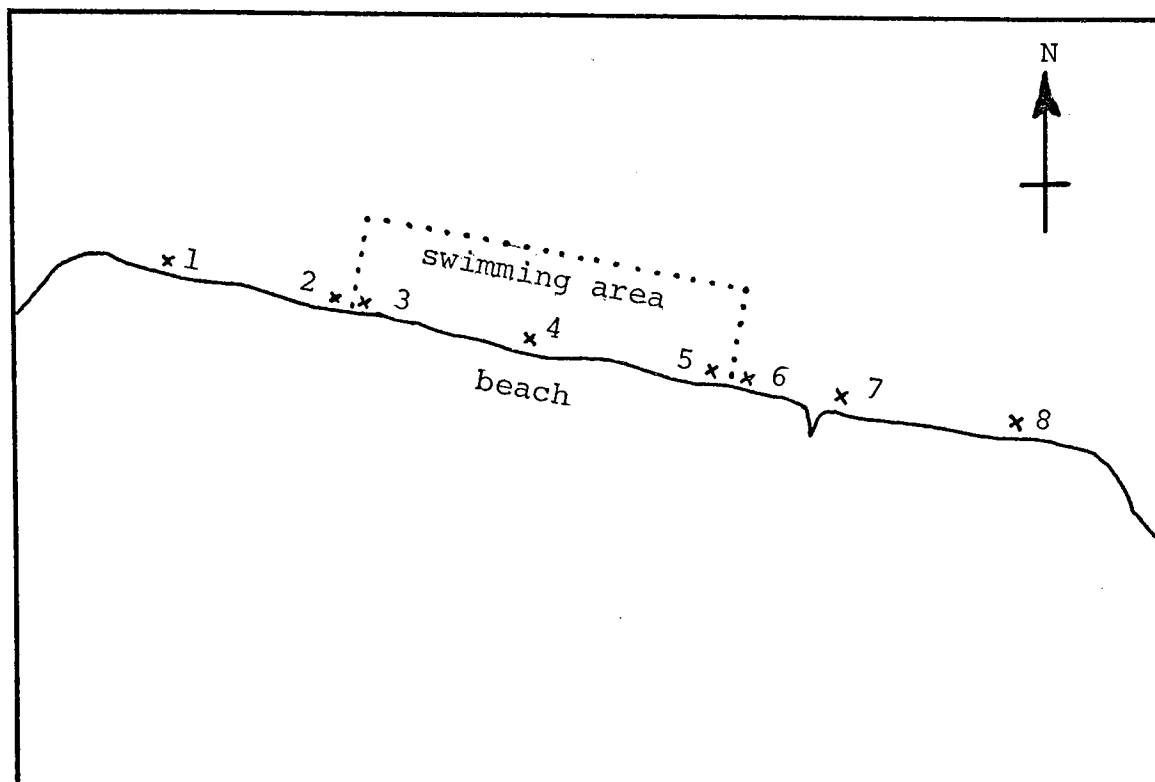


Figure 2. Sediment sampling points, Acacia swimming area, Canyon Lake, Arizona.

Water samples taken during the first sampling period (July, 1973) were analyzed for fecal coliform bacteria only. Turbidity determinations were made on the August, 1973, water samples as well as fecal coliform analyses. Turbidity, fecal coliform, and fecal streptococci analyses were administered to water samples collected during the remainder of the sampling periods. User car count (number of cars in Acacia parking lots), water temperature, wind direction, and relative wind velocity (light, moderate, strong) were recorded at each sampling time during every sampling period.

When the sediment samples were collected on Tuesday mornings the swimming area and adjacent beach were devoid of users so the lake bottom was undisturbed and easily visible. Small plastic vials were used to scoop four samples from each of the eight stations (Van Donsel and Geldreich, 1971, advise multiple sampling in light of studies which show that bacterial densities fluctuate widely within a small area of sediment-water interface). The vials containing the samples were iced en route to the laboratory.

Laboratory Procedures

Water samples were analyzed for fecal coliform and fecal streptococci bacteria by the membrane filter method (Standard Methods, 1971). Millipore (Millipore Corp., Bedford, Massachusetts) filters (0.45 μm) were used. The

media used throughout the study were M-FC broth and M-Enterococcus agar, respectively. Although most of the water samples contained low concentrations (many were less than 20 per 100 ml) of coliforms, suspended sediment in the water prohibited the use of greater than 100 ml sample filtration volume.

Upon return to the laboratory, each sediment station's four samples were combined in a sterile graduated cylinder. Sterile buffer water (as per Standard Methods, 1971) was then added to the sediment and supernatant until a one-to-one mixture of sediment and water was obtained. This mixture was thoroughly agitated and, finally, the appropriate aliquots were drawn off for dilution and inoculation according to MPN multiple tube techniques for fecal coliform and fecal streptococci bacteria (Standard Methods, 1971). Lactose broth was used as the presumptive test medium, brilliant green lactose bile broth served as the confirmed test medium, and EC medium was used in the elevated temperature test for the detection of fecal coliforms. Media used for the presumptive and confirmed tests for fecal streptococci were azide dextrose and ethyl violet azide broths, respectively.

Turbidity determinations were made in the laboratory with a portable Hach kit (Hach Chemical Co., Ames, Iowa).

Statistical Analysis

A stepwise multiple regression analysis was made of all the data by computer. Fecal coliform count was the dependent variable while car count, car count at the previous sampling time, the square of car count, turbidity, temperature, reservoir level, and 24-hour reservoir fluctuation were the independent variables. Each station's data was analyzed separately. The data were also subdivided by sampling periods so that regressions were run for each station during each sampling period. Another analysis was made for each station with the data from all sampling periods combined. Since turbidity data were not available for the July, 1974 sampling period and were incomplete for the August, 1973 period, turbidity was not included as an independent variable for these two periods. It was, however, incorporated into the combined period analysis by deleting those data sets for which turbidity readings were lacking. The July, 1974 data were included in the combined period analysis, but were not considered independently because it consisted of too few sampling times.

Each of the indicated regression analyses were run in duplicate. One employed the raw data while the other used a log transformation of all data. The regression which yielded the highest R^2 * is reported herein. For each regression only those variables which were significantly correlated with coliform count at the 0.10 level are reported.

*Regression coefficient squared.

RESULTS AND DISCUSSION

Relationship Between Fecal Coliform Count and Car Count

An appreciation for the relationship between fecal coliform count and car count may be gained by examination of Figures 3 through 7. Figure 3 shows fecal coliform count and concurrent car count for stations 6 and 7 during the weekend preceding the fourth of July, 1973. Except for the anomaly of the morning of July 4, reflecting the enormous influx of recreationists, the data for station 7 indicate an excellent correlation between coliform count and car count. The tendency toward synchronous rises and falls in the numbers is evident for station 6 also, even though it is not as refined as that for station 7. The prevailing westerly wind causing water movement toward station 6 was probably the principle agent responsible for the generally higher coliform counts at station 6.

Of the several inferences which may be drawn from a survey of Figures 3 through 7 probably the most important is the mild correlation of car count with coliform count. Assuming car count is an accurate indication of the number of people actually using the water and adjacent beach at a given time, the data imply a casual relationship between user load and coliform count. The logic of this deduction is supported

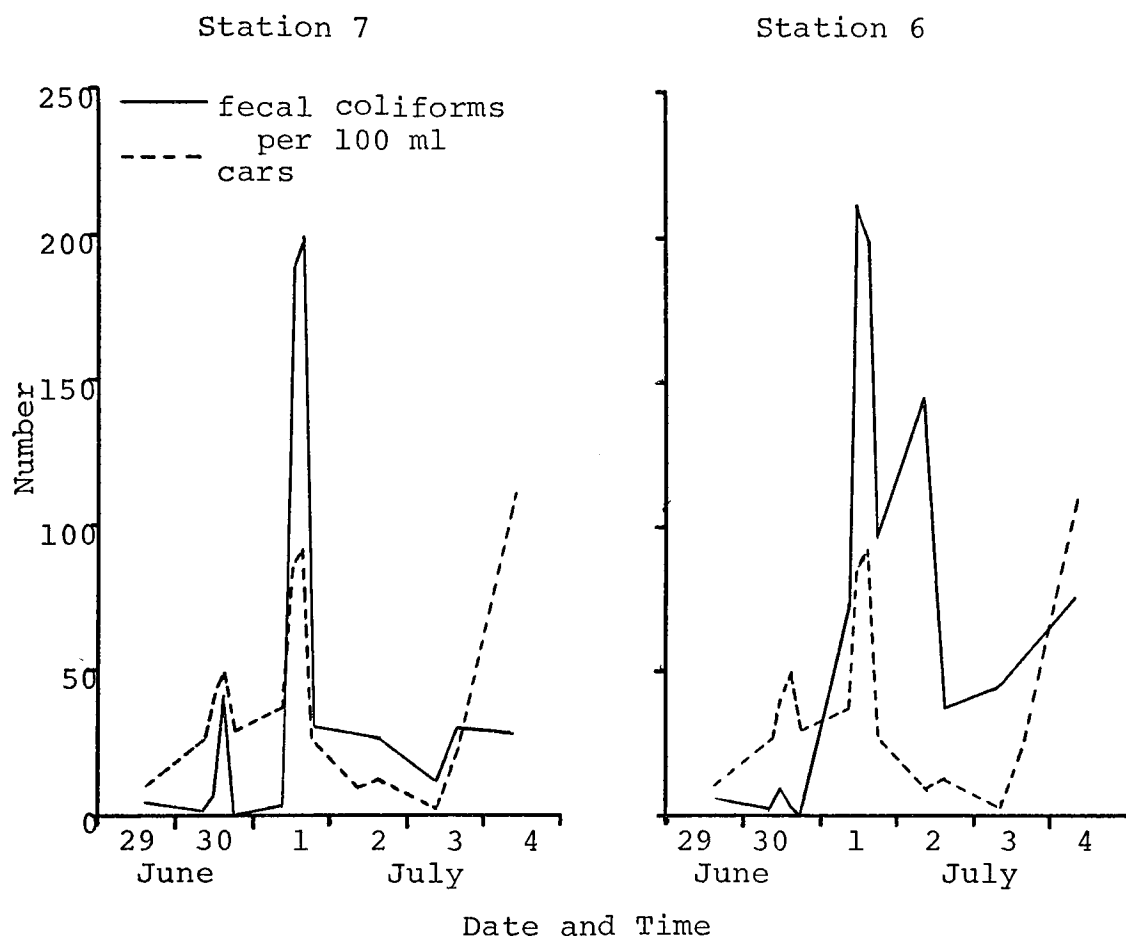


Figure 3. Relationship of car counts as an index of visitor use and fecal coliform counts for sampling stations 6 and 7, June 29 to July 4, 1973.

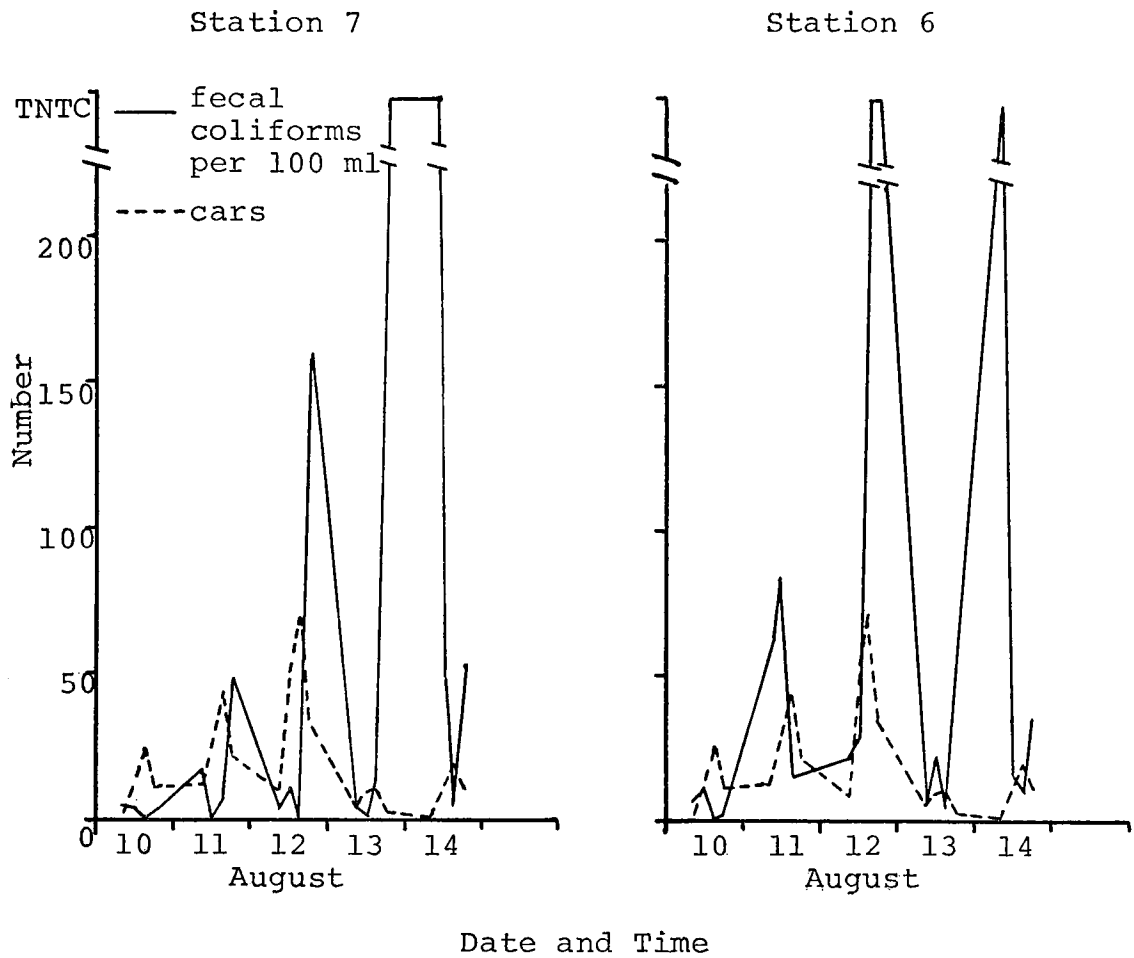


Figure 4. Relationship of car counts and fecal coliform counts for sampling stations 6 and 7, August 10 to August 14, 1973.

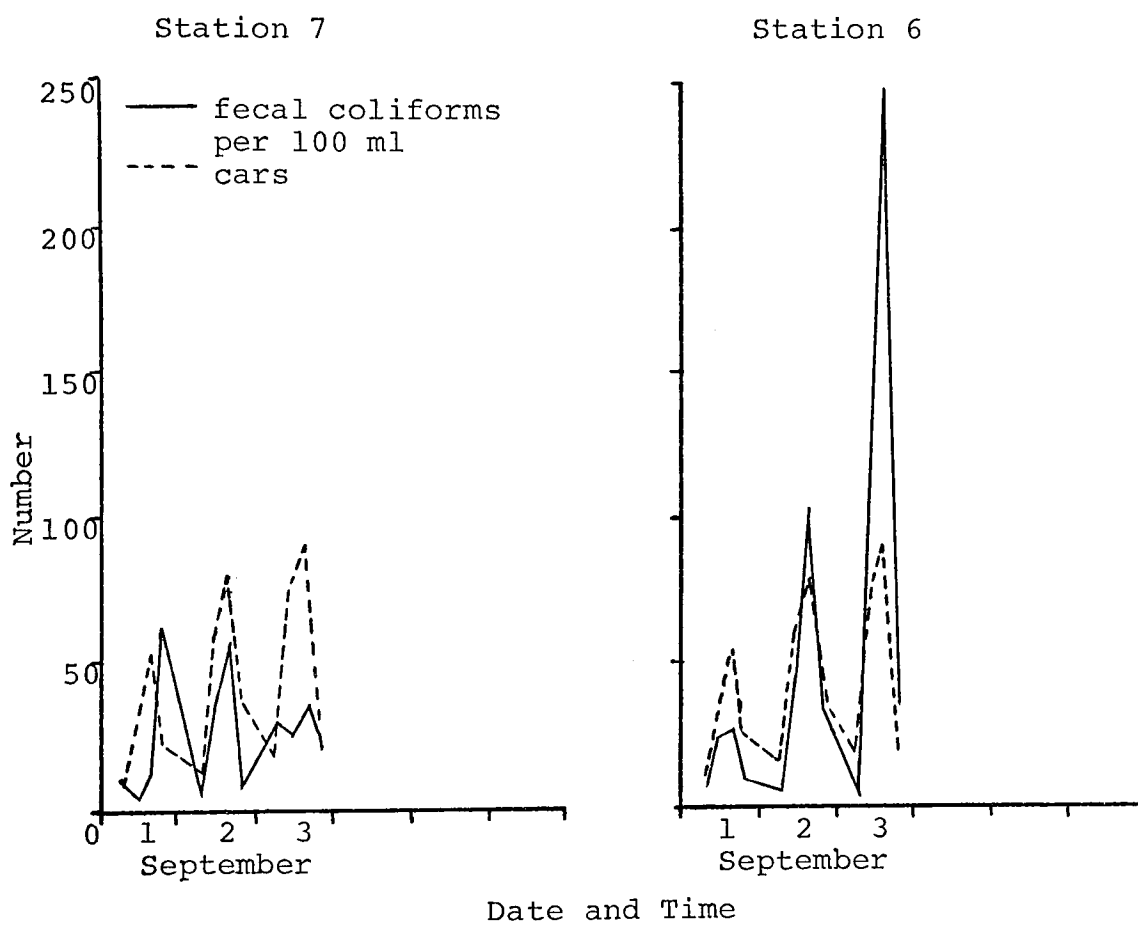


Figure 5. Relationship of car counts and fecal coliform counts for sampling stations 6 and 7, September 1 to 3, 1973.

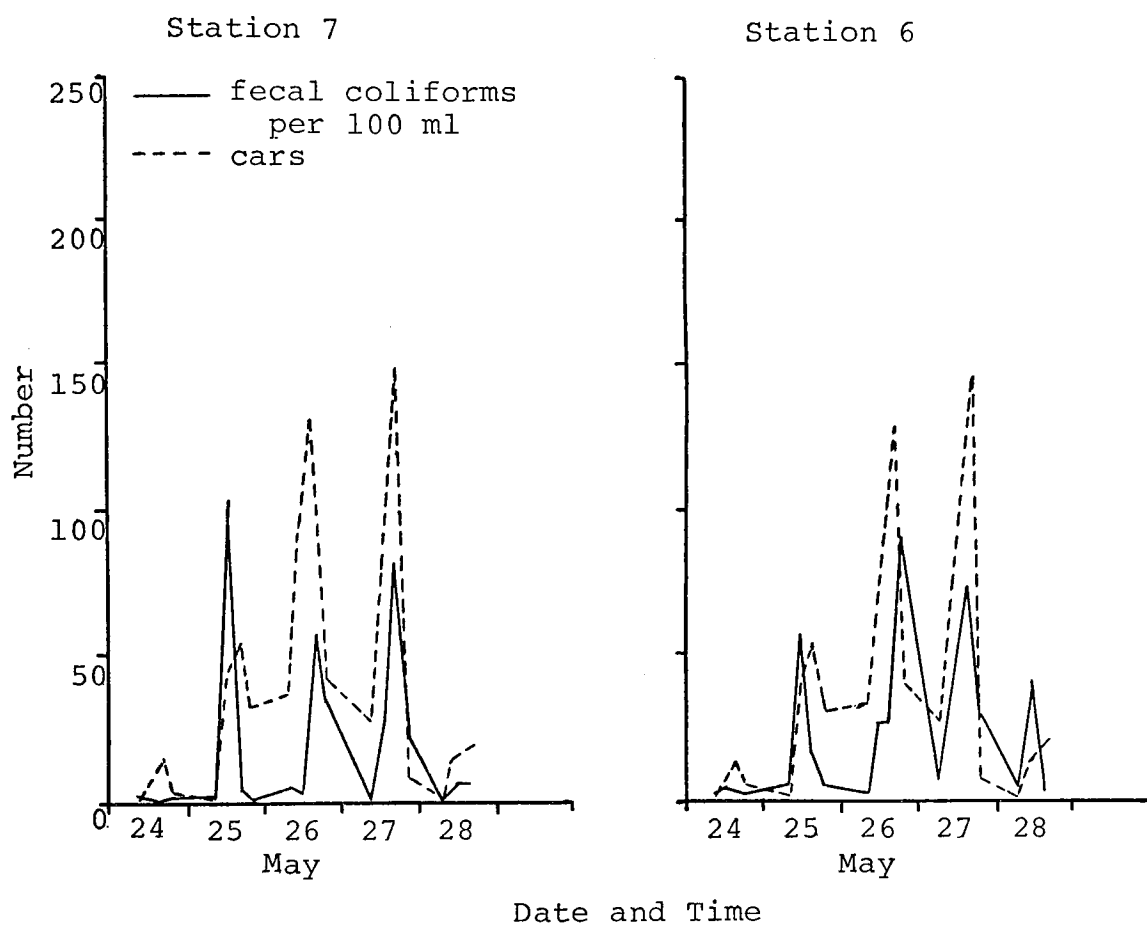


Figure 6. Relationship of car counts and fecal coliform counts for sampling stations 6 and 7, May 24 to 28, 1974.

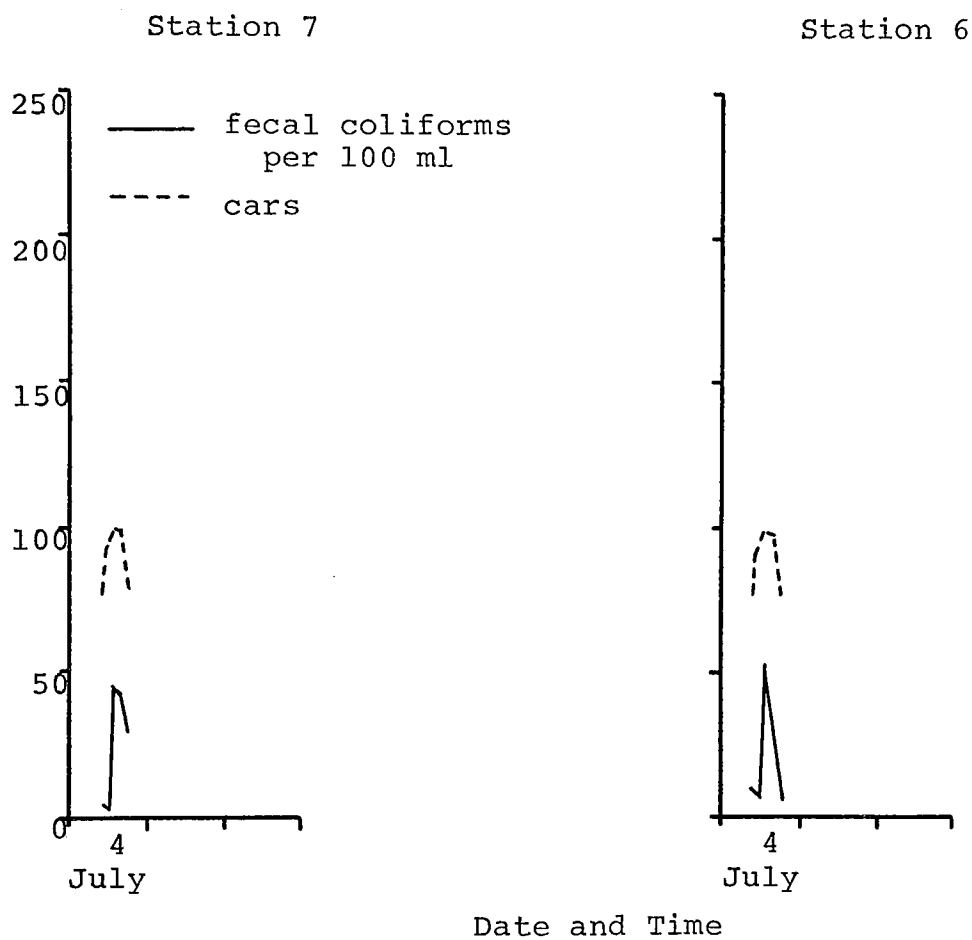


Figure 7. Relationship of car counts and fecal coliform counts for sampling stations 6 and 7, July 4, 1974.

by data from artificial tank studies which show that, under conditions of normal body hygiene, fecal coliform and fecal streptococci bacteria may be shed in relatively large numbers by swimmers (Robinton and Mood, 1966, and Hanes and Fossa, 1970). The regression analyses demonstrated a correlation between coliform count and car count which varied from one station to another and from one period to another (Table 1). The erratic degree of correlation clearly indicates that other factors contribute to the observed levels of bacterial contamination.

Counts of cars were made instead of actually counting users because the former could be done much more rapidly. One of the goals of the study was to define, if possible, the relationship between coliform count and some parameter(s) which could be routinely and conveniently monitored by management personnel, such as a count of users. As considerable difficulty would be encountered in attempting to enumerate recreationists on a crowded beach, car counts were chosen as the most viable alternative to an assessment of user load.

Another manifestation of the coliform data is the brevity of the high counts. Peak counts seemed to persist for only a few hours, if indeed that long, before sharply abating. Each day's highest count generally subsided by 50 percent or more (commonly much more) by the subsequent sampling time, either four or 12 hours later. Studies of bacterial survival found in the literature report

Table 1. Results of statistical analyses showing correlation of independent variables with fecal coliform count.

Date	Station	Factor*	R ² **
July, 1973	7	CC	.43
"	6	CC ²	.28
Aug., 1973	7	CC-1	.52
"	6	CC-1	.60
"	10	CC-1 + CC ²	.74
"	11	CC-1	.46
Sept., 1973	7	Nothing sig. at 0.10 level	
"	6	CC ²	.82
"	10	Log. Turb.	.44
"	11	Turb.	.30
May, 1974	7	CC	.36
"	6	Log Turb.	.56
"	10	CC-1 + Turb.	.73
"	11	Turb.	.43
All dates	7	Log CC	.20
"	6	Log Turb.	.48
"	10	Turb. + CC ²	.46
"	11	Log Turb.	.22

*All variables shown significant at 0.10 level

CC = car count

CC² = square of car count

CC-1 = car count at previous sampling time

Turb. = turbidity

**Correlation coefficient squared

inconsistent and diverse results (McFeters and Stuart, 1972; Geldreich et al., 1968; Postgate and Hunter, 1962), but with a reasonable degree of confidence, it may be inferred that while it is quite possible for a 50 percent coliform die-off to occur within 12 hours, it is doubtful that such a condition would occur in four hours. It is likely, therefore, that the observed rapid subsidence in coliform numbers is due largely to some combination of these factors: wind and current driven circulation of water, dispersion or diffusion of the organisms unaided by wind or current forces, sedimentation of the organisms with clay, silt, and sand particles, and predation by larger aquatic organisms (such as protozoa). Although these influences are difficult to quantitatively access, the data repeatedly substantiate the role of the prevailing westerly wind in carrying the organisms to the east. Station 10 and 11 commonly displayed a dampened surge in coliform count one sampling period subsequent to the corresponding peak in user load and coliform count back at the swimming area.

The effect of a brief thundershower upon the coliform count is clearly discernable from the data of August 13 and 14, 1973 (Figure 4). At 3:00 p.m. on August 13, the highest count was 16 fecal coliforms per 100 ml at station 7. A light shower, of perhaps 10 minutes duration, occurred at about 4:00 p.m. At the 7:00 p.m. sampling all four stations' coliform counts had increased a minimum of 700 percent

while the car count decreased from 11 to three. The next morning at the 7:00 sampling, under calm wind conditions, three of the four stations recorded coliform counts "too numerous to count" (TNTC)* per 100 ml. By 12:30 p.m., under the influence of a light north wind, only station 11 was still TNTC. Judging from the paucity of rainfall and the short response time of the high coliform count, the source of bacteria was probably near-shore or beach contamination which was readily washed into the lake by the rain and any accompanying over-land flow.

Relationship Between Fecal Coliform Count and Other Parameters

Turbidity

It has been reported that bacterial concentrations in sediments are commonly many times higher than in overlying waters (Van Donsel and Geldreich, 1971). In light of this premise it would seem logical to expect that a body of water whose sediment interface has been agitated would contain more bacteria than would a water body with a quiescent benthic zone. Turbidity measurements were taken assuming they would give a fair indication of the degree of sediment (and accompanying bacteria) dispersion into the overlying water.

*This means that the culture dish was over-crowded with coliform colonies -- a condition which renders accurate enumeration very impractical as well as technically meaningless (Geldreich, Jeter, and Winter, 1967).

The regression analyses determined the extent of correlation between turbidity and coliform levels. Such a correlation, if highly significant, could indicate that the sediment is an important immediate source of bacteria. Table 1 shows that turbidity was significantly correlated to coliform count in eight of the possible 12 regressions.

Temperature

The highest and lowest water temperatures encountered during this study were 33° C (92° F) and 17° C (63° F). The difference between daily maximum and minimum temperatures was generally about 3° C. Although temperature is known to be one of the major environmental factors influencing bacterial survival and growth rates, the other agents causing physical removal of the bacteria from the sampling waters probably far outweigh any effect of temperature on the observed coliform levels. If the bacteria were able to persist suspended in the sampling waters for an extended period of time (12 hours or more), ambient water temperature would have a marked effect on viable bacteria concentrations at subsequent sampling times. In such instances the general rule for fecal coliform bacteria, under starving conditions, is that survival time is inversely related to temperature (within the range of natural water temperatures) (McFeters and Stuart, 1972). Under the circumstances prevailing within the study

area, however, it is doubtful that water temperature exerts a significant influence on coliform levels. Results of multiple regression analysis support this assumption.

Reservoir Data

Along with the aforementioned parameters, change in reservoir level (feet) and change in reservoir storage (acre-feet) for each 24-hour period were incorporated into multiple regression analyses. It was postulated that large fluctuations in reservoir level and accompanying changes in storage may wash organisms from the beach areas as the water rises and falls. If this mechanism was at all operative, its effects were masked by the more dominant processes controlling coliform levels. Neither of these parameters were proven to be of significance by the regression analysis.

Thus, the only variables which were significantly correlated with coliform count were car count and turbidity. That these correlations were highly variable and all others were insignificant seems to indicate a pollutional regime produced and moderated by a complex array of physical, chemical, and biological factors. Evidently, at least a substantial portion of the observed bacteria emanate from the users themselves or as the result of some alteration of site conditions effected by the users presence (such as sediment agitation). However, in the aggregate, roughly 50 percent of the variation or fluctuation in coliform

count cannot be accounted for by the magnitude of user load and/or the turbidity level. The magnitude of coliform deposition by a given number of users and the subsequent dissemination and abatement of their numbers is a function of many variable components. The former (bacterial deposition) depends on the indigenous microbial flora, hygienic habits, and sanitary conscientiousness of individual users. The primary dissemination agents have previously been listed. In the event that survival is of importance in the attainment of given coliform levels, then factors which influence life processes must be reckoned with. Some of these factors include exposure to sunlight, temperature, pH, organic and inorganic nutrients, chemical toxicity, and the presence of competing or antagonistic organisms (Geldreich et al., 1968). All of these, acting interdependently, render very difficult the task of formulating an equation or model capable of predicting coliform levels based on chemical and physical data.

The R^2 values of Table 1 illustrate that a relationship which is of predictive value during one sampling period may not even significantly exist at subsequent periods. The actual regression equations formulated from the Canyon Lake data, therefore, are largely meaningless and are not included in this report. The real value of the statistical analysis was to identify the independent variables which consistently relate, albeit to a variable degree, to the level of fecal contamination in the waters of the swimming

area. It was expected that the intensity of use would relate positively to bacterial pollution. This was confirmed by the results shown in Table 1. Somewhat less anticipated, though, was the high proportion of significant correlations of turbidity with coliform count. There is certainly some interdependence of the variables car count and turbidity, but the fact that turbidity so many times was more closely related to coliform count than was car count indicates that turbidity carries some significance that user load alone does not. Since it provides a measure of the degree of agitation of sediments and associated microorganisms, the correlation of turbidity with coliform count suggests a substantial benthic bacterial population which is able to materially affect the quality of overlying waters when dispersed.

Fecal Streptococci Indicator Group

Use of the fecal streptococci group as a bacteriological indicator of water quality has been increasing in recent years. The earlier literature, however, was inconsistent in its terminology and definition of the group. This had caused confusion concerning their occurrence in the environment, their distribution in warm-blooded animal feces, and, thusly, their very sanitary significance. Since the advent of membrane filter methodology and the development of improved media for the detection of fecal streptococci it became necessary to revise the definition of the

streptococci indicator group. What for many years had been referred to as enterococci, is now labeled "fecal streptococci." The fecal streptococci group includes intestinal streptococci from all warm-blooded animal fecal wastes. This definition includes S. bovis and S. equinus (non-human sources) as well as the more familiar enterococci group (Lancefield's group D. streptococcus) (Geldreich and Kenner, 1969).

Fecal Coliform to Fecal Streptococci Ratio

Although the fecal streptococci indicator group is of somewhat limited sanitary significance when used alone (due to the generally ubiquitous occurrence of two varieties of one of its member species) it has been demonstrated that, within certain limitations, the fecal coliform to fecal streptococci ratio for a given water sample is of considerable utility in determining the source of pollution. Table 2 shows that the fecal coliform to fecal streptococci ratio is 4.4 for human feces and less than 0.7 for all other warm-blooded animals studied. Obviously, a useful analytical tool is implied. Water samples yielding fecal coliform to fecal streptococci ratios less than 0.7 likely are polluted by animal waste and those with ratios greater than 4.0 by human waste (Geldreich and Kenner, 1969). Intermediate values imply source combinations in proportions accordant with the proximity of the ratio to the boundary values.

Table 2. Bacterial densities and fecal streptococcus distributions in warm-blooded animal feces.*

Fecal Source	No. of Samples	Densities/G**		Ratio FC/FS	Total Strains Exam.	Occurrence (%)			
		Fecal Coliforms	Fecal Streptococci			Enterococci	S. bovis S. equinus	Atypical S. faecalis	S. faecalis liquifaciens
Human	43	13,000,000	3,000,000	4.4	1,067	73.8	None	None	26.2
Animal pets									
Cat	19	7,900,000	27,000,000	0.3	268	89.9	1.5	2.2	6.3
Dog	24	23,000,000	980,000,000	0.02	585	44.1	32.0	14.4	9.6
Rodents	24	160,000	4,600,000	0.04	539	47.3	17.1	0.4	35.3
Livestock									
Cow	11	230,000	1,300,000	0.2	438	29.7	66.2	None	4.1
Pig	11	3,300,00	84,000,000	0.04	296	78.7	18.9	None	2.4
Sheep	10	16,000,000	38,000,000	0.4	321	38.9	42.1	None	19.0
Poultry									
Duck	8	33,000,000	54,000,000	0.6	328	51.2	48.8	None	None
Chicken	10	1,300,000	3,400,000	0.4	275	77.1	1.1	None	21.8
Turkey	10	290,000	2,800,000	0.1	317	76.7	1.6	None	21.8

*From Geldreich and Kenner (1969, p. R339).

**Median values.

Fecal coliform to fecal streptococci ratios were determined for more than one hundred water samples during the course of this study. The distribution of ratios was:

<u><0.7</u>	<u>.7-2.0</u>	<u>2.0-4.0</u>	<u>>4.0</u>
73%	18%	7%	2%

The figures indicate that the dominate source of contamination was animal waste. The low ratios were prevalent at all times of the day and during all parts of the recreation season. At no time were livestock seen in the Acacia area nor was there ever any evidence of livestock having frequented the area when investigators were not present. Certainly no wild animal capable of contributing significant contamination was present during the day when humans inhabited the area. Whenever moderate numbers of people were gathered at the swimming area, however, pet dogs could be seen freely romping over the beach and in the water. Fecal matter was occasionally in evidence on the beach. No doubt a portion of the water contamination was of canine origin, but it is impossible to determine just how much.

To further address the question, "What is the source of the fecal contamination?" approximately 80 fecal streptococci colonies from 40 membrane filter plates of the July 4 and July 7 samplings were streaked for isolation on KF agar and biochemically assayed for strain type according to Breed, Murray, and Smith (1957) and the procedure of Geldreich,

Clark, and Huff (1964). By comparing the resultant fecal streptococci distribution of this analysis with those of Geldreich and Kenner (1969) (Table 2) it was hoped to gain some insight into the source of fecal streptococci. All the fecal streptococci colonies assayed, however, were enterococci. This finding is incongruous with the distributions given in Table 2 for the feces of humans and dogs, the two most likely sources of fecal contamination in the Acacia swimming area. A glance at the table shows that the distribution of 100 percent enterococci fits none of the distributions shown. Even if the organisms were entirely of human origin about one-fourth of the isolated colonies should have been a non-typical variety (Streptococcus faecalis var. liquifaciens) of the dominant member (S. faecalis) of the enterococci group. Likewise, water freshly contaminated by dog feces should contain about one-third S. bovis and S. equinus. However, if as suspected, bacteria are stored in bottom sediments and later dispersed by swimmers, the resultant fecal streptococci distributions after storage could greatly differ from those shown in Table 2 even though the ultimate bacterial source is the same. According to Figure 8*, a fecal streptococci distribution originally characteristic of human pollution (74% enterococci and 26% S. faecalis

*Since the data depicted in Figure 8 are for stormwater storage, it is assumed that the relative rates of survival of the fecal streptococci biotypes will be the same in bottom sediments as in stormwater.

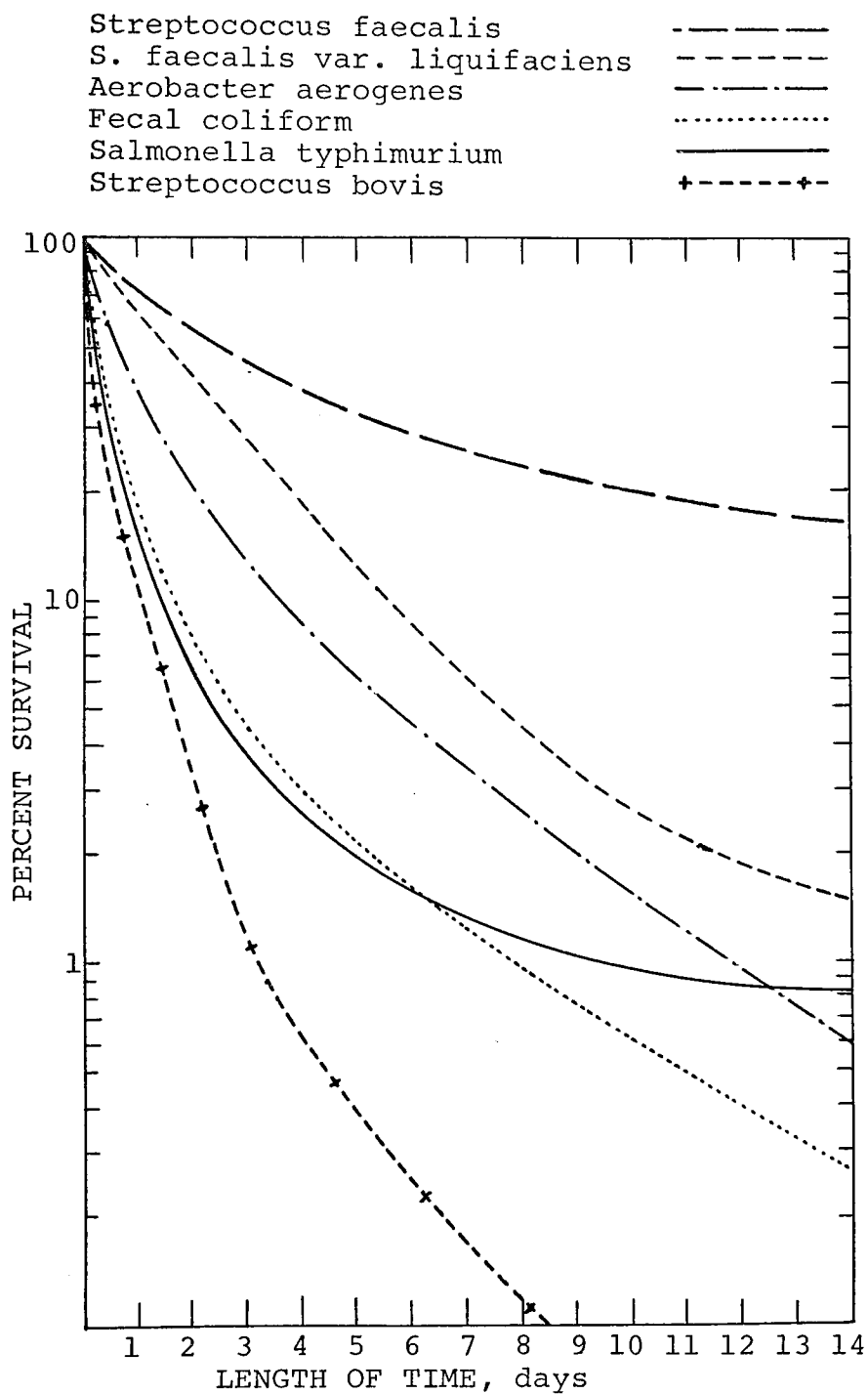


Figure 8. Persistence of selected enteric bacteria in stormwater stored at 20° C. --

(From Geldreich and Kenner, 1969, p. R342.)

var. liquifaciens) would, after only seven days of storage, consist of 90 percent enterococci. After a total of 14 days storage that same distribution would be composed of 97 percent enterococci and only 3 percent S. faecalis var. liquifaciens. The figure also shows that a fecal streptococci distribution characteristic of dog feces will shift within seven days to one predominantly composed of the enterococci group due to the virtual extinction of S. bovis and S. equinis.

Bacterial Analysis of Sediment

The results of the analysis of sediment samples are shown in Table 3. The extremely high concentrations of bacteria found in the bottom sediment are consistent with findings by Van Donsel and Geldreich (1971) who report fecal bacteria commonly 100 to 1,000 times as numerous in mud samples as in the overlying water. Only five water sample analyses were available to compare with their corresponding mud sample results, but for these five the fecal coliform concentrations in the sediment were 21, 490, 1350, 2700, and 6000 times those in the overlying water. Fecal streptococci sediment-to-water ratios were similar. Of the fecal coliform to fecal streptococci ratios calculated for the sediment samples 81 percent were less than 0.7 and the remaining 19 percent were between 0.7 and 2.0. This distribution of ratios is very similar to that observed for the water samples.

Table 3. Results of bacterial analyses of sediment samples.

-- (Number/100 ml of supernatant)

Date (1974)	Station	Total Coliform	Fecal Coliform	Fecal Streptococci	FC/FS
June 11	1	1600	920	>2400	<0.37
"	2	>2400	170	920	0.18
"	3	920	49	280	0.18
"	4	540	70	1600	0.04
"	5	920	280	350	0.80
"	6	>2400	>2400	>2400	*
"	7	>2400	>2400	>2400	*
"	8	>2400	130	1600	0.08
June 25	1	9200	330	2400	0.14
"	2	5400	790	1800	0.44
"	3	3500	1300	>24,000	<0.05
"	4	9200	1400	2400	0.58
"	5	16,000	3500	5400	0.65
"	6	16,000	2200	5400	0.41
"	7	>24,000	3500	>24,000	<0.15
"	8	>24,000	16,000	9200	1.74
July 9	1	>24,000	1300	5400	0.24
"	2	16,000	5400	5400	1.00
"	3	16,000	5400	5400	1.00
"	4	>24,000	5400	9200	0.59
"	5	9200	5400	9200	0.59
"	6	>24,000	>24,000	>24,000	*
"	7	>24,000	5400	>24,000	<0.23
"	8	>24,000	5400	16,000	0.34

*Ratio indeterminate.

In view of the foregoing data it seems only logical to assume that a very significant proportion of the coliforms occurring in the sampling waters are of benthic origin. They are dispersed into the overlying water as sediment is agitated by swimmers and wave action. The ultimate, biological source of the bacteria must be postulated, in the absence of contrary evidence, to be the human recreationists and their pets.

The hypothesized circumstantial sequence responsible for the observed data is as follows.

Fecal coliform and fecal streptococci bacteria are introduced into the water of the swimming area by human users and dogs. The value of the fecal coliform to fecal streptococci ratio in freshly contaminated water will depend on the relative pollutional contribution from each of these sources. The pollutional load of any individual day or weekend is relatively small. Many of the bacteria, however, are deposited in the benthic zone of the immediate area by the process of sedimentation. In the protective environment of the bottom sediments microbial survival is greatly enhanced (Van Donsel and Geldreich, 1971). Thus, at the beginning of the recreation season concentrations of sediment stored bacteria are minimal (complete die-off from the previous year is assumed) and copious recreational activity results in only minor levels of bacterial water pollution. As the season progresses, an increment of bacteria is added to the

sediment population each weekend (the swimming area receives little use through the week). Correspondingly, water bacterial counts, under conditions of equivalent area usage, increase with seasonal progression due to the continual enrichment of the bacterial reservoir (i.e., the bottom sediments). This phenomenon is culminated at some time toward the end of the season when conditions dictate a reduction in increment additions of bacteria (i.e., decrease in area usage) and possibly a lessening of bacterial survival times due to changes in water temperature and chemistry.

The preceding theory recognizes sediment storage as the immediate source of the dominate portion of bacterial contamination occurring in the swimming area water. Figure 9 shows survival characteristics, in lake sediment mud, for the two coliform groups, fecal streptococci, and Salmonella. The survival curves clearly show that fecal streptococci far out-live fecal coliforms. A similar divergence of survival rates has been shown to occur in stormwater stored at 20 degrees C (Geldreich and Kenner, 1969). A fecal coliform to fecal streptococci ratio of initial value 4.0 will, as Figure 9 illustrates, decrease within a period of seven days to a value of approximately 1.0. It can be seen that even though the contamination may be predominately from human users, a brief storage in the bottom sediment allows an alteration of the bacterial populations such that,

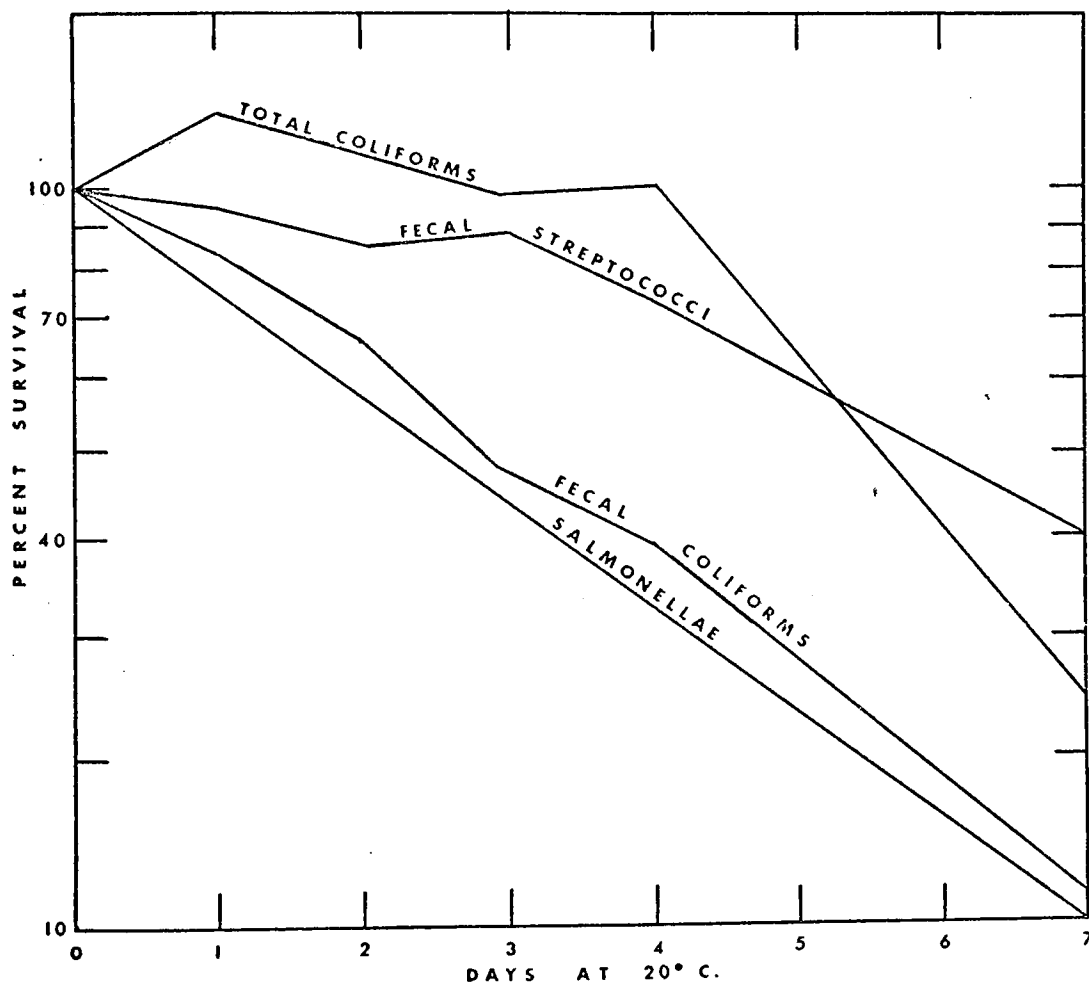


Figure 9. Averaged survival of salmonellae and indicator bacteria in 3 mud samples stored at 20° C. --

(From Van Donsel and Geldreich, 1971, p. 1083.)

upon subsequent dispersion into overlying waters, the fecal coliform to fecal streptococci ratios assume values incongruous with those characteristic of waters polluted by human waste.

The foregoing discussion assumes that, as is normally thought to be the case for fresh water lakes and streams, the enteric bacteria exist under starving conditions with growth being limited primarily by the nonavailability of a suitable carbon source. Studies have shown, though, that in some instances only a very minute quantity of organic matter is necessary to actually support bacterial growth. Allen, Pasley, and Pierce (1952) report that 1.0 ppm organic matter may induce a profound departure from the true form of the death curve for Escherichia coli, the predominant constituent of the fecal coliform group. Substantial E. coli growth occurred in a medium containing only 0.2 ppm peptone, 0.05 ppm glucose, and a 5 day BOD (18.3 degrees C) of 0.26 ppm. Shehata and Marr (1971) obtained substantial growth for E. coli at glucose levels as low as 0.018 ppm and at phosphate levels of 10 ppm. At nutrient concentrations near these values the E. coli growth rate was directly proportional to the nutrient concentration.

Hendricks and Morrison (1967) were able to grow E. coli, Enterobacter aerogenes, a Salmonella and a Shigella species in the extract from stream bottom samples collected near a sewage outfall. At 16 degrees C the least population

growth for these four organisms in 72 hours was a 16-fold increase. It was noted that extensive growth of enteric bacteria can occur in the microenvironment of the bottom sediment where nutrients can be in high concentration surrounded by a relatively vast area devoid of nutrients. A later study by Hendricks (1972) demonstrated that there are sufficient nutrients in autoclaved river water taken from below a sewage outfall (no designation of type of sewage treatment) to support limited bacterial growth.

In a related investigation, Hendricks (1970) studied nutrient binding by river bottom sediments and conditions for their removal and use by enteric bacteria. He found that very high concentrations of ammonia nitrogen, protein, and hexose can be adsorbed by bottom sediments which, after relatively mild laboratory treatment, can be metabolized by pathogenic and non-pathogenic bacteria to promote growth.

The studies cited suggest that some aquatic systems probably contain sufficient nutrients to support the growth of bacterial populations. Lake and stream bottom sediments are particularly susceptible to organic enrichment by the processes of mechanical sedimentation and chemical adsorption of nutrient compounds on silt and clay particles. Areas subject to concentrated human or animal activity may be so enriched. It is, therefore, quite possible that the

benthic bacteria in the Acacia area are exogenously metabolizing and reproducing, thereby augmenting the water pollution problem as the sediments are disturbed.

CONCLUSIONS AND RECOMMENDATIONS

Throughout the period of study, 14 of 256 (5.5%) water samples taken from the four sampling stations equaled or exceeded the 200 fecal coliforms per 100 ml standard. Five of the high counts were associated with a rain shower. Some perspective of these results may be gained by considering the following recommendations of the Federal Water Pollution Control Administration with regard to water quality for water contact activities: "... based on a minimum of not less than five samples taken over not more than a 30-day period, the fecal coliform content of primary contact recreation waters shall not exceed a geometric (log) mean of 200/100 ml, nor shall more than 10 percent of total samples during any 30-day period exceed 400/100 ml." Under the sampling scheme used in this study, waters of the Acacia swimming area are easily within the limits of the above recommendations. The intent of the recommendations, though, is to insure that recreationists undergo minimal risk of exposure to pathogenic organisms. The validity of the 200 fecal coliform per 100 ml standard is supported by studies which show that sharp increases in the frequency of Salmonella detection occur when fecal coliform densities exceed 200 organisms per 100 ml of fresh water (Dutka and Bell, 1973, and Geldreich, 1970). While conformity to the 200

fecal coliform per 100 ml level is always desirable, it is sometimes not practical. This is the essence of the recommendation by the FWPCA.

Compliance with the spirit of the federal standards (i.e., that a recreational water at all times contain less than 200 fecal coliforms per 100 ml) in the Acacia swimming area may not always be possible under unlimited use regardless of what other steps are taken. It is quite possible that the area has a carrying capacity such that, when exceeded, the coliform standard will be breeched. It is also possible that if appropriate steps are taken to reduce the probability and/or magnitude of contamination and to control it once it has occurred, restrictions on the number of users would not be necessary. Those steps will now be outlined.

As previously noted, dogs were in evidence in the Acacia area whenever large numbers of people were present. Because dog excreta is known to be a potential source of pathogenic organisms (Summers, 1967, and Butler and Busbee, 1967) contamination from dog waste should be guarded against. The ordinance prohibiting pets in the picnic and swimming area should be enforced, particularly on high-use weekends.

Boats driven by large horse-power engines are very common on Canyon Lake. The propellers of these engines are capable of disturbing sediment at depths of many feet. As the sediment is dispersed into the water so also are the

microorganisms harbored there. To prevent this undesirable circumstance from detrimentally affecting the water quality of the swimming area, a wide buffer zone should be established around the swimming area into which no motor boat may enter. This buffer zone should be marked by a second set of bouys at a depth where the propellers do not disturb the bottom sediments. The outlying set of swimmer-safety bouys now surrounding the Acacia area would serve this purpose well if they were enforced. Boaters were frequently seen beaching their craft at the periphery of the swimming area and, on a few occasions, boats were seen lashed to the bouys which define the boundary of the swimming area. These practices aid in the resuspension of settled organisms and should be discontinued.

Two rain showers occurred during this study while sampling was in progress. A light shower fell on August 13, 1973, and a fairly heavy rain storm struck on July 7, 1974*. Fecal bacteria levels rose sharply after each of the rains. The high winds accompanying these summer convective storms vigorously churn the near-shore waters so that they become heavily laden with sediment. Any bacteria which were present in the sediment are also dispersed into the water. This

*For undetermined reasons most of the fecal coliform cultures for July 7 were overgrown with non-fecal coliform organisms, thus rendering the cultures unusable. The fecal streptococci cultures, however, were good and the results from them form the basis for the following statement.

mechanism, along with contamination incurred by runoff which reaches the lake from the beach, picnic area, and parking lot, is responsible for the sudden and striking increases in fecal bacteria levels following a rain.

To what degree water quality will diminish as the result of a rainstorm will depend on the quantity and intensity of rainfall, the velocity and duration of accompanying wind, sediment bacteria levels, and the sanitary condition of the recreation area near the water. It is likely that intense summer storms will always cause the fecal coliform count in the swimming area to exceed 200 per 100 ml. It would be advisable, therefore, to close the area to swimming following a heavy rain until such time that bacteriological monitoring of the water demonstrates resumed compliance with safety standards. No one magnitude of rainfall which would be required to produce unsafe water could apply at all times of the recreation season, but the data indicate that sub-standard water quality conditions may be associated with as little as one-quarter inch of rain.

Since the very substantial sedimentary bacterial population of the swimming area probably contributes a large proportion of the fecal bacteria found in the overlying water, measures which would decrease this population should lessen the frequency of high bacterial counts. One such measure might be the chlorination of bottom sediment in the swimming area. During the week when the reservoir level

is low solid calcium hypochlorite ($\text{Ca}(\text{OCl})_2$) could easily be scattered in the shallows of the swimming area which bears most of the recreational traffic. The pellets would sink to dissolve on the bottom where the disinfectant chlorine could reduce bacterial levels. The feasibility of this treatment would need to be studied before implementation, though, as at least two complications might arise which could render the treatment ineffectual. First, the chlorine demand of the bottom material may be so high as to require an inordinate amount of chlorine to achieve the desired disinfection. Secondly, the chlorine might not be able to penetrate the sediment to a depth great enough to kill a significant proportion of the bacteria. Nonetheless, in view of the benefit which could be gained in this circumstance from an efficacious disinfectant, the expediency of its use should be investigated.

A practice which should decrease the threat of serious bacterial pollution is the establishment of swimming beaches in areas where water currents are active. If the fecal bacteria are quickly moved out of the recreation area by currents and diluted with uncontaminated water their concentrations are less likely to reach undesirably high levels in the bottom sediment. Areas where currents are active could be located by tracer dye studies.

Similarly, it would be helpful to locate boat ramps and other possible sources of sediment disruption in places where wind and currents would not normally carry the sediment and associated organisms to nearby swimming areas.

This study and others attest to the importance of the role of a sedimentary bacterial population in determining the bacterial quality of its overlying water. Van Donzel and Geldreich (1971) have pointed out that "... mud may serve as a concentrated and stable index of the quality of the overlying water, particularly where there is a great variability in the bacterial quality of the water." Such variability does certainly exist in the waters of the Acacia swimming area.

The determination of sediment bacterial levels on a regular basis could provide a valuable management tool for Acacia and areas like it. While such sampling would not satisfy current water quality criteria, it would indicate the relative sanitary condition of the area. Once a data base and some experience is accumulated, it may be possible to relate sediment bacterial levels to the level of contamination in the overlying water under given conditions. This would allow management to anticipate potential pollution problems before they occur so that appropriate steps could be taken to protect recreationists from exposure to pathogens.

LITERATURE CITED

- Allen, L.A., S.M. Pasley, and M.A.F. Pierce. 1952. Some factors affecting the viability of fecal bacteria in water. *J. of General Microbiology*, 7:36.
- Barbaro, R.D., B.J. Carroll, L.B. Tebo, and L.C. Walters. 1969. Bacteriological water quality of several recreational areas on the Ross Barnett Reservoir. *J. of Water Pollution Control Federation*, 41:1330.
- Breed, R.S., E.G. Murray, and N.R. Smith. 1957. *Bergey's manual of determinative bacteriology*, 7 Williams and Wilkins Company, Baltimore.
- Butler, C.E. and C.E. Busbee. 1967. Human enteric pathogens in dogs in Fairbanks, Alaska. *Public Health Reports*, 82:465.
- Carswell, J.K., J.M. Symons, and G.G. Robeck. 1969. Research on recreational use of watersheds and reservoirs. *J. of American Water Works Assn.*, 61:297.
- Davis, H.S. 1969. Salmonella-fecal coliform relationships in streams. Paper presented at New England Water Pollution Control Assn. meeting, Wakefield, Mass.
- Dutka, B.J. and J.B. Bell. 1973. Isolation of Salmonella from moderately polluted waters. *J. of Water Pollution Control Federation*, 45:317.
- Federal Water Pollution Control Administration. 1968. Report of the Committee on Water Quality Criteria, 243 pp. U.S. Government Printing Office, Washington, D.C.
- Gallagher, T.P. and D.F. Spino. 1968. The significance of numbers of coliform bacteria as an indicator of enteric pathogens. *Water Research*, 2:169.
- Geldreich, E.E. 1967. Fecal coliform concepts in stream pollution. *Water and Sewage Works*, 114:R-98, 107.
- Geldreich, E.E. 1970. Applying bacteriological parameters to recreational water quality. *J. of American Water Works Assn.*, 62:113.

- Geldreich, E.E. 1972. Buffalo Lake recreational water quality: a study in bacteriological data interpretation. *Water Research*, 6:913.
- Geldreich, E.E., L.C. Best, B.A. Kenner, and D.J. Van Donsel. 1968. The bacteriological aspects of stormwater pollution. *J. of Water Pollution Control Federation*, 40:1861.
- Geldreich, E.E., H.F. Clark, and C.B. Huff. 1964. A study of pollution indicators in a waste stabilization pond. *J. of Water Pollution Control Federation*, 36:1372.
- Geldreich, E.E., H.L. Jeter, and J.A. Winter. 1967. Technical considerations in applying the membrane filter procedure. *Health Laboratory Science*, 4:113.
- Geldreich, E.E. and B.A. Kenner. 1969. Concepts of fecal streptococci in stream pollution. *J. of Water Pollution Control Federation*, 41:R336.
- Hanes, N.B. and A.J. Fossa. 1970. A quantitative analysis of the effects of bathers on recreational water quality. *Advances in Water Pollution Research*, 2:HA-9.
- Hendricks, C.W. 1970. Enteric bacterial metabolism of stream sediment eluates. *Canadian J. of Microbiology*, 17:551.
- Hendricks, C.W. 1972. Enteric bacterial growth rates in river water. *Applied Microbiology*, 24:168.
- Hendricks, C.W. and S.M. Morrison. 1967. Multiplication and growth of selected enteric bacteria in clear mountain stream water. *Water Research*, 1:567.
- Lee, R.D., J.M. Symons, and G.G. Robeck. 1970. Watershed human-use level and water quality. *J. of American Water Works Assn.*, 62:412.
- Mackenthum, K.M. and W.M. Ingram. 1967. Biological associated problems in freshwater environments - their identification, investigation, and control. U.S. Dept. of Interior, Federal Water Pollution Control Administration.
- McPeters, G.A. and D.G. Stuart. 1972. Survival of coliform bacteria in natural waters: field and laboratory studies with membrane filter chambers. *Applied Microbiology*, 24:805.

- Mechalas, B.J., K.K. Hekimian, L.A. Schinazi, and R.H. Dudley. 1972. Water quality criteria data book, Vol. 4-an investigation into recreational water quality. U.S. Environmental Protection Agency. 18040 DAZ.
- Moore, B. 1959. Sewage contamination of coastal bathing waters in England and Wales. A bacteriological and epidemiological study. *J. of Hygiene, Camb.*, 57:435.
- Pelczar, M.J. and R.D. Reid. 1965. *Microbiology*, 2nd ed. McGraw-Hill, New York.
- Postgate, J.R. and J.R. Hunter. 1962. The survival of starved bacteria. *J. of General Microbiology*, 29:233.
- Robinton, E.D. and E.W. Mood. 1966. A quantitative and qualitative appraisal of microbial pollution of water by swimmers: a preliminary report. *J. of Hygiene (G.B.)*, 64:489.
- Shehata, T.E. and A.G. Marr. 1971. Effect of nutrient concentration on the growth of Escherichia coli. *J. of Bacteriology*, 107:210.
- Smith, R.J., R.M. Twedt, and L.K. Flanigan. 1973. Relationships of indicator and pathogenic bacteria in stream waters. *J. of Water Pollution Control Federation*, 45:1736.
- Standard methods for the examination of water and wastewater. 1971. 13th ed., American Public Health Assn., New York.
- Stevenson, A.H. 1953. Studies of bathing water quality and health. *American J. of Public Health*, 43:529.
- Summers, J.L. 1967. The sanitary significance of pollution of water by domestic and wild animals - a literature review. USPHS Shellfish Sanitation Technical Report.
- Van Donsel, D.J. and E.E. Geldreich. 1971. Relationships of Salmonella to fecal coliforms in bottom sediments. *Water Research (G.B.)*, 5:1079.