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Occurrence and Distribution of Bacterial Indicators and Pathogens in Canal Communities Along the Texas Coast

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Increased construction of residential canal communities along the southern coastline of the United States has led to a concern about their impact on water quality. Pollution of such dead-end canals is potentially hazardous because of their heavy usage for recreational activities. Coliforms, fecal coliforms, and salmonellae in the surface water and bottom sediments of six selected residential coastal canals were monitored over a period of 17 months. No statistically significant relationship was observed between the organism concentrations and temperature, pH, turbidity, and suspended solids content of water. An inverse relationship between the concentration of indicator organism and salinity of water was found, however, to occur at a 99.9% level of significance. All of the microorganisms studied were found to be present in greater numbers in sediments than in the overlying water, often by a factor of several logs. Heavy rainfall resulted in large increases in the number of organisms in both water and sediment samples. Our results indicate that bottom sediments in the shallow canal systems can act as reservoirs of enteric bacteria, which may be resuspended in response to various environmental factors and recreational activities.

An increase in the construction of residential canal communities along the East and Gulf coasts of the United States has led to concern about the impact of such man-made canals on the environment. Pollution of such dead-end canals is potentially hazardous because of their heavy usage for recreational activities. There are more than 50 canal communities along the Texas Gulf coast, the majority of which are located in Galveston County. Residential canals of six communities utilizing a variety of waste disposal methods were studied to determine their effect on bacteriological water quality within the canals.

The communities are designed so that each home has canal frontage, which allows owners to have direct water access for their boats, as well as for other recreational activities. The result is a maze of interconnecting canals (Fig. 1) that eventually lead into a bay or other large bodies of water. Many of the communities, especially along the Texas coast, are designed primarily for resort purposes and are occupied only on weekends and during the summer, but others are designed as permanent family residences. The growth of these communities has been rapid and largely unregulated, and their effect on water quality has yet to be thoroughly ascertained. Pollution of such canal systems is especially undesirable because of their heavy usage for such recreational activities as bathing, boating, skiing, fishing, and skin and scuba diving.

MATERIALS AND METHODS

Sampling sites. The canal communities studied border Galveston Bay (Fig. 2). These communities were built upon marsh land that was filled, in large part, from material dredged in the same area to form a network of canals that allow residents access to the bay. A diagram of the network of one of these canals is shown in Fig. 1. The majority of the homes are occupied during the entire summer months but only on weekends during the rest of the year. Several of the communities utilize septic tanks for the treatment of household wastes, whereas others depend upon small, packaged sewage treatment plants that discharge unchlorinated wastes. The age, depth, and type of waste disposal system for each of the communities studied are summarized in Table 1. All samples were collected from the shores of representative canals within each community.

Samples. Surface water samples were collected in sterile, wide-mouth, screw-capped bottles. Sediment samples were obtained with the help of an Ekman dredge and were placed in individual plastic bags. The samples were stored on ice for transport to the laboratory. In all cases, the elapsed time between sampling and analysis never exceeded 5 h.

Analysis of coliforms. Lactose and EC broth (Difco Laboratories, Detroit, Mich.) were employed to determine the most probable number (MPN) per 100 ml of coliforms and fecal coliforms, respectively, using a five-tube multiple-dilution technique (1). Cold 0.3 mM phosphate buffer was used to make

dilutions. Sediment samples were initially diluted 1:1 with sterile, buffered water, and 20, 2, or 0.2 ml of this diluted mixture was inoculated in the appropriate medium to give a final figure of 10, 1, or 0.1 ml of sediment, respectively. Double-strength broths were used when sample volume inoculated was equal to or more than 10 ml.

Isolation and enumeration of salmonellae. Salmonellae were detected by a three-tube multiple-dilution technique. Appropriate amounts or dilutions of the sample were inoculated, for enrichment, into three replicate tubes of tetrathionate broth containing 1:100,000 brilliant green. After incubation at 41.5°C (28) for 48 h, loopfuls from each tube were streaked on plates of brilliant green agar containing 0.08 g of sulfadiazine per liter. After incubating at 37°C for 24 h, two suspect colonies from each plate were inoculated into triple sugar iron (TSI) agar slants and further incubated for 24 h at 37°C. Strains exhibiting a characteristic reaction on TSI agar were purified and subjected to a slide agglutination test with salmonella poly "O" antiserum (Difco) and with O group sera. Isolates exhibiting agglutination were considered to be salmonellae.

Other parameters. Salinity and turbidity of water samples were determined by using a T/C refractometer (AO Instruments Corp., Buffalo, N.Y.) and a turbidimeter (model 2100A, Hach Chemical Co., Ames, Iowa), respectively. Temperature and pH of the water were recorded concurrently with sampling. The concentration of suspended solids was determined by filtering three 100-ml portions through desiccated, preweighed fiberglass filters (Whatman, grade GF/C). The filters were rinsed with distilled water to remove salts, desiccated for 48 h, and reweighed. The difference was reported as milligrams of suspended solids per liter of water.

Statistical analysis. Product-moment correlation coefficients were calculated on a DEC10 computer using an SPSS statistical package. Significance statistics were calculated for each of the coefficients.

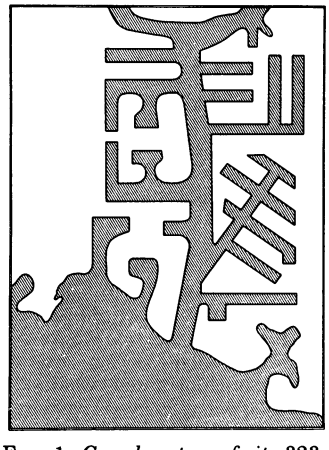

FIG. 1. *Canal system of site 323.*

RESULTS AND DISCUSSION

MPN of indicator organisms. The MPNs of total and fecal coliforms of the communities

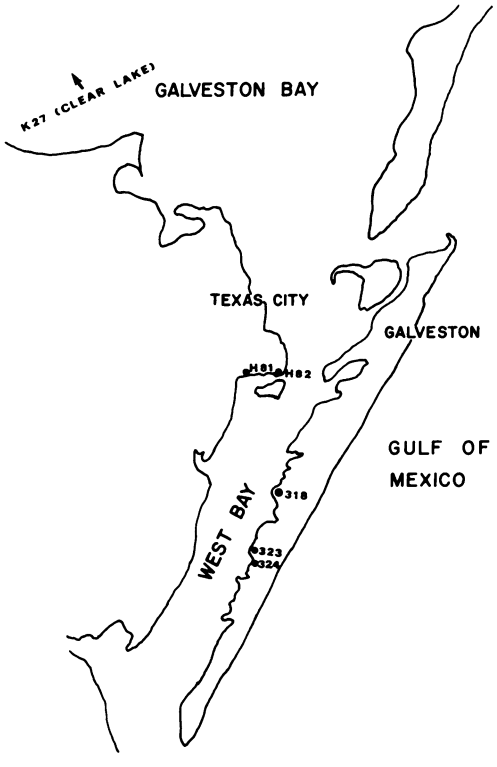

FIG. 2. *Locations of canal community sampling stations.*

TABLE 1. *Characteristics of canal communities studied*

Station no.	Age[a] (yrs)	Depth[b] (feet)	Disposal system
H81	12	6-14 (1.8-4.3)	Collection system and treatment plant
H82	12	6-14 (1.8-4.3)	Collection system and treatment plant
K27	14	12 (3.7)	Collection system and treatment plant
318	9	7-8 (2.1-2.4)	Septic tank; later changed to collection system and treatment plant
323 and 324	23	6-11 (1.8-3.4)	25% septic tank; 75% collection system and treatment plant

[a] Period for which the canal has been in operation.

[b] Range of depth of the water column in the canal. Depth in meters is shown in parentheses.

under study were determined over a 17-month period. The population of total coliforms in the water column was found to vary between 5 and 35,000, and that of fecal coliforms was between 2 and 24,000. The concentrations of total and fecal coliforms in sediments, however, varied between 940 and 2,400,000 and between 2 and 92,000, respectively. Coliform counts at sites H81, H82, and K27 (hereinafter termed as the most polluted sites) were considerably higher than those at the other three sites. This may be due to the fact that the communities located on these highly polluted canals had collection systems that discharged the water directly into the canals, whereas the other three had mostly septic tanks. According to Gonchariuk et al. (13), home septic tank systems are potentially very effective in removing pathogens if operated within their design capacities. Our results indicate that they were effective even considering the high water table in the areas studied. However, generalizations should probably not be made since soil conditions and proximity of the septic tanks to the canals would influence the occurrence of fecal bacteria within the canals.

Total coliform levels were always higher than fecal coliform levels, which is not surprising since total coliforms can originate from nonfecal sources such as plants and soils (9). In general, the number of indicator organisms at all of the sampling sites was lower for water than for sediment samples. Also, there was comparatively less fluctuation in the bacterial concentration in sediment than in water samples. According to Greenberg (15), adsorption and sedimentation tend to remove organisms from suspension and concentrate them in bottom deposits, where they continue an active existence. Rittenberg et al. (21) found high coliform levels in mud extending several miles from marine sewage outfalls discharging primary effluent, suggesting that survival of bacteria was increased after sedimentation. Van Donsel and Geldreich (29) examined a wide variety of sediments from bathing beaches, recreational lakes, rivers, and creeks and found that total coliform, fecal coliform, and fecal streptococci concentrations were 100 to 1,000 times higher in sediments than in the overlying water. The presence of large numbers of organisms in bottom sediments as compared to that in water is particularly hazardous in light of the observation by Grimes (16) that increased fecal coliform counts in water followed disturbance and relocation of bottom sediments by dredging. He further stated that maintenance dredging of bottom sediments heavily contaminated with enteric pathogens could produce a temporary health hazard in downstream recreational areas. The observation by Geldreich (8) that pathogens can survive in the bottom deposits of a river or lake for several weeks before they die also supports the above theory. The ability of enterobacteria to utilize nutrients released from sediments has been shown (17, 19). Gerba and McLeod (10) concluded on the basis of laboratory results that *Escherichia coli* could survive and even grow for periods of time in unsterile natural seawater when sediment obtained from the canals observed in this study was present. Studies by Gerba and Schaiberger (12) indicated that viruses become readily adsorbed to particulate matter involved in sediment formation, which may prolong their survival time. Pathogens adsorbed to canal bottoms pose little danger to public health, but resuspension of sediments in response to currents, storms, boat traffic, dredging, and changes in salinity and organic matter (3, 12, 16, 30) can result in release of adsorbed bacteria or viruses into the overlying water, thus posing a hazard to human health.

In contrast to our studies Sayler et al. (24) found lower numbers of indicator organisms in sediment than in water samples from five locations on the upper Chesapeake Bay. These stations were located in water ranging from 6 to 8.5 m in depth and often several kilometers from the nearest shore. The shallowness of the canals we studied and the limited flushing action probably aid in the build-up of nutrients within the canals, allowing more favorable conditions for their persistence in sediments than in open bay areas along a coast.

Seasonal occurrence of indicator organisms at the six sites is shown in Fig. 3 and 4. The number of organisms was usually higher in winter months than in the summer. This is a bit unusual because one would expect the number to be higher in summer when there is heavy usage of the canals. However, our data are in accord with those of Sayler et al. (24) and Faust et al. (5), who found higher coliform levels during the winter months in open bay waters. Faust et al. (5) found that fecal coliform survival in estuarine water was strongly influenced by temperature, with die-off increasing rapidly with elevated temperatures. Thus, even though the amount of waste being discharged during the summer may have been greater, fecal coliform numbers were less because of their rapid die-off.

Sharp peaks were observed in the number of total coliforms in water and sediment samples at the three most polluted sites in June, No-

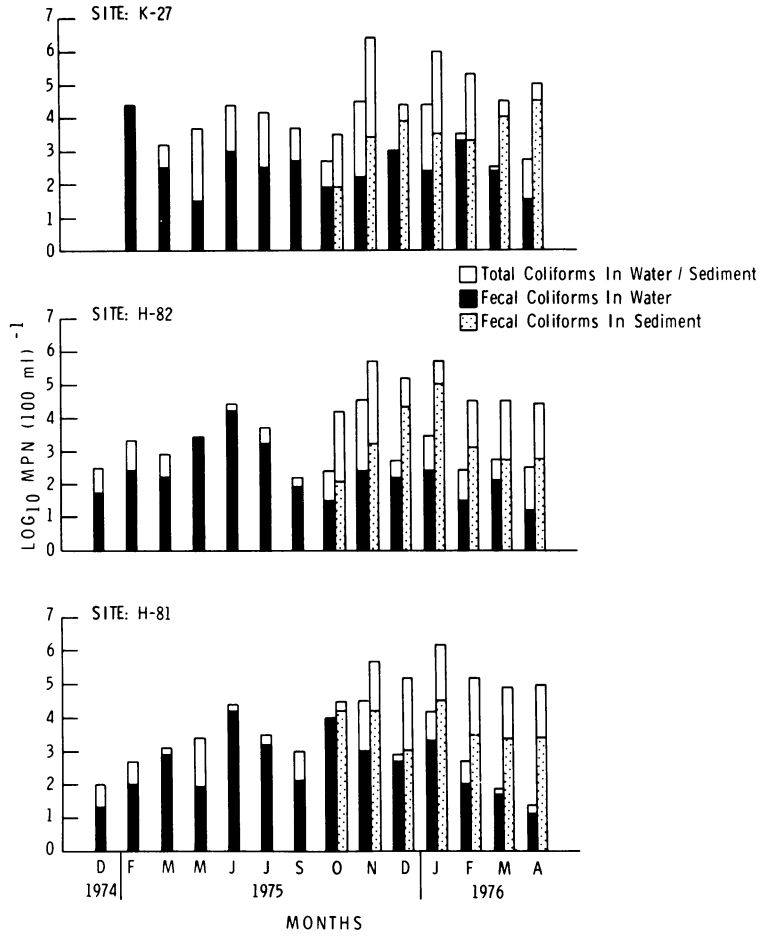

FIG. 3. *Comparison of monthly distribution of total and fecal coliforms in water and sediment from heavily polluted sites.*

vember, and January. These peaks were always associated with rainfall within 48 h of sampling. The peaks in the number of total coliforms were not always associated, however, with peaks in fecal coliforms, which indicates that most of the total coliforms after rainfall were from surface runoff. An increase in the number of coliforms after rainfall has also been reported by Feachem (6) and Gerba and Schaiberger (11). Sporadic increases in the MPN of bacteria were observed at some of the stations and could not be associated with rainfall. This same situation was encountered by Feachem (6), who found peaks of fecal coliforms during or immediately after a storm and at other times due to unexplained factors. No clear-cut relationship was observed between rainfall and the level of fecal coliforms, which is in accord with the data of Feachem (6). Similarly, Gray (14) observed peaks of *E. coli* associated with rainfall during the previous 12 h on three occasions, but a decrease on two occasions. A peak in the number of fecal coliforms in sediment did not always correspond to a peak in the water column; i.e., a peak of fecal coliforms was observed more often in the water column than in the sediment.

Table 2 shows the means, minima, maxima, and standard deviations of total coliforms and fecal coliforms at the six stations under study. Both groups of organisms were found in higher numbers in the sediment than in the water column at all of the stations and on all occasions. Total coliforms in the sediment samples were 3 to 4,783 times higher than in the water samples (median = 143), whereas this ratio for fecal coliforms was 1 to 383 (median = 10). As expected, the fecal coliform concentrations were less than a third of the total coliform concentrations; the fecal coliform counts in the

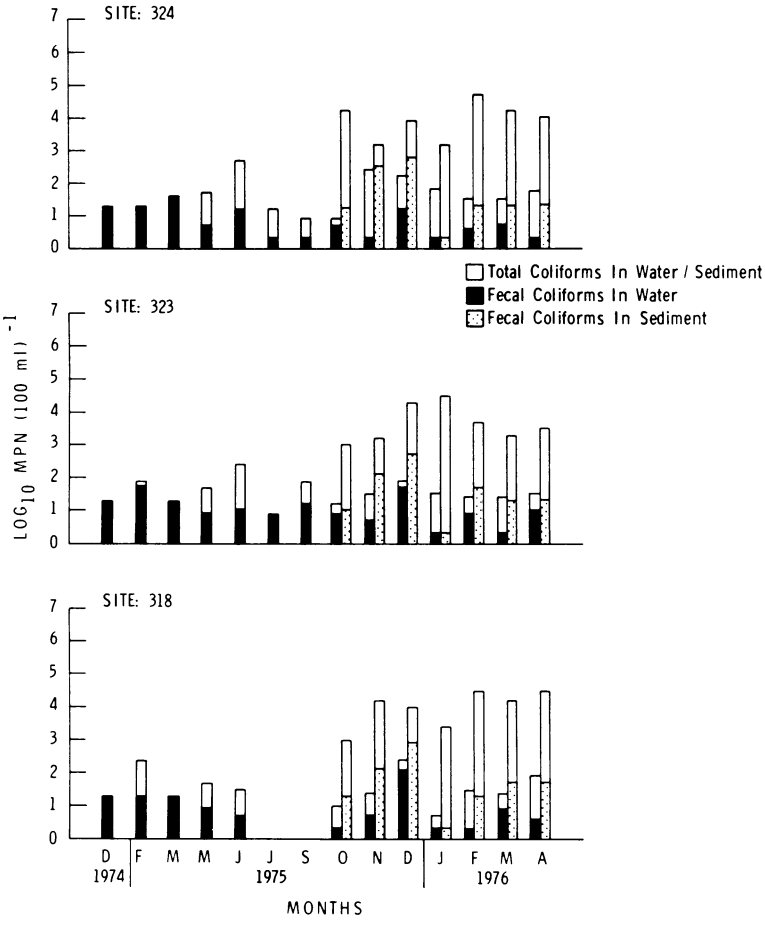

FIG. 4. *Comparison of monthly distribution of total and fecal coliforms in water and sediment samples from lightly polluted sites.*

TABLE 2. *Means, minima, maxima, and standard deviations of indicator organisms isolated from six sites*

Station no.	Total coliforms (MPN/100 ml)				Fecal coliforms (MPN/100 ml)				Total coliform/fecal coliform ratio (mean)
	Mean[a]	Minimum	Maximum	Standard deviation	Mean	Minimum	Maximum	Standard deviation	
Surface water									
H81	6,866	23	35,000	10,880	2,382	13	16,000	4,846	8
H82	5,320	170	35,000	10,568	1,528	17	16,000	4,223	15
K27	10,910	350	35,000	12,124	2,335	31	≥24,000	6,539	45
318	64	5	240	82	19	2	130	36	7
323	52	8	240	59	15	2	50	15	6
324	92	8	540	144	10	2	40	11	19
Bottom sediment									
H81	382,143	35,000	1,600,000	562,554	9,731	120	28,000	10,687	175
H82	192,857	16,000	540,000	242,119	16,806	49	92,000	35,731	150
K27	577,571	26,000	≥2,400,000	861,447	7,440	79	35,000	12,327	264
318	16,791	940	35,000	13,844	152	2	790	114	611
323	8,791	940	28,000	11,013	103	2	490	176	2,088
324	14,229	1,700	46,000	15,364	151	2	630	245	813

[a] Means were calculated assuming that the ≥ and < counts were equal to the counts reported.

sediment samples were higher than the water counts but not as high as the total coliform counts. A statistically significant correlation was observed between the log MPN of total coliforms and the log MPN of fecal coliforms in water (Fig. 5). A least-square regression analysis gave the relationship: log total coliforms (MPN/100 ml) = 0.96 [log fecal coliforms (MPN/100 ml)] + 0.87X. The correlation coefficient (r) for this relationship was 0.847, significant at a 99.9% probability level.

A significant relationship was also found to exist between total coliform and fecal coliform concentrations in sediment when data from all the sites were subjected to least-square regression analysis, which gave the relationship: log total coliforms (MPN/100 ml) = 3.2 [log fecal coliforms (MPN/100 ml)] + 0.53X (Fig. 6). The correlation coefficient (r) for this relationship was 0.717, which was also significant at a 99.9% level of probability.

The means of total coliform/fecal coliform ratios in water were between 6 and 45, whereas they were between 150 and 2,088 for sediment samples. This indicates that a large proportion of bacteria in the sediment samples were total coliforms (which represent both human and nonhuman sources) rather than fecal coliforms. This is also supported by the data of Carney et al. (4), who reported that fecal contamination was more often responsible for coliforms in the water column than in the sediment.

Other parameters. The physical and chemical characteristics of water samples from the six stations are shown in Table 3. The data reveal that salinity of the water was consistently low at the sites with the highest coliform counts. The lowest temperatures (9 to 12°C) occurred in January and the highest (31°C) occurred in September. The changes in the turbidity, salinity, suspended solids, and pH values do not, however, fall into a readily discernible pattern. Neither is there any correlation between these parameters and coliform counts, except salinity.

Product-moment correlation coefficients were computed between bacterial concentrations and other physicochemical parameters of the water samples from the six sites (Table 4). Total and fecal coliforms in water and sediment samples

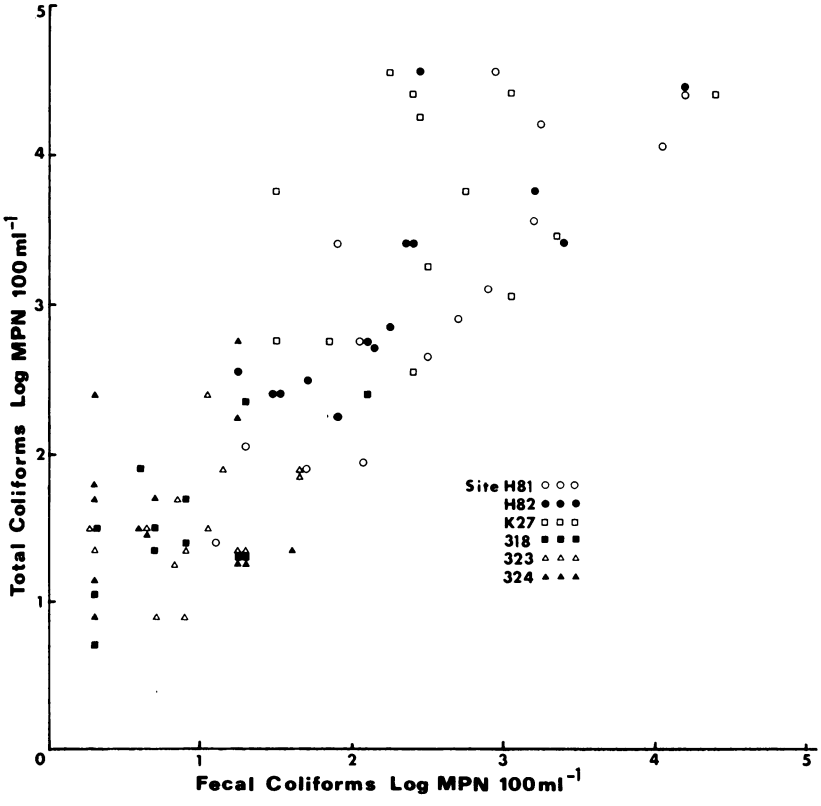

FIG. 5. *Correlation analysis of total and fecal coliforms in surface water.*

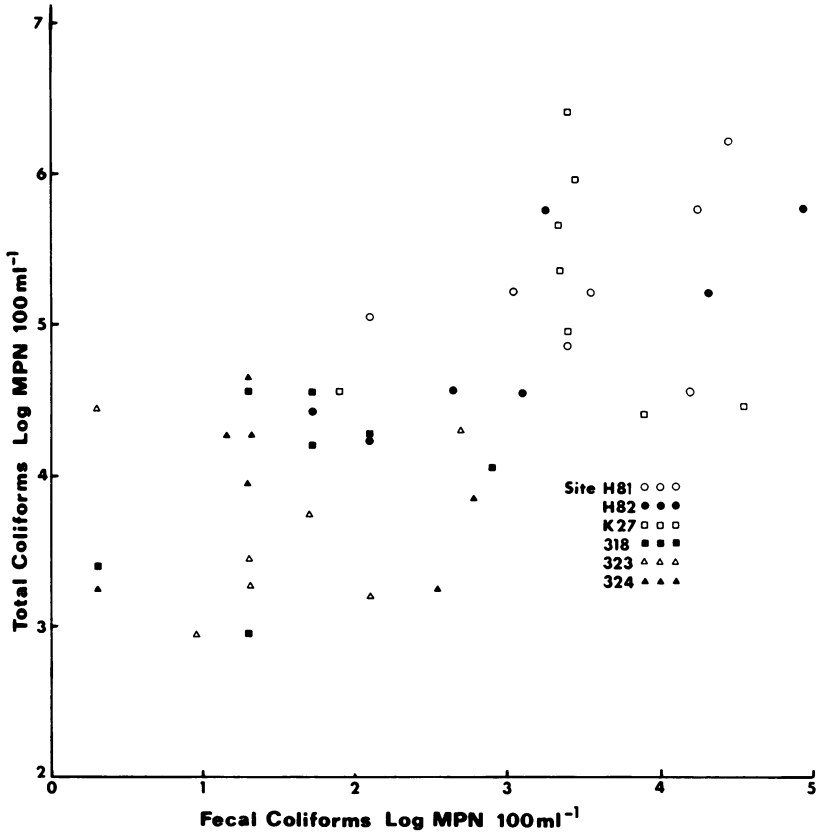

FIG. 6. *Correlation analysis of total and fecal coliforms in bottom sediments.*

TABLE 3. *Physicochemical characteristics of water samples taken at six sites*

Station no.	Turbidity (NTU)[a]		Salinity (g/kg)		Suspended solids (mg/liter)		pH		Temp (°C)	
	Avg	Range	Avg	Range	Avg	Range	Avg	Range	Avg	Range
H81	9.0	3.5-15.0	15.8	3.0-23.0	12.2	0.8-23.0	8.0	7.4-8.7	21	12.0-31.0
H82	7.8	3.0-11.0	15.3	5.6-25.0	12.2	1.2-23.0	8.0	7.7-8.5	21	11.0-30.0
K27	17.2	5.9-42.0	10.0	1.0-21.0	18.0	1.7-33.0	8.1	7.5-8.5	21	12.0-29.0
318	13.2	2.1-45.0	21.0	14.0-30.0	17.1	1.5-56.0	8.1	7.9-8.4	20	11.0-29.0
323	7.5	2.1-16.0	22.5	16.0-30.0	10.7	1.8-28.0	8.2	7.9-8.4	23	9.0-30.0
324	5.8	2.3-11.0	21.4	4.0-30.0	10.5	1.2-20.0	8.2	7.9-8.5	21	9.0-30.0

[a] Between 9 and 14 measurements were taken at each station. NTU, Naphelometric turbidity units.

were strongly correlated to each other at a 99.9% level of probability. A strong negative correlation was observed between total coliforms and salinity. With decreasing salinity, there was a corresponding increase in the value of total and fecal coliforms, both in water and sediment samples. This relationship has also been demonstrated by Roper and Marshall (22), who showed that *E. coli* remained firmly adsorbed to saline sediments but was rapidly desorbed after dilution of the electrolyte below a critical concentration. An inverse correlation between survival of *E. coli* and salinity of water has been demonstrated previously by Faust et al. (5). The observed increase in the number of organisms may be due partly to desorption of bacteria after dilution as a result of a heavy rainfall. Such effects would not be observed in deeper water or in areas of sparse rainfall, because dilution of the seawater would not be as great. This could explain why an increase in turbidity did not correlate with an increase in

TABLE 4. *Product-moment correlation coefficients of all measured parameters*[a]

Parameter	Temp	pH	Turbidity	Salinity	Suspended solids	TCW	TCS	FCW	FCS	SAL/W	SAL/S
Temp	1.0000	−0.2329	0.3587[b]	0.1829	0.0298	0.0595	−0.2709	−0.0278	−0.2723	−0.1473	−0.0964
pH		1.0000	−0.1565	0.2905	0.1481	−0.3714[b]	−0.2015	−0.2398	0.0113	−0.0309	0.3351
Turbidity			1.0000	−0.2225	0.2819	0.2657	0.0886	0.1048	0.0355	−0.1269	0.0727
Salinity				1.0000	0.3211	−0.7550[b]	−0.5963[b]	−0.6301[b]	−0.6192[b]	−0.0153	−0.1225
Suspended solids					1.0000	−0.0908	0.0256	−0.0205	−0.0822	−0.1272	0.2801
TCW						1.0000	0.7712[b]	0.8470[b]	0.7732[b]	0.0487	0.2853
TCS							1.0000	0.6964[b]	0.7169[b]	0.1177	0.3927
FCW								1.0000	0.8465[b]	0.1161	0.4715
FCS									1.0000	0.2457	0.4885[b]
SAL/W										1.0000	−0.0265
SAL/S											1.0000

[a] TCW, TCS, FCW, FCS, Log MPN (per 100 ml) of total coliforms in water, total coliforms in sediments, fecal coliforms in water, and fecal coliforms in sediments, respectively. SAL/W and SAL/S, MPN (per 100 ml) of salmonellae in water and sediment, respectively.

[b] Significant at a 99.9% level of probability.

the number of fecal organisms in the water column, as had been observed by Sayler et al. (24). Deeper water would require the actual suspension of sediment material to cause a concurrent increase in the number of organisms in the water column, whereas, in shallower water, sediment-associated bacteria could also be resuspended by a decrease in salinity. The impact of sediment-associated bacteria on the quality of the overlying water is in great part related to the depth of the water. In deep, open bay waters the volume of water above the sediment would be such that, if the organisms were entirely resuspended, their impact on the total number of fecal organisms in the water column would be negligible. However, in shallow, man-made canals they could have a marked effect on the total number of organisms in suspension. Considering the area of sediment material sampled in relationship to the volume of overlying water, as much as a 100% increase in the number of organisms in the water column would occur in the shallower canals if the organisms in the sediment were resuspended. It is known that the greatest number of bacteria occur in the upper few millimeters of sediment (29), which is the sediment profile most easily resuspended by changing environmental conditions.

It is interesting that temperature and turbidity had a strong positive correlation, which is again in contrast to the results of Carney et al. (4), who found greater values of turbidity in winter than in summer. There was no effect of pH on any of the variables studied, except on total coliforms in water which gave a strong negative correlation. A strong correlation was also found to occur between salmonellae in sediment samples and fecal coliforms in water samples. Temperature, turbidity, and suspended solids did not have any correlation with various microbiological parameters.

Effect of distance from sewage outfall on water quality. In several of the canal systems studied, the pollution originated from point sources, i.e., sewage outfalls. To determine the change in water quality in relation to distance from a source of pollution within a canal system, water and sediment samples were obtained near a sewage outfall serving one of the canal communities under study. The samples of water and sediment were taken at distances of 100, 300, and 600 feet (ca. 30.5, 91.4, and 182.8 m, respectively) from the outfall (Table 5). As expected, the MPNs of indicators and pathogens in the water and sediment samples decreased as a function of distance from the outfall, probably due to a dilution effect. On all occasions, however, the bacterial concentrations were higher in sediments than in the overlying water, and most of the bacteria in water near the outfall were of fecal origin.

Cross-sectional analysis of a canal. Table 6 shows a comparison of the bacterial counts obtained from surface water and sediment samples taken across the width of the canal at site K27. Apparently, the sediment toward the midpoint of the canal contains a higher percentage of organisms than does sediment on the banks of this canal. The number of organisms in water samples was similar at all of the sampling points across the width of the canal. It has been shown that water in a river is homogeneous with respect to microorganism distribution (31). Studies of polluted freshwater canal communities in southern Florida have shown that the greatest concentration of organic sludge occurs in the canal center (20). The apparent concentration of bacteria in sediments near the

middle of the canal suggests that the values for coliforms in sediments may be much higher than reported in this study because, out of necessity, our samples were always obtained from the bank of the canal rather than from the middle.

MPN of salmonellae. Salmonellae were isolated 17 of 36 times from sediment samples at all of the six sites examined (Table 7). However, only one of the simultaneously collected water samples was positive for salmonellae. The density of salmonellae in sediment samples was low, however, the highest being 150/100 ml. Salmonellae densities as high as 790/100 cm^3 have been reported in polluted freshwater sediments by Van Donsel and Geldreich (29). Although the density of salmonellae in the water and sediment was rather low, the organisms

TABLE 5. *Distribution of bacteria in relation to distance from the sewage outfall*[a]

Distance from the sewage outfall (feet)	Total coliforms (MPN/100 ml)		Fecal coliforms (MPN/100 ml)		Salmonellae (MPN/100 ml)	
	Water	Sediment	Water	Sediment	Water	Sediment
0	8,330	1,383,300	8,070	817,700	3	10
100 (30.5)[b]	650	1,363,300	310	113,300	3	4
300 (91.4)[b]	580	103,300	170	56,100	<3	3
600 (182.8)[b]	240	3,300	110	1,100	<3	3

[a] All MPN values are the mean of three different observations.
[b] Meters.

TABLE 6. *Comparison of microbial populations across the width of the canal at site K27*[a]

Location on lateral section	Total coliforms (MPN/100 ml)		Fecal coliforms (MPN/100 ml)		Salmonellae (MPN/100 ml)	
	Water	Sediment	Water	Sediment	Water	Sediment
A (east bank)	13,410	508,750	3,820	20,730	≤3	≤3
B	19,990	357,500	1,150	97,580	≤3	14
C (midpoint)	19,820	878,000	6,500	92,680	≤3	45
D	8,010	995,500	2,900	120,150	≤3	43
E (west bank)	13,970	203,500	2,000	18,630	≤3	17

[a] Mean of samples taken on four different occasions from two different locations on the canal.

TABLE 7. *Serovars of salmonellae isolated from six canals and their relationship to concentrations of indicator organisms*

Station no.	Sample	Month	MPN (per 100 ml) of:			Total coliforms/fecal coliforms	Fecal coliforms/salmonellae	Salmonellae isolates	
			Total coliforms	Fecal coliforms	Salmonellae			No.	Serovar
H82	Water	Dec.	490	140	11	3.5	13	3	B
H81	Sediment	Dec.	160,000	1,100	11	145	100	3	B
H81	Sediment	Jan.	1,600,000	28,000	30	57	933	1	B
H81	Sediment	Feb.	160,000	3,500	40	46	88	1	F
H81	Sediment	Mar.	70,000	2,400	40	29	60	1	F
H82	Sediment	Dec.	160,000	22,000	11	7	2,000	3	B
H82	Sediment	Jan.	540,000	92,000	70	6	1,314	2	B
K27	Sediment	Nov.	2,400,000	2,600	9	923	289	2	B
K27	Sediment	Dec.	26,000	7,000	4	4	1,750	1	F
K27	Sediment	Jan.	920,000	2,800	9	329	311	2	B
K27	Sediment	Feb.	220,000	2,200	150	100	15	3	B
K27	Sediment	Mar.	350,000	35,000	90	10	389	2	B,F
K27	Sediment	Apr.	92,000	2,400	90	38	27	2	F
318	Sediment	Nov.	16,000	130	3	123	43	1	B
318	Sediment	Dec.	11,000	790	4	14	198	1	B
323	Sediment	Nov.	1,600	130	15	12	9	3	B
323	Sediment	Dec.	21,000	490	3	43	163	1	B
324	Sediment	Dec.	7,000	630	3	11	210	1	B

were recovered by straightforward isolation procedures. Also, the absence of pathogens in samples positive for fecal contamination is no guarantee that microbial hazards are absent from such areas. To quote Carney et al. (4): "Enteric pathogens like salmonella and shigella may not survive in the estuarine environment or may become debilitated or altered by the low temperature, high salt concentration, and other environmental influences, so that selective media are, in essense, a final blow."

The density relationship of salmonellae and fecal coliforms in sediment samples was not constant, but varied between 1:9 and 1:2,000, with a median of 1:198. If the number of salmonellae in the sediment sample is compared to the number of fecal coliforms in the water sample, the median ratio is 1:13 (range = 1:0.3 to 1:275), which is much higher than a median of 1 salmonella in mud per 150 fecal coliforms in the overlying water in freshwater systems (29). The minimum density of fecal coliforms per 100 ml associated with isolation of salmonellae was 130 for sediment and 140 for water. Of the 17 times that salmonellae were isolated, the fecal coliform concentration was less than 2,000/100 ml 6 times. Salmonellae have been isolated in the past from water with low coliform counts (2, 26, 27).

Salmonellae were always isolated when the fecal coliform concentration was >2,000/100 ml, except on two occasions when the water and sediment samples had fecal coliform values of 2,200/100 ml and 17,000/100 ml, respectively. The average mean ratios relating pathogens to indicators were 1 salmonella to 45 total coliforms and 13 fecal coliforms for water samples and 1 salmonella to 29,128 total coliforms and 465 fecal coliforms for sediment samples. Data collected from field investigations throughout the United States showed that salmonella isolations could occur with nearly 100% frequency when the fecal coliform concentration was >2,000/100 ml (8).

The isolation of greater numbers of salmonellae from the bottom sediments than from the overlying water in the present study is supported by the data of Van Donsel and Geldreich (29), who isolated salmonellae from 22 of 48 sediment samples from small streams and recreational lakes, whereas only 4 of the simultaneously collected water samples were positive for this organism. Similarly, of the 195 samples of sediment and river water examined over a 1-year period, approximately 90% of the salmonella isolates were from bottom sediments (18). Hendricks (17) demonstrated that certain strains of *Salmonella* and *Shigella* can metabolize substrates present in aqueous extracts of bottom sediments at 24°C or below. Savage (23) found extended survival time of *S. typhi* in sterilized freshwater mud. Thus, survival of these organisms can be expected to be longer in the sediment of the canal than in the water column.

Only two salmonella serovars were isolated during this study. It is interesting to note that both B and F serovars were isolated from the sites with the highest coliform counts, whereas only type B was isolated from lightly polluted sites (no. 318, 323, and 324). Of 33 isolates, 27 were type B. On one occasion, both types B and F were encountered in a single sediment sample from site K27. Type B is the most frequently reported serovar in disease outbreaks due to salmonellae in the United States. The observation that 1 to 5% of all the fecal coliforms recovered from recreational waters can be identified serologically as enteropathogenic *E. coli* (9), coupled with an increased rate of recovery of indicator organisms as well as of salmonellae, lead us to believe that sediments can act as reservoirs of proven pathogenic bacteria.

Although bacterial standards for judging the potential health hazards for recreational use of marine waters have never been unequivocally agreed upon because of the need for epidemiological studies, arbitrary bacterial standards have been utilized in the United States. The National Technical Advisory Committee on Water Quality Criteria has recommended a limit of 1,000 total coliforms per 100 ml and 200 fecal coliforms per 100 ml for recreational water (7). This value was regularly exceeded in the three sites that utilized collection systems.

We believe that the occurrence of large numbers of enteric bacteria and viruses (C. P. Gerba, S. M. Goyal, E. M. Smith, and J. L. Melnick, Mar. Pollut. Bull., in press) in the canal bottom sediments is significant in that it may greatly affect the overall long-term water quality of the canal system. In a previously reported study (10), we demonstrated that bacteria of fecal origin survived for a much greater period of time in sediment obtained from these canals than in the overlying water. Viruses are also known to persist for longer periods of time in marine water when associated with solids (12), and adsorbed viruses are also infectious (25). Thus, evaluation of health hazards should be concerned with the presence of pathogens in the sediment as well as in the water column, especially in such shallow water as present in canal communities that are heavily used for recreational purposes. The heavy boat traffic

contributes to the continual resuspension of sediment in the canals in addition to the effects of currents and storms.

The very design of canal communities, with many dead-end canals, probably aggravates the water quality problem by reducing tidal flushing action. This aids in the build-up of waste material in the bottom of the canals. These communities are too remote for connection to major sewage treatment facilities available in larger cities along the coast of Texas, and septic tanks or small, packaged treatment plants must be relied upon for sewage treatment. The results of this study indicate that discharge of treated wastewater could pose a potential public health hazard. Better design criteria of canal communities, such as elimination of sewage discharge into or near the canals by construction of longer outfall pipes or construction of canals to allow better tidal flushing, should be encouraged to reduce the accumulation of pathogenic microorganisms in the water and sediment.

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