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Indirect Reuse of Domestic Wastewater for Recreational Lakes: Evaluation of the Sanitary Quality of the Yellowhouse Canyon Lakes, Lubbock, Texas

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Abstract

The city of Lubbock, Texas has practiced domestic wastewater reuse through land irrigation since the 1930's. This city's wastewaters have been used to irrigate the Gray farm. The hydraulic loading of this farm has been such that the wastewaters developed a groundwater mound under the farm. As part of developing a series of recreational lakes (Yellowhouse Canyon Lakes) within the city, groundwaters were pumped from this mound to the uppermost lake. During low runoff periods, the Gray farm groundwater was the primary source of water for these lakes. A study was conducted on the sanitary quality of the Yellowhouse Canyon Lakes located in and near the city of Lubbock, Texas. Contact recreation (swimming) was not allowed in these lakes, based in part on public health considerations, because of their potential contamination by domestic wastewaters. During a period of drought, i.e., no surface runoff to the lakes, the fecal coliform-fecal streptococcus numbers and ratios in all of the lakes met US EPA water quality criteria and state of Texas water quality standards for swimming in the lakes. However, moderate to intensive rainfall-runoff events caused the fecal coliform-fecal streptococcus numbers to increase significantly. While generally these organism ratios would indicate that they are being derived primarily from warm-blooded (non-human) animals, the magnitude of the increase in the numbers of both organisms and the possibility of domestic wastewater being contributed to the lakes during rainfall-runoff events raises questions about the public health risk presented by swimming and water skiing in these waterbodies. It is possible that human enteric pathogens are present in sufficient concentrations after a runoff event to significantly increase the risk of contracting enteric (intestinal) diseases as a result of contact recreation. The fecal coliform-fecal streptococcus numbers decrease rapidly, usually within a few weeks following a rainfall-runoff event, indicating rapid die-off and removal of these organisms from the water.

It is concluded that there is minimal risk of contracting intestinal diseases from swimming, water skiing, or other contact recreation in the Yellowhouse Canyon Lakes during periods of no or little rainfall which results in small runoff to the lakes. However, caution should be exercised in swimming in these waters during or immediately after, i.e., for a period of several weeks, a rainfall-runoff event that results in moderate to large amounts of runoff entering the lakes.

Introduction

The Yellowhouse Canyon Lakes are a series of impoundments on the North Fork of the Double Mountain Fork of the Brazos River (NF/DMF/BR) located within the city and within a few miles east of the city of Lubbock, Texas (see Figure 1).

Introduction

The Yellowhouse Canyon Lakes are a series of impoundments on the North Fork of the Double Mountain Fork of the Brazos River (NF/DMF/BR) located within the city and within a few miles east of the city of Lubbock, Texas (see Figure 1). These waterbodies represent an important recreational asset to the residents of the region. They are currently used primarily for warm water sport fishing and picnicking. The upper lakes within Lubbock are also used for non-motorized boating. The two lower lakes, Buffalo Springs Lake and Lake Ransom, are utilized for motorized boating and water skiing. Swimming is not allowed in any of the lakes. There is interest, however, in expanding the uses of these lakes to include swimming. Contact recreation (swimming and wading) is restricted based in part on public health considerations associated with the concern about the possibility of these waters containing human pathogens that could cause such diseases as typhoid fever, infectious hepatitis, amoebic and bacillary dysenteries, giardiasis, etc.

The human pathogens potentially present in the lakes could be derived from several sources, including the well water pumped from the Gray farm located east of Lubbock to Lakes I or II. Well water is derived from a groundwater mound resulting from excessive application of the city of Lubbock's domestic wastewaters for crop irrigation on the Gray farm. This well water is the primary source of make-up water for the upper lakes (I and II) and contributes to the waters of all lakes.

Lake III, MacKenzie Park Lagoon, and Lake VI also receive city of Lubbock urban stormwater drainage via storm sewers. While the city has separate sanitary (household, commercial and industrial wastewaters) and urban stormwater drainage sewerage systems, there is concern about the sanitary quality of urban stormwater drainage because of the possibility of leaks in the sanitary system, cross connections between the two systems, and the introduction of fecal material from animals within the city.

Buffalo Springs Lake receives water discharged from Lake VI, as well as both surface and groundwater seepage from the Gray farm area. The surface water runoff could contain drainage from land that has been irrigated with Lubbock domestic sewage. Most of the city of Lubbock domestic sewage applied at the Gray farm is non-chlorinated and would be expected to contain human pathogens. The Gray farm drainage could readily contain animal manure from cattle. While according to the Texas Department of Water Resources (TDWR, 1981) permit there should be no drainage from the Gray farm to the NF/DMF/BR, the authors observed drainage from the Gray farm in early March, 1984 as part of an inspection of the NF/DMF/BR between 50th Street, Loop 289, and Buffalo Springs Lake. Buffalo Springs Lake also could receive human pathogens via runoff from the community of Buffalo Springs Lake's streets and breaks in the sewerage system serving the campgrounds and homes-cottages surrounding the lake.

Lake Ransom could receive human pathogens from Buffalo Springs Lake discharge, as well as from breaks in the Ransom Canyon sewerage system and street runoff. Therefore, there is adequate justification to be concerned about the sanitary quality of the Yellowhouse Canyon Lakes and, while some samples have been taken of these waters over the years in order to investigate their fecal coliform content, no systematic study has been undertaken of the sanitary quality of the Yellowhouse Canyon Lakes system. This paper presents results of a study conducted during the summer and fall of 1983 in which periodic samples

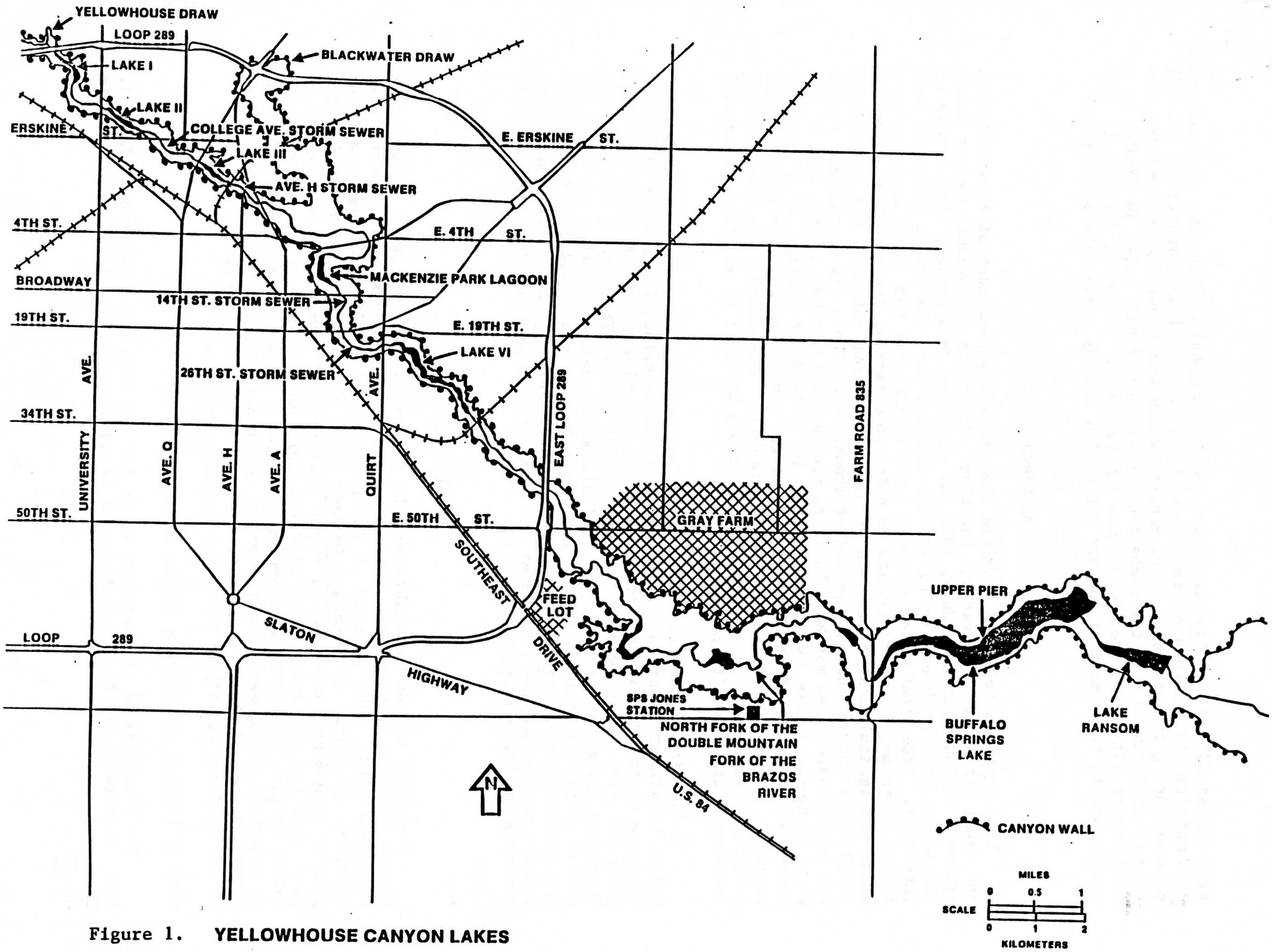

Figure 1. YELLOWHOUSE CANYON LAKES

were taken of each of the Yellowhouse Canyon Lakes for the purpose of determining the numbers of fecal coliform and fecal streptococcus (FC-FS) present during this period. Also, consideration was given to determining the causes of increases in the numbers of FC-FS. While this paper is focused on a particular situation for a series of lakes in Lubbock, Texas, it has applicability to permitting contact recreation in many urban lake situations.

Approach

The approach followed involved the periodic measurement of fecal coliform and fecal streptococci at various locations within the Yellowhouse Canyon Lakes system. Beginning in late June, 1983 and extending into August, 1983 samples of the water from each of the lakes were obtained near the dam at about two week intervals. After that date, through late summer and the fall, samples were taken after major runoff events in order to determine the potential impact of urban and agricultural runoff on FC-FS numbers and ratios. The mid-summer sampling occurred during a period of drought when there was no rainfall runoff for approximately two months. Further, during late October, 1983, one of the most intense rains ever experienced in Lubbock (7 in/day, 17.8 cm/day) occurred. Sampling of the lakes persisted for several weeks after this rainfall event in order to examine the FC-FS die-off. Therefore, the study period covered several months of drought conditions followed by moderate and several intense rainfall-runoff events.

In addition to the samples collected by the authors, the city of Lubbock Water Treatment Plant laboratory had collected samples of the urban stormwater drainage within the city and to the east of the city on the NF/DMF/BR. This data has also been reviewed as part of this study. The city of Lubbock Water Treatment Plant laboratory conducted all FC-FS analyses using the membrane filter technique for determination of the Most Probable Number (MPN) of these organisms following Standard Methods procedures (APHA et al., 1981). Additional details on the sampling procedures and locations, as well as the actual data, is presented by Lee and Winkler (1984).

Results

A summary of the data obtained in this study is discussed below. The interpretation of this data is based on the state of Texas Department of Water Resources (TDWR, 1981) standard of 200 organisms per 100 ml of water and the approach advocated in Standard Methods (APHA et al., 1981) where FC-FS ratios greater than 4 are indicative of fecal coliforms of human origin. Ratios of less than 0.7 are indicative of fecal coliforms of non-human, warm-blooded animal origin, and fecal coliform ratios between 0.7 and 4 are considered to be of possible mixed warm-blooded animal and human origin. A subsequent section discusses some of the problems with the use of fecal coliforms as an indicator of the sanitary quality of water for contact recreation.

City of Lubbock Yellowhouse Canyon Lakes

The locations of the sampling sites for the data are presented in Table 1. Table 2 presents the fecal coliform and fecal streptococcus data obtained in this study.

TABLE 1

LOCATION OF SITES SAMPLED FOR BACTERIOLOGICAL ANALYSIS

Designation	Description of Sample Site
Lake I	Mid-dam at Lake I
Lake II	Mid-dam at Lake II
College Ave. Storm Sewer	Off Avenue U below Lake II
Lake III	Mid-dam at Lake III
Avenue H Storm Sewer	Below Lake III and Atzlan Park off Avenue H
Yellowhouse Canyon @ N. MacKenzie Park	NF/DMF/BR* below and to the left of the Avenue A MacKenzie Park entrance
MacKenzie Park Lagoon Outlet	NF/DMF/BR at outlet of MacKenzie Park dam near Broadway Avenue.
14th Street Storm Sewer	West on Broadway to an extension of 14th Street
26th Street Storm Sewer	Southwest of Mae Simmons Park near railroad
Lake VI	Mid-dam at Lake VI
Railroad (37th & Guava)	NF/DMF/BR below Lake VI dam
50th & Loop 289	NF/DMF/BR at 50th Street near Loop 289
Buffalo Lake Entrance	NF/DMF/BR at FM 835
Mid-upper part Buffalo Springs Lake	End of pier at upper Buffalo Springs Lake
Buffalo Springs Lake Party House	End of pier near Party House at mid-Buffalo Springs Lake
Buffalo Springs near Dam	End of pier near dam
Lake Ransom near Dam	End of pier near dam

*North Fork of the Double Mountain Fork of the Brazos River

Table 2 (continued)

	Date of Sample Collection											
	2-18-83			3-23-83			6-13-83			6-29-83		
	Fecal Coliforms No./100 ml	Fecal Streptococcus No./100 ml	FC/FS Ratio	Fecal Coliforms No./100 ml	Fecal Streptococcus No./100 ml	FC/FS Ratio	Fecal Coliforms No./100 ml	Fecal Streptococcus No./100 ml	FC/FS Ratio	Fecal Coliforms No./100 ml	Fecal Streptococcus No./100 ml	FC/FS Ratio
Lake I	-	-	-	-	-	-	-	-	-	10	0	*
Lake II	-	-	-	-	-	-	-	-	-	30	2,100	0.0
College Ave. Storm Sewer	80	120	0.7	60	40	*	7,700	4,000	1.9	-	-	-
Lake III	-	-	-	-	-	-	-	-	-	20	0	*
Ave. H Storm Sewer	-	-	-	-	-	-	8,200	3,800	2.2	-	-	-
Yellowhouse Canyon @ N. MacKenzie Park (creek)	100	180	0.6	80	100	0.8	300	700	0.4	-	-	-
MacKenzie Park Lagoon Outlet	660	1,140	0.6	350	500	0.7	40	50	*	10	400	0.0
14th St. Storm Sewer	10	40	*	20	30	*	140	420	0.3	-	-	-
26th St. Storm Sewer	480	100	4.8	530	610	0.9	100	390	0.3	-	-	-
Lake VI	-	-	-	-	-	-	-	-	-	20	100	0.2
Railroad (37th & Guava) (creek)	30	140	0.2	40	100	0.4	30	100	0.3	-	-	-
50th at Loop 289 (creek)	610	360	1.7	900	350	2.6	100	400	0.2	330	700	0.5
FM 835 at entrance to Buffalo Springs Lake (creek)	60	300	0.2	40	110	0.4	10	30	*	20	1,300	0.0
Mid-upper part Buffalo Springs Lake	-	-	-	-	-	-	-	-	-	40	1,000	0.0
Buffalo Springs Lake Party House	-	-	-	-	-	-	-	-	-	-	-	-
Buffalo Springs Lake near Dam	-	-	-	-	-	-	-	-	-	10	0	*
Lake Ransom near Dam	-	-	-	-	-	-	-	-	-	0	0	*

- no sample taken
* no applicable ratio
TNTC too numerous to count
CONF confluent growth

able 2 (continued)

Date of Sample Collection

	10-2-83			10-13-83			10-21-83			10-28-83		
	Fecal Coliforms No./100 ml	Fecal Streptococcus No./100 ml	FC/FS Ratio	Fecal Coliforms No./100 ml	Fecal Streptococcus No./100 ml	FC/FS Ratio	Fecal Coliforms No./100 ml	Fecal Streptococcus No./100 ml	FC/FS Ratio	Fecal Coliforms No./100 ml	Fecal Streptococcus No./100 ml	FC/FS Ratio
Lake I	-	-	-	10	40	*	-	-	-	11,200	900	12.4
Lake II	-	-	-	310	160	1.9	TNTC	TNTC	*	1,200	1,500	0.8
College Ave. Storm Sewer	120	60	*	-	-	-	-	-	-	-	-	-
Lake III	-	-	-	840	270	3.1	TNTC	TNTC	*	2,800	2,500	1.1
Ave. H Storm Sewer	420	180	2.3	-	-	-	-	-	-	-	-	-
Yellowhouse Canyon @ N. MacKenzie Park (creek)	-	-	-	-	-	-	-	-	-	-	-	-
MacKenzie Park Lagoon Outlet	-	-	-	1,140	660	1.7	TNTC	TNTC	*	6,100	2,400	2.5
14th St. Storm Sewer	300	200	1.5	-	-	-	-	-	-	-	-	-
26th St. Storm Sewer	TNTC	300	*	-	-	-	-	-	-	-	-	-
Lake VI	-	-	-	260	140	1.8	19,000	1,400	13.6	1,000	300	3.3
Railroad (37th & Guava) (creek)	-	-	-	-	-	-	-	-	-	-	-	-
50th at Loop 289 (creek)	-	-	-	760	90	*	TNTC	TNTC	*	7,700	2,200	3.5
FM 835 at entrance to Buffalo Springs Lake (creek)	-	-	-	1,020	30	*	16,000	8,000	2.0	5,000	2,400	2.1
Mid-upper part Buffalo Springs Lake	-	-	-	930	230	4.0	3,400	2,600	1.3	2,100	1,200	1.8
Buffalo Springs Lake Party House	-	-	-	10	10	*	-	-	-	-	-	-
Buffalo Springs Lake near Dam	-	-	-	-	-	-	2,700	900	3.0	1,800	700	2.6
Lake Ransom near Dam	-	-	-	130	110	1.2	3,200	4,000	0.8	1,300	5,000	0.26

- no sample taken
* no applicable ratio
TNTC too numerous to count

Table 2 (continued)

	Date of Sample Collection								
	11-16-83			11-17-83			12-18-83		
	Fecal Coliforms No./100 ml	Fecal Streptococcus No./100 ml	FC/FS Ratio	Fecal Coliforms No./100 ml	Fecal Streptococcus No./100 ml	FC/FS Ratio	Fecal Coliforms No./100 ml	Fecal Streptococcus No./100 ml	FC/FS Ratio
Lake I	-	-	-	50	3,400	0.0	-	-	-
Lake II	-	-	-	50	4,200	0.0	-	-	-
College Ave. Storm Sewer	200	100	2.0	-	-	-	900	800	1.1
Lake III	-	-	-	400	400	1.0	-	-	-
Ave. H. Storm Sewer	2,000	3,700	0.5	-	-	-	-	-	-
Yellowhouse Canyon @ N. MacKenzie Park (creek)	400	500	0.8	-	-	-	200	100	2.0
MacKenzie Park Lagoon Outlet	200	500	0.4	400	200	2.0	700	300	2.3
14th St. Storm Sewer	-	-	-	-	-	-	-	-	-
26th St. Storm Sewer	-	-	-	-	-	-	-	-	-
Lake VI	-	-	-	50	200	0.2	-	-	-
Railroad (37th & Guava) (creek)	100	100	1.0	-	-	-	100	100	1.0
50th at Loop 289 (creek)	1,900	2,400	0.8	4,600	2,600	1.8	100	100	1.0
FM 835 at entrance to Buffalo Springs Lake (creek)	100	800	0.1	50	2,400	0.0	100	200	0.5
Mid-upper part Buffalo Springs Lake	-	-	-	50	800	0.1	-	-	-
Buffalo Springs Lake Party House	-	-	-	-	-	-	-	-	-
Buffalo Springs Lake near Dam	-	-	-	50	3,200	0.0	-	-	-
Lake Ransom near Dam	-	-	-	100	200	0.5	-	-	-

\- no sample taken

The city of Lubbock Yellowhouse Canyon Lakes' (Lakes I, II and VI) fecal coliform numbers during the summer and fall of 1983 met the state of Texas water quality standards of 200 fecal coliforms per 100 ml except during the October, 1983 sampling. There were two periods of rainfall during October which resulted in appreciable runoff to the lakes via storm sewers. One of these events occurred on October 10 where about 1 inch (2.5 cm) of rain fell within the city of Lubbock in one hour. The other occurred during the period of October 17 through October 20 where an excess of 8 inches (20 cm) of rain fell within the city, most of which occurred on October 19--approximately 7 inches (17.8 cm) in 24 hours. The rainfall on this day was a record for the city that resulted in large amounts of untreated sewage from the city being discharged to the storm sewers that empty into the lakes below Lake II. There was moderate contamination of Lakes I, II and VI on October 13 and gross contamination of these lakes, as well as the others, on October 21. As might be expected, the October 13 sampling showed a FC-FS ratio of less than 4 for each of the lakes indicating a possible mixed origin for the fecal coliforms.

The situation for Lake III is somewhat different than for the other lakes in that, in addition to exceeding coliform standards in October, 1983, on August 9, 1983, large numbers of fecal coliforms were found in this lake's water. This is not surprising since, at the time of the sampling, raw sewage was entering this lake from a city of Lubbock sewerage system. On several occasions during the year the investigators noted raw sewage entering Lake III, which, according to a city of Lubbock Department of Public Works' representative (D. Bell), was related to mechanical blockage of a sewage lift-station located near the dam of Lake III. Bell indicated that the city of Lubbock was in the process of correcting this problem.

It is interesting to find that in general for Lakes I, II, III and VI, all of which showed instances of excessive concentrations of fecal coliforms likely to be of human origin, within one month, i.e., the next sampling period, the numbers of fecal coliforms had decreased to concentrations acceptable for unrestricted contact recreation in the state of Texas. This is to be expected, since there are a variety of mechanisms that would tend to cause removal of fecal coliforms within the lakes which include organism die-off to settling, predation, etc.

The data for the MacKenzie Park Lagoon outlet frequently showed elevated concentrations of fecal coliforms; however, with few exceptions, such as during October, 1983, when raw sewage was entering the lakes in large amounts, the FC-FS ratios for the MacKenzie Park Lagoon waters were indicative of fecal coliforms of non-human origin. This is to be expected because of the large number of ducks and geese present in MacKenzie Park.

The principle sources of fecal coliforms and fecal streptococci for Lakes I through VI are the urban-rural runoff and/or storm sewers that discharge to these lakes. Large numbers of both of these organisms are found in the storm water drainage. Generally, however, the FC-FS ratios are such that the fecal coliforms are likely to be of non-human origin or of mixed origin. There were some exceptions to this, such as from the College Avenue storm sewer on September 15, 1982, where the fecal coliforms appeared to have been derived principally from human origin. There does not appear to be a substantial amount of city of Lubbock sewage entering the storm sewers following a rainfall-runoff event. It is therefore concluded that the fecal coliforms found in the storm sewers are principally derived from the animal population within the city.

Impact of Gray Farm Operations on Sanitary Quality of Buffalo Springs Lake and Lake Ransom

The data collected at Lake VI are indicative of the impact of the city of Lubbock on the fecal coliform numbers in the NF/DMF/BR. The location of these stations is above any runoff from the Gray farm area or by-passing of wastewaters from the Lubbock domestic wastewater treatment plant. The data at 50th Street frequently shows elevated concentrations of fecal coliforms compared to those found at Lake VI, indicating land runoff from the Gray farm area as a potential source. These fecal coliforms generally were of mixed or non-human origin. This is to be expected because non-chlorinated domestic sewage is being applied to the land for crop irrigation in this region, and at times large numbers of cattle graze the forage crops grown with the sewage effluent. Another possible source of fecal coliforms in this reach of the stream is a city of Lubbock storm sewer that discharges into the creek below the city's wastewater treatment plant. The city of Lubbock also has used the area near the stream for sewage sludge disposal. While sludge is no longer disposed of at this location, the previously disposed sludge could be a source of fecal coliforms for the storm sewer which runs through the sludge disposal area.

A comparison of the data collected between the sampling station at 50th Street and the Buffalo Springs Lake entrance sampling station shows that at times, large numbers of fecal coliforms were present in the waters entering Buffalo Springs Lake. Generally, however, there is a decrease in total fecal coliform numbers between these two sampling stations, indicating fecal coliform die-off. This die-off-removal is to be expected since there are several ponds on the river between these two stations which would, especially during low to moderate flow conditions, significantly increase the residence time of the water in traveling from one station to another.

The samples collected during the summer and fall of 1983 from Buffalo Springs Lake and Lake Ransom showed that, in general, these waters met the state of Texas fecal coliform standards for contact recreation. As expected, however, after periods of moderate to heavy rainfall-runoff events, such as occurred in early and late October, 1983, the waters of these lakes contained sufficient numbers of fecal coliforms of potential human origin to raise serious questions about the appropriateness of contact recreation in these waters. Lake Ransom, the lower-most of the Yellowhouse Canyon Lakes, shows the best overall sanitary quality of the lakes due to the fact that it receives almost no local drainage and that essentially all of its water is derived from Buffalo Springs Lake, which is a highly-efficient "trap" for human enteric organisms.

The above discussion is predicated on the assumption that fecal coliforms are reliable indicators of the sanitary quality of water for contact recreation. As discussed below, subsequently the US EPA has questioned the reliability of use of this organism as an indicator of gastroenteritis (intestinal upset).

Previous Studies

There have been a number of studies on the sanitary quality of the Yellowhouse Canyon Lakes. The TDWR and its predecessor organizations have been monitoring the NF/DMF/BR since 1972. Examination of these data (see Lee and Winkler, 1984) shows the same general patterns as found in this study, namely that there are decreasing concentrations of fecal coliforms as one proceeds from

50th and Loop 289 to the Lake Ransom dam. It is evident that the Gray farm operations that add drainage to the NF/DMF/BR downstream of 50th Street have not been a significant source of fecal coliforms for Buffalo Springs Lake. Other studies are also in accord with the results found in this study (Caldwell, 1978; Shelton, 1981). It is important to point out, however, that while most of the Buffalo Springs Lake and Lake Ransom data show fecal coliform numbers less than the state of Texas water quality standard of 200 organisms per 100 ml, there have been some samples with organism numbers in excess of this value, indicating that there is a potentially significant public health risk associated with contact recreation in these waters at times.

Human enteric viruses in well water and soil have been reported to be found beneath the Gray farm (Goyal et al., 1984). Coxsackie B3 and unidentified viruses were found in these waters. These results indicate that these viruses have been able to penetrate through the soil column to the groundwaters. This is of significance from several points of view. It would not affect to any great extent the use of Gray farm well water as make-up water for the upper Yellowhouse Canyon Lakes within the city of Lubbock since this water is routinely chlorinated before discharge to the lakes. While surface runoff could contribute both fecal coliforms and human enteric viruses (see discussion below), groundwater seepage from springs in the canyon walls near the stream from the Gray farm is estimated to be on the order of 800 gal/min (50 liters/second), and would not be expected to contribute any fecal coliforms, but could contribute human enteric viruses found in the groundwater of the Gray farm. While viruses have been found to be somewhat mobile in groundwaters, bacteria are generally not readily transported in groundwater systems. Therefore, the sanitary quality of the waters entering Buffalo Springs Lake, with respect to exposure to human enteric viruses, is unknown at this time; however, because of the proximity of non-chlorinated effluent and groundwater seepage entering the river just above Buffalo Springs Lake, concern is warranted and studies should be done to determine if those who are recreating within the waters of Buffalo Springs Lake and Lake Ransom are being exposed to unnecessary public health risks due to the city of Lubbock delivering non-chlorinated wastewaters to the Gray farm.

The presence of these viruses could, however, affect the public health/sanitary quality of Buffalo Springs Lake and Lake Ransom from both surface runoff and seepage. These viruses are being transported by surface runoff to the NF/DMF/BR and, therefore, it is likely that under periods of high flow there could be contamination of Buffalo Springs Lake by human enteric viruses derived from the Gray farm.

Public Health Considerations for Swimming--Contact Recreation

There are basically three areas of concern associated with swimming, wading, and water skiing in "polluted" waters. The most significant is that of contracting an enteric disease such as typhoid fever, the dysenteries, infectious hepatitis, or giardiasis. While many of these diseases are readily curable by antibiotics, they are normally debilitating for a period of time. The USA incidence of diseases of this type that can be associated with contact recreation is low--the frequency of occurrence is rare.

The second type of disease associated with swimming is gastroenteritis. While rarely significantly debilitating, these diseases are highly uncomfortable. The incidence of such a disease, while unknown, is believed to be frequent. The significance of swimming in "polluted" waters as a source of such diseases as compared to other sources is unknown. However, a high correlation has been found between gastroenteritis in swimmers and enterococci and E. coli (Cabelli et al., 1982; Cabelli, 1983; Cabelli et al., 1983). A relatively poor correlation was found between fecal coliforms and the incidence of gastroenteritis in swimmers. The results of these studies raise serious questions about the usefulness of fecal coliform as an indicator of the sanitary quality of waters for contact recreation. Subsequent to completion of this study, the US EPA revised their water quality criteria for contact recreation to use enterococcus and E. coli rather than fecal coliforms as indicator organisms for the sanitary quality of water used for contact recreation.

The third area of concern to swimmers or others who are participating in contact recreation is the possibility of developing infections of the eyes, ears, nose, and throat. It has been generally known that swimmers tend to have a much greater incidence of these types of infections than non-swimmers, and, while it is not well-documented, it appears that swimming in more "polluted" waters may result in a greater incidence of these types of infections than swimming in well-chlorinated swimming pools (Seyfried et al., 1985a, 1985b). The organisms that frequently cause these diseases (staphylococcus and pseudomonas) are ubiquitous. The classical sanitary quality assessment (FC-FS ratios) may have limited applicability in predicting the incidence of such diseases in swimmers.

Discussion

These studies show that there is significant cause for potential concern about the sanitary quality of the Yellowhouse Canyon Lakes after a rainfall-runoff event. The increase in FC-FS following runoff from adjacent lands which are or could be contaminated with non-chlorinated domestic wastewaters raises serious questions about allowing contact recreation in the Yellowhouse Canyon Lakes. Studies have shown that fecal coliforms are not a reliable indicator organism of the suitability of waters for swimming, water skiing, wading, etc. The relatively poor correlation obtained between gastrointestinal upset of swimmers and fecal coliforms in the water is not surprising. A review of the basis by which the fecal coliform standard for contact recreation was established by the US EPA showed that it was not based on definitive studies that clearly demonstrated a high degree of correlation between organism numbers and disease. Cabelli et al. (1983) present an informative review of this topic.

Cabelli and his coworkers have developed correlations between the numbers of enterococci found in a water and the incidence of gastrointestinal upset in swimmers of the water. This information provides a basis by which it is possible to estimate the risk of contracting gastroenteritis by swimming in a waterbody.

Recommended Monitoring Program

It is recommended that the municipalities and other regulating agencies concerned with water quality in their lakes initiate a water quality monitoring program in which enterococci and E. coli are monitored at weekly intervals beginning about April 15 and ending about October 15, i.e. the potentially significant contact recreation period. These samples should be collected at the dams or outlets in any region where swimming is contemplated. Particular attention should be given to sampling following rainfall-runoff events in order to define the disappearance rate of these organisms should they be introduced to the lakes or the tributaries by land runoff.

The finding of human enteric viruses in the Gray farm well water provides substantial justification for a more intensive study of the sanitary quality of surface and groundwater seepage in areas where domestic wastewaters have been applied to land. In addition to measuring enterococci and E. coli, human enteric viruses of the type that have been isolated from the Gray farm well water, as well as other types of viruses, should be monitored. If these studies show potentially significant increases in enterococci, E. coli and/or human enteric viruses which could likely be attributable to areas that have received domestic wastewaters, and those responsible for management of the wastewater farm areas are unable to control all of the runoff, then domestic wastewaters delivered to the farm should be disinfected as a public health safety measure. If it is found that groundwater seepage from the farm is contributing human enteric viruses to surface waters, corrective measures should be initiated in which all seepage and surface runoff from the farm is disinfected. This disinfection should be done in such a way as to minimize adverse effects on the fisheries of downstream lakes which may necessitate dechlorination, if chlorination is used for disinfection purposes, before the waters enter the lake. Newbry et al. (1983) have found that chlorine present in domestic wastewater treatment plant effluents can persist for long periods of time in the receiving waters for these effluents.

It is suggested but not mandatory that FC-FS also be monitored. The inclusion of these organisms would enable a comparison to be made between the current state standards and US EPA criteria for contact recreation with those that have been developed based on enterococci and E. coli monitoring.

Should swimming be allowed in any lakes, such as the Yellowhouse Canyon Lakes, then epidemiological studies of the type conducted by Cabelli et al. (1982, 1983) should be conducted for several years to determine whether swimmers utilizing the lakes have significantly different incidences of gastrointestinal upset as well as other diseases commonly associated with water contact. It would be of interest to compare the disease incidence (as possibly being associated with water contact) of lake swimmers to the incidence of similar diseases for individuals swimming only in municipal or other swimming pools, as well as similar disease incidence for non-swimmers.

Non-public Health Aspects of Swimming in the Yellowhouse Canyon Lakes

While this study focused on the sanitary quality of the Yellowhouse Canyon Lakes for contact recreation, there are other aspects of contact recreation (swimming) that should be considered. In 1973 the US EPA published the National Academy of Science and National Academy of Engineering review water quality criteria (NAS/NAE, 1973). In addition to the sanitary quality of the water, the National Academy Committee that addressed water quality criteria for swimming considered water pH and clarity. The committee concluded, based on a review of the literature, that water pH in excess of about 8.5 could be irritating to swimmers. Water pH's as high as 9.0 could be allowed for those waters with a low buffer capacity (related to alkalinity) and low dissolved solids. The Yellowhouse Canyon Lakes typically have high buffer capacity and high dissolved solids. Therefore, a non-irritating pH for swimming in these waters would be on the order of 8.5. A review of the data collected on the Yellowhouse Canyon Lakes shows that the pH's of Canyon Lakes I and II were on the order of 8.2 to 8.7 (Caldwell, 1978; Shelton, 1981). Some pH values close to 9.0 were found for Lakes I and II. Based on the studies conducted during fall 1982 through fall 1983 of the Yellowhouse Canyon Lakes and from the data available from previous studies, it appears that swimmers might find some eye irritation as a result of swimming in the Yellowhouse Canyon waters, especially during late afternoon when algal photosynthesis would tend to cause elevated pH in the water.

The NAS/NAE review also considered water clarity, indicating that swimming in turbid waters would tend to promote accidents in which swimmers would run into each other and to objects on the bottom of the swimming area. The NAS/NAE in 1973 indicated that the water clarity for swimming should have a minimum Secchi depth of 4 ft (1.2 m). Studies of the Yellowhouse Canyon Lakes generally showed Secchi depths less than 1 m during the summer months (Shelton, 1981; King, 1983). Immediately following the record-setting precipitation in October, 1983, the Secchi depths in the Yellowhouse Canyon Lakes, especially Lakes I and II, decreased to a few cm due to the transport of erosional materials from the watershed. Generally however, the Secchi depths in the Yellowhouse Canyon Lakes as well as many lakes are controlled by planktonic algae. The control of the eutrophication of these lakes (phosphorus load reduction) would tend to improve the water clarity in the lakes and therefore increase the Secchi depth. This would also tend to lower the maximum pH's found that are associated with algal photosynthesis.

Therefore, it may be concluded that, from a water clarity point of view, something-less-than-desired swimming water quality is typically present in the Yellowhouse Canyon Lakes. It is recommended that under these conditions, all obstructions on the bottom of the swimming area which could potentially cause harm to swimmers be removed, and that signs be posted to inform swimmers of the water depth in the swimming area.

From an overall point of view it appears that there may be some eye irritation to swimmers and that the water is more turbid than is typically desired. Neither of these characteristics nor any other characteristics known to the authors, other than the concern about the sanitary quality of these waters for a few weeks after a major rainfall-runoff event, is adequate justification for continued restriction of non-contact recreation in these waterbodies. The focal point of concern should be the sanitary quality of the waters and the safety of the swimmers from boat traffic. Swimming should be restricted to designated areas in which boats are not allowed.

Management of Excessive Fertilization of the Yellowhouse Canyon Lakes

The studies by Lee and Winkler (1984) have shown that the well water pumped from under the Gray farm, which receives the domestic wastewaters from the city of Lubbock, contains large amounts of aquatic plant nutrients (nitrogen and phosphorus) which would tend to promote excessive aquatic plant growth within the lakes. It was found that the Yellowhouse Canyon Lakes are highly eutrophic where especially during the summer months obnoxious algal blooms occur within these waterbodies.

Jones and Lee (1982) have discussed the development of a high degree of recreationally related water quality in the Rawhide Electric Generating Station Cooling Impoundment. The only source of water for this impoundment was treated domestic wastewaters from the city of Fort Collins, Colorado. It was found that through phosphorus control in the domestic wastewaters by treatment for its removal it was possible to produce a high quality recreational lake water that had few problems associated with algal and other plant growth in the waterbody. A similar approach could be followed in the Yellowhouse Canyon Lakes where the well water taken from the Gray farm that is pumped to Lake I could be treated for phosphorus control. This would significantly improve the algal related water quality in this lake, as well as Lake II, during periods of low runoff from the watershed. However, during periods of moderate to high runoff from the nearby agricultural lands and the city, sufficient aquatic plant nutrients would likely be added to the lakes to cause them to experience occasional excessive algal growths. Further information on the approach that can be followed to assess the potential benefits of limiting aquatic plant nutrient inputs to waterbodies as a means of controlling excessive algal growth within the waterbodies is provided by Jones and Lee (1986) and Lee and Jones (1988).

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References

APHA, AWWA, and WPCF, Standard Methods for the Examination of Water and Wastewater, 15th ed., American Public Health Association, Washington, D.C. (1981).

Cabelli, V.J., Dufour, A.P., McCabe, L.J., and Levin, M.A., "Swimming-Associated Gastroenteritis and Water Quality," American Journal of Epidemiology 115:606-616 (1982).

Cabelli, V.J., "Public Health and Water Quality Significance of Viral Diseases Transmitted by Drinking Water and Recreational Water," Wat Sci Tech 15:1-15 (1983).

Cabelli, V.J., Dufour, A.P., McCabe, L.J., and Levin, M.A., "A Marine Recreational Water Quality Criterion Consistent with Indicator Concepts and Risk Analysis," Journ Water Pollut Control Fed 55:1306-1314 (1983).

Caldwell, T.R., "Limnological Characteristics of the Lubbock Canyon Lakes," M.S. thesis, Department of Civil Engineering, Texas Tech University, Lubbock, TX (1978).