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EFFECTS OF WASTEWATER EFFLUENT CHLORINATION ON BACTERIAL DENSITIES IN RECEIVING WATER

by

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INTRODUCTION

In the summer of 1984, the Water Quality Section of the Illinois State Water Survey conducted a study to assess the impacts of the Greater Peoria Sanitary District CGPSD) ammonia discharges on the Illinois River. As a part of this study, bacterial samples were collected- for enumeration of. fecal coliform (FC), total col i form (TC), and fecal streptococcus CFS).

The purpose of the bacterial enumerations was to evaluate the effects of wastewater effluent chlorination on the bacterial densities in the receiving water.

Acknowledgments

Many Illinois State Wa ter Survey personnel collected samples for bacterial analyses. Dr. Raman K. Raman reviewed the report, Gail Taylor edited the final report, Linda Johnson typed the manuscript, and William Motherway, Jr., prepared the illustrations.

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INDICATOR BACTERIA

Bacteria, protozoan cysts, and viruses are normal inhabitants of water, soil, human and animal gut and skin, plant surfaces, and indeed almost every location on earth. Polluted water is hazardous because diseases such as cholera, dysentery, typhoid, giardiasis, schistosomiasis, and hepatitis are transmitted via the oral-fecal route.

In determinations of microbiological water quality, a number of bacterial indicators are enumerated to determine the possible presence of disease-causing organisms derived from fecal pollution. Indicator organisms, such as TC, FC, and FS, are used because they indicate the presence of fecal contamination and ideally are correlated with the number of pathogens in water.

Enumeration of bacterial indicators is used instead of isolation and identification of pathogens because bacterial indicators are easier and less expensive to isolate and enumerate than pathogens. Also, water contaminated by human waste will typically contain many more of these indicator organisms than pathogens. Indicator bacteria are present at relatively high concentrations and are shed at all times.

Although no organism or group of organisms is a perfect indicator, total coliform has been used as a measure of the fecal contamination of drinking water and surface waters for more than seven decades. For drinking water quality, the standard is one (1) coliform colony per 100 mL of water. The total coliform includes a group of heterotrophic bacteria, many of which have little in common with each other except that they are always present in the intestinal tract of humans and other warm-blooded animals. Thus, the occurrence and densities of TC have been useful in assessing the sanitary conditions of water. The literature indicates that the absence of TC or other indicators is evidence of a bacteriologically safe water, though not one that is necessarily safe from viruses.

Several strains of TC do not originate from fecal matter but instead originate in the soil. This confuses the use of TC as a water quality indicator. For more than two decades, fecal coliform, a subgroup of total coliform, has been used as an indicator of pollution from warm-blooded animal feces: FC is a more precise bacteriological indicator than TC for assessing water quality. The Illinois Pollution Control Board (1982) has adopted rules limiting the density of FC in waters.

One of the shortcomings of using FC is the inability to differentiate between human and other warm-blooded fecal contaminations. In 1964, Geldreich et al. first proposed the use of an FC to FS ratio as a more valuable tool for assessing pollution sources than the sole use of FC concentrations. Their findings (Geldreich, 1967; Geldreich et al., 1964; Geldreich and Kenner, 1969) showed that the FC:FS ratio in human feces and in water polluted with human waste is always greater than 4.0, while the ratios pertaining to farm animals, cats, dogs, and rodents and to separate storm waters and farmland drainage are less than 0.7.

The application of these findings, within limits, permits the use of FS densities as a method for differentiating the source of bacterial pollution in surface waters. The use of the FC:FS ratio for stream samples would be valid only during the initial 24-hour travel downstream from the point of pollution discharge into the receiving stream.

Fecal streptococcus tests are commonly used in the sanitary analysis of water supplies in European countries. In the United States, TC, FC, and FS have all been used as pollution indicators at various times CKabler, 1968; APHA et al., 1980). The correlation between col i forms and pathogens has been studied by many investigators. Unfortunately, bacterial indicators are generally not reliable indexes for viruses. The absence of indicators does not assure that viruses are also absent. Many investigators are looking for improved indicator recovery methods and for other organisms which can be used as new indicators. Until a good alternative is discovered, it is valid to use TC as an indicator of enteric pollution in water supplies and FC and FS as indicators for sewage and stream sanitation.

Bacterial Standards

On October 26, 1982, the Illinois Pollution Control Board repealed and amended the bacterial standards contained in Sections 302.209, 302.406, and 304.121 of its Rules and Regulations (IPCB, 1982). However, a First District Appellate Court order, dated February 1, 1983, stayed the effect of the repeal and amendment until further order of the court. That means that the rules from before the repeal are still in effect. They are:

> Section 302.209 Fecal Coliform [for general water use]
>
> Based on a minimum of five samples taken over not more than a thirty day period, fecal coliform (STORET number 31616) shall not exceed a geometric mean of 200 per 100 mL, nor shall more than 10% of the samples during any thirty day period exceed 400 per 100 mL.
>
> Section 302.406 Fecal Coliform [for secondary content and indigenous aquatic life]
>
> Based on a minimum of five samples taken over not more than a thirty day period, fecal coliform (STORET number 31616) shall not exceed a geometric mean of 1,000 per 100 mL, nor shall more than 10% of the samples during any thirty day period exceed 2,000 per 100 mL.
>
> Section 304.121 Bacteria [for general effluent]
>
> No effluent governed by this Part shall exceed 400 fecal coliform per lOOmL.

Section 302.209 applies to the Illinois Waterway (Illinois River) while Section 304.121 is applicable to the wastewater effluent from the GPSD.

THE PRESENT STUDY

Study Area

The GPSD wastewater treatment facility is a high rate activated sludge plant using the Kraus process of returning digester supernatant to the contact tanks. The secondary effluent is passed through 84 rotating biological contactors for ammonia removal. Deep tertiary stabilization ponds are utilized to remove total suspended solids and some 5-day biochemical oxygen demand (BOD_5). The plant effluent is chlorinated.

The design capacity of the wastewater plant is 37 million gallons per day (mgd). The average annual dry weather flow is about 25 mgd. The major industrial waste loads are contributed by the Archer Daniels Midland Company and Bemis Bag Company.

The GPSD wastewater treatment plant is located in the southern part of Peoria (figure 1). The plant's overland discharge fans into four discrete channel flows entering the Illinois Waterway at river mile (RM) 160.08 to RM 159.93 (figure 2). Under normal effluent-flow conditions, the effluent is discharged through channels A, B, and C (figure 2) into the river. The flow distributions in these channels are generally in the ratio of 4:1:2. When the effluent flow is greater than 40 mgd, the discharge occurs through all four channels.

The study area within the Illinois River stretches from approximately 1 mile above the outfall area commencing at RM 160.95 to about 2 miles below the outfall area, terminating at RM 158.01.

The Illinois State Water Survey has long-term data on bacterial quality at RM 161.60. This location is about 1.5 miles upstream of the GPSD outfall. The geometric mean, range, and geometric standard deviation of TC, FC, and FS values for each of the months July through October from 1971 through 1984 are summarized in table 1.

Methods and Procedures

River samples were collected for bacterial analyses on ten different dates during the period from July 24 through October 25, 1984.

On four of the sampling dates treatment plant discharges were chlorinated, on five sampling dates they were unchlorinated, and on one occasion there was no plant discharge (table 2D. Samples were collected by means of a battery operated pump sampling system discussed in detail by Butts et al. (1985). The transect location, distance from the shoreline, and depth at

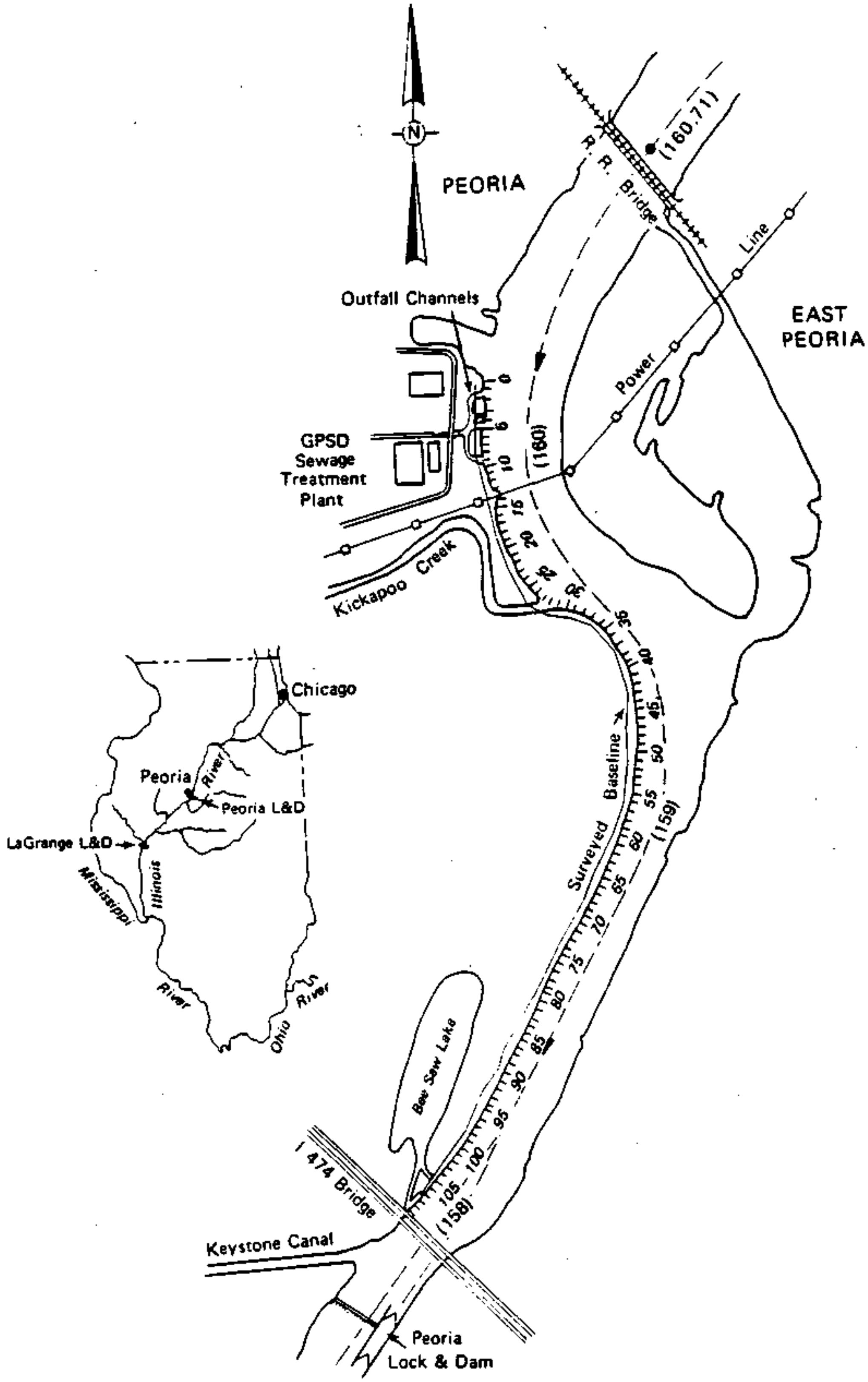

Figure 1. Study area

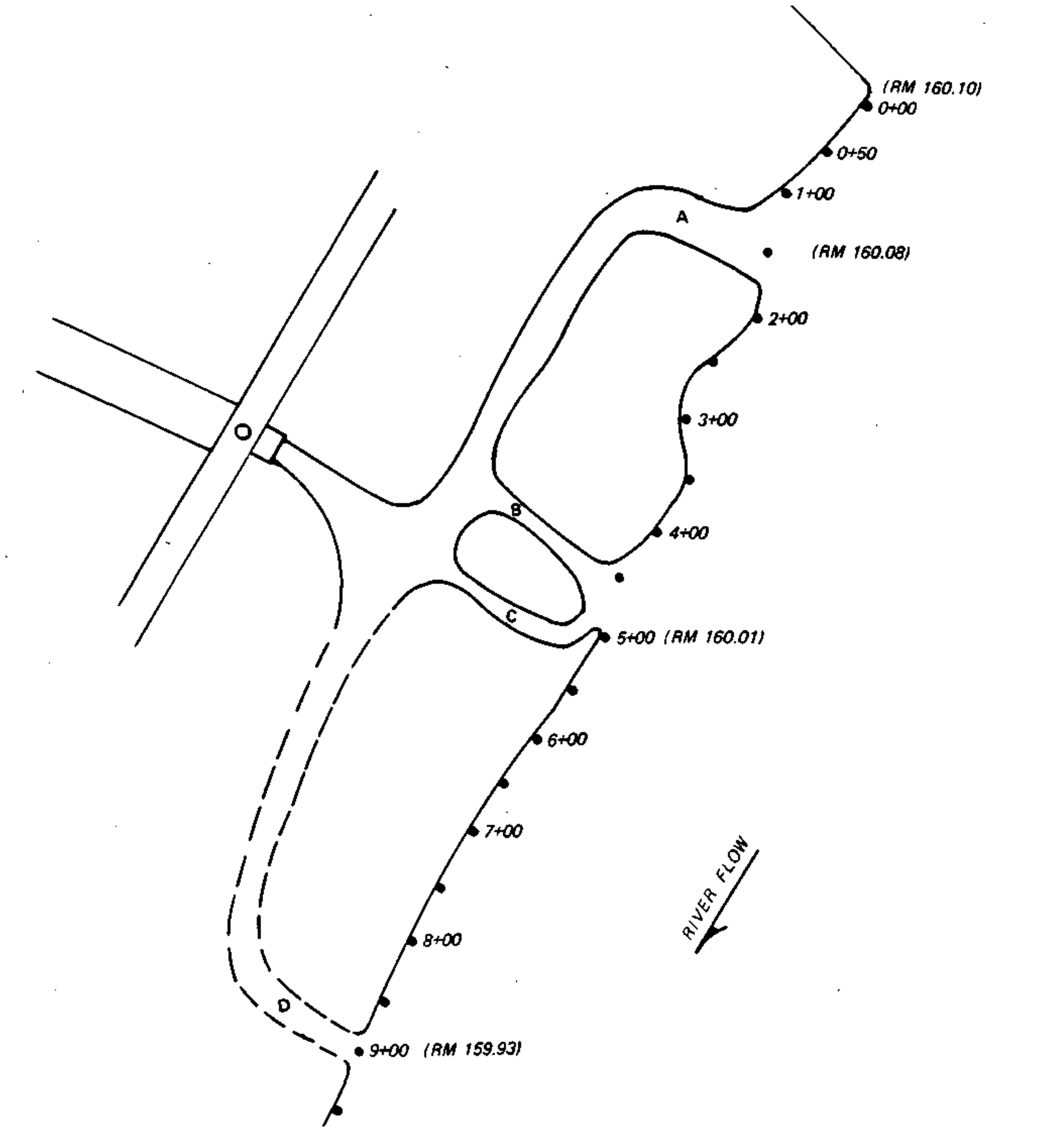

Figure 2. Effluent outfall area

Table 1. Summary of Indicator Bacterial Densities in the Illinois River at RM 161.6

1971 through 1984	Geometric mean, per 100 mL			Range, per 100 mL			Geometric standard deviation		
	FC	TC	FS	FC	TC	FS	FC	TC	FS
July	530	3,000	130	20-8,300	130-670,000	21-1,300	3.3	5.4	2.5
August	430	3,200	150	48-13,000	150-400,000	30-700	3.1	4.3	2.2
September	490	3,300	170	32-16,000	150-120,000	24-2,700	3.4	4.3	2.6
October	390	3,000	160	47-6,800	470-88,000	10-2,200	2.8	3.2	2.9

Table 2. Physical and Hydraulic Conditions on Sampling Dates

	Discharge		Pool	Dam operation			Water temperature, °C			
							GPSD		River	
Date	GPSD*, mgd	River, cfs	stage, msl	Wickets down	Valves open	Needles in	Begin	End	Begin	End
1984										
7/24	25, C	8,840	440.35	0	6	0	25.0		29.5	30.0
8/20	0	8,117	440.04	0	6	0	26.0		25.5	26.0
8/21	35	7,848	439.68	0	6	0	24.1	25.0	25.5	26.0
8/28	45	6,088	439.47	0	0	51	24.1	26.1	25.7	25.8
8/30	21, C	6,857	440.08	0	0	107	26.0		27.0	27.0
9/11	55	7,572	440.41	0	0	0	23 .0	24.0	22.5	24.5
9/13	21, C	5,525	440. 11	0	0	63	24.0		24.0	24.0
9/18	50	5,224	440.56	0	0	63	22.0	22.5	20.0	21.0
10/23	30	8,837	440.43	6	6	40	19.8	21.0	15.0	15.0
10/25	23, C	8,257	440.20	6	6	28	25.0		13.0	14.5

*C = effluent was chlorinated; l mgd = 1.547 cfs

which bacterial samples were collected differed for each of the sampling dates, primarily as a result of the needs of the mixing zone study, which is discussed in detail elsewhere (ibid). The locations of the sampling points are indicated in the figures showing the results of this investigation and in the raw data included in the appendix. On July 24, 1984, surface, 3-foot depth, mid-depth, and near bottom samples were collected at selected transects covering the entire stretch of the study area as conditions permitted. On October 23, 1984 and again on October 25, 1984 only surface, mid-depth, and near bottom samples were collected at selected transects extending to about 1000 feet downstream of the outfall. Otherwise only one sample was collected at any vertical on a river transect. The samples were ice-cooled in the field and kept refrigerated until examined. Culturing of the bacterial samples in the specific media was begun on the day of collection and completed the following day.

The membrane filter techniques recommended in Standard Methods CAPHA et al., 1980) were used for the bacterial analyses. Fecal coliform counts were made with the M-FC agar standard method (APHA et al., 1980) and the two-step enrichment method (Lin, 1976). For total coliform and fecal streptococcus enumerations, the M-Endo agar LES two-step method and KF-streptococcus agar method, respectively, were used. For bacterial culturing, three different sub-sample volumes of each sample were filtered through 0.45-µm membrane filters.

RESULTS AND DISCUSSION

The dates and physical conditions under which samples were collected are summarized in table 2. As indicated previously, the ten runs included four when effluent discharges were being chlorinated, five when the discharges had no chlorination, and one when there was no effluent discharge at all.

The effluent flow from the GPSD plant contributes minimally to the Illinois River flows, generally less than 1.5 percent. During the study period, the river flow was low to moderate.

Fecal Coliform

July 24 Run. The July 24, 1984 sampling was planned to investigate whether bacterial counts varied with depth. Depth samples were taken at seven locations in four river transects. The observed FC counts for different depths in the four transects are depicted in figure 3. Generally, FC densities in the water column were different with depth (figure 3), especially at the effluent outfall area (figure 3b). However, there was no discernible pattern.

Samples for RM 160.71 upstream of the outfall can be used as reference or baseline conditions. At this transect, FC densities in the water column 100 feet from shore were found to be significantly higher than those for the samples taken at mid-channel (550 feet offshore, figure 3a). FC counts at mid-channel were below 200 FC/100 mL, while all four observations for the location 100 feet offshore were above 200 FC/100 mL. Wastewater effluent was chlorinated on this date. The river water temperature (30°C) was significantly higher than the effluent temperature (25°C). The FC count in the chlorinated effluent was not determined.

Figure 3b reveals that six of the eight samples from station (St.) 5+00 (RM 160.01) showed FC densities higher than 200 counts/100 mL. On this date, surface samples were collected at St. 25+00 (200 feet offshore) and at St. 32+00 (50 feet offshore). These samples had counts of 280 FC/100 mL and 270

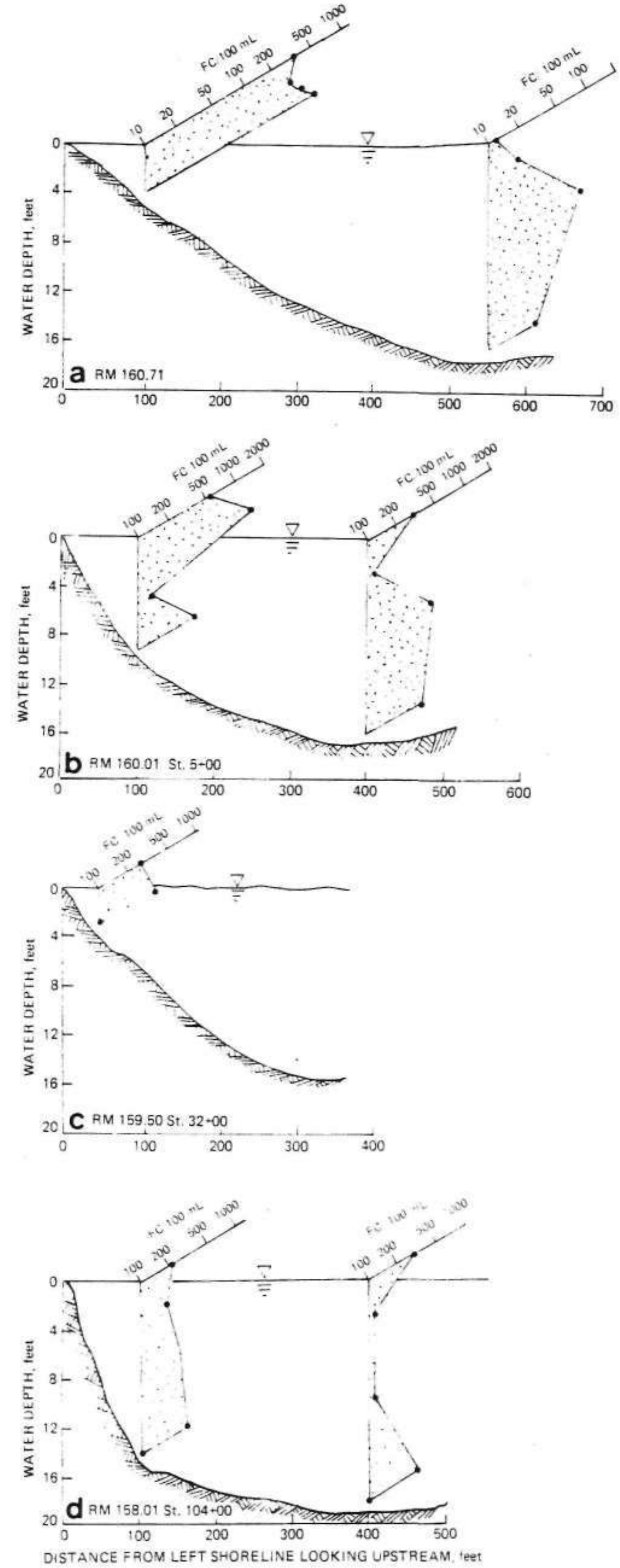

Figure 3. Profiles of FC densities, July 24 (effluent chlorinated)

FC/100 mL, respectively. In the transects from stations 25+00 to 104+00, densities were found to be less than 400 FC/100 mL (appendix).

Auaust 20 and 21 Runs. In order to provide the desired effluent flow rate for the mixing zone dye study below the outfall, for some runs, the GPSD had to store its effluent in the deep tertiary ponds for a few days prior to each actual day of the dye study. The plant did not discharge its effluent to the river on August 20, so it was a gopd opportunity for determining the baseline conditions downstream of the outfall. On August 20, 1984 all the samples had FC counts less than 200 per mL (figure 4). On this and the next eight sampling runs, only bottom samples were collected at stations from 0+50 to 43+00, and only mid-depth samples were taken at other downstream stations. Figure 4 shows

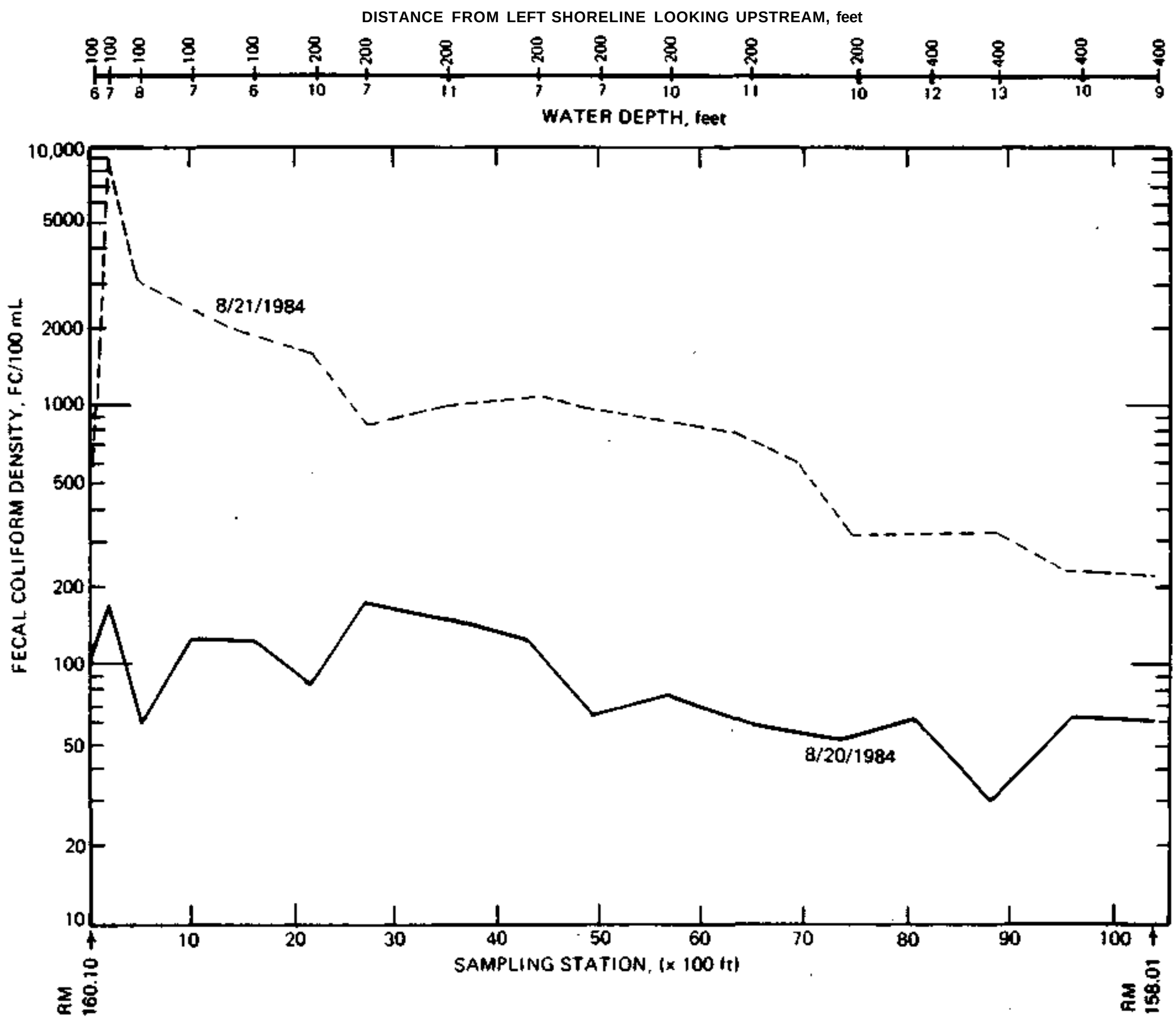

Figure 4. Longis??udinal profiles of FC density, August 20 (no effluent discharged) and August 21 (effluent non-chlorinated)

the longitudinal profile of FC densities for August 20 and 21, 1984. The bottom abscissa represents the sampling transect designations. The top abscissa shows both distance from the shore and the depth at which a sample was collected. Sampling locations coincided with the locations of the highest dye concentrations observed at the chosen transects during the previous dye run. However, the locations of the highest dye concentrations differed for each run.

On August 21, 1984, the GPSD effluent was discharged without chlorination. On this date, the effluent temperature was lower than the river water temperature (table 2). As expected, FC counts at St. 2+00 C100 feet offshore, sample from 7-foot depth) increased from 610/100 mL at St. 0+50 (100 feet upstream of the outfall) to 9200/100 mL (figure 4). Figure 4 also indicates that FC density decreased rapidly to 3000/100 mL at St. 5+00 and then decreased gradually downstream to 600 FC/100 mL at St. 70+00 (200 feet offshore, mid-depth sample). Between stations 75+00 and 104+00, FC densities were fairly constant below 400 per 100 mL and were less than that at the reference station 0+50 (610 FC/100 mL). It appears that the impact of the GPSD's discharge on the river bacterial quality extended up to St. 70+00 on this date.

<u>August 28 and 30 Runs</u>. There was no effluent discharge on August 27, 1984. The GPSD discharged at the rate of 45 mgd on August 28, 1984 without any chlorination. Again, the effluent temperature (24.1 C) was lower than the river temperature (25.7 C). The effluent FC counts at the beginning and end of the sampling run were 31,000 and 29,000 per 100 mL, respectively.

The longitudinal FC density profile for August 28 is shown in figure 5. An unexpectedly high count of 20,000 FC/100 mL was observed at 100 feet above the outfall channel A (St. 0+50). This was mainly due to the backflow of the treatment plant discharge in the river. According to Butts et al. (1985), the dam operations, the river flow and effluent discharge rates, and the temperatures of both the effluent and river water played important roles in the mixing patterns. Nevertheless, the river FC densities decreased rapidly within 1000 feet downstream, even though the effluent was partly discharged at ditch D (St. 9+00), and then gradually decreased to less than 400 per 100 mL at St. 46+00. The FC values reached a fairly constant level thereafter.

If the FC densities observed at stations beyond 46+00 can be considered as background levels, then the impact of the effluent on the bacterial quality of the river water extended to a distance of about 4500 feet below the outfall.

The treatment plant operation on August 30, 1984 was typical of dry weather, with a 21-mgd discharge rate. The effluent was chlorinated on this date. The results are plotted in figure 5. The upstream reference point (St. 0+50) had 900 FC/100 mL. No fecal coliform was detected in either chlorinated effluent or in

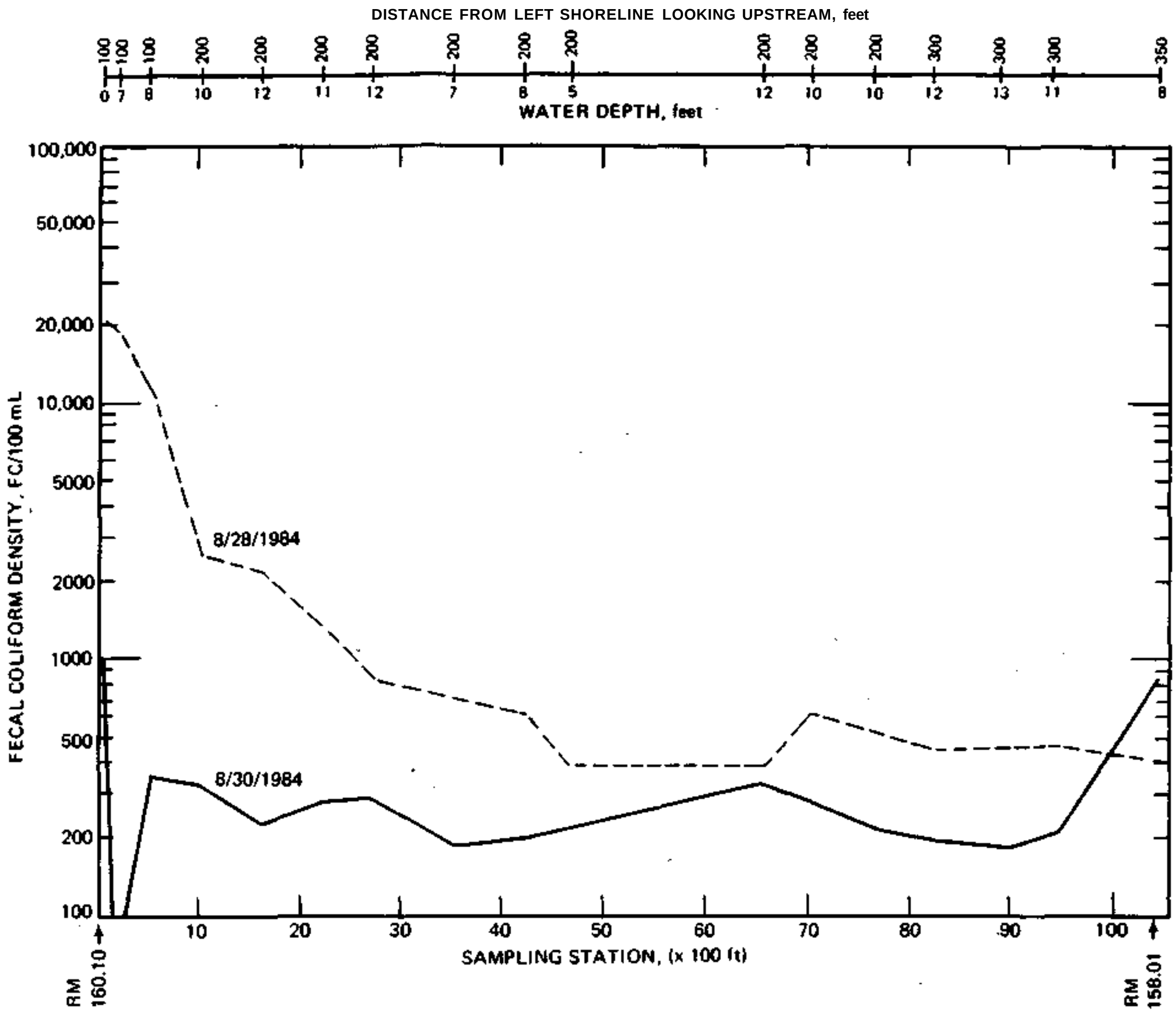

Figure 5. Longitudinal profiles of FC density, August 28 (effluent non-chlorinated) and August 50 (effluent chlorinated)

the sample collected at St. 2+00. For other downstream stations, with the exception of St. 104+00 C810 FC/100 mL), the FC values ranged from 180 to 330 per 100 mL. Only four stations showed FC densities less than or equal to 200 FC/100 mL. This is probably due to the high background FC levels in the river water.

<u>September 11 and 13 Runs</u>. During the period of these two runs, the temperatures of the effluent and the river water were similar (table 2)

On September 11, 1984, again for the purpose of the dye study, the plant discharged its effluent without chlorination. The effluent discharge rate was the highest at 55 mgd. High FC counts (13,000 per 100 mL) were observed at the reference point St. 0+50, as a result of the high rate of discharge of

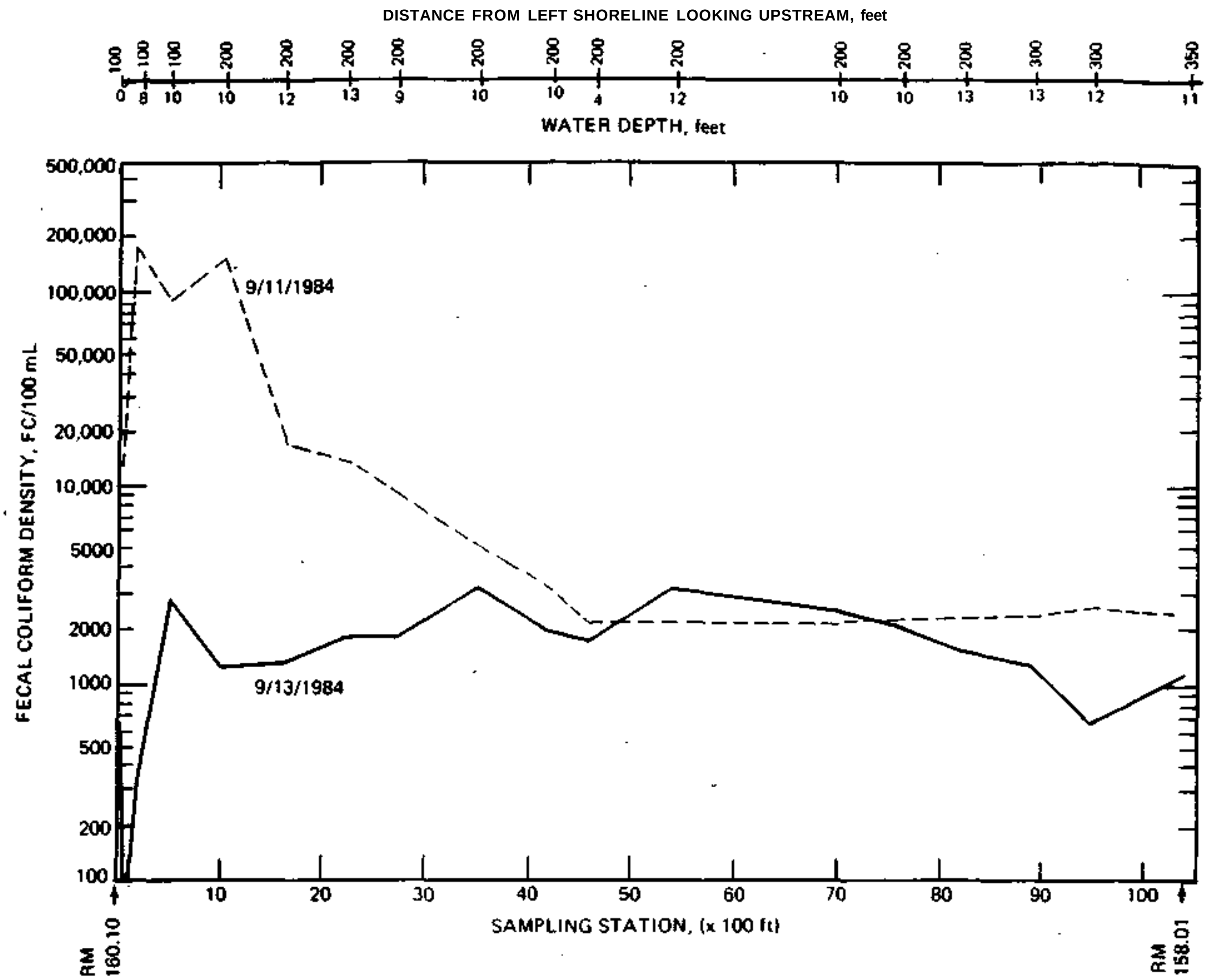

Figure 6. Longitudinal profiles of FC density, September 11 (effluent non-chlorinated) and September 13 (effluent chlorinated)

unchlorinated effluent. The FC concentration for wastewater effluent and for St. 2+00 were both 180,000 per 100 mL. Figure 6 shows that there was a significant FC reduction from St. 10+00 through St. 42+00. The river reach between St. 46+00 and St. 104+00 had steady FC concentrations of 2200 to 2800 per 100 mL. For this run, the impact of unchlorinated effluent on the river extended to about 4500 feet downstream if this steady rate is considered as the background level.

On September 13, 1984, both the effluent flow and river flow were low (table 2D. The chlorinated effluent had 12 FC/100 mL. The two-step enriched method (Lin, 19761 was used for FC enumeration on the September 13 chlorinated samples.

Figure 6 indicates that the FC values for stations 0+50 and 2+00 were respectively 650 and 310 per 100 mL. FC counts

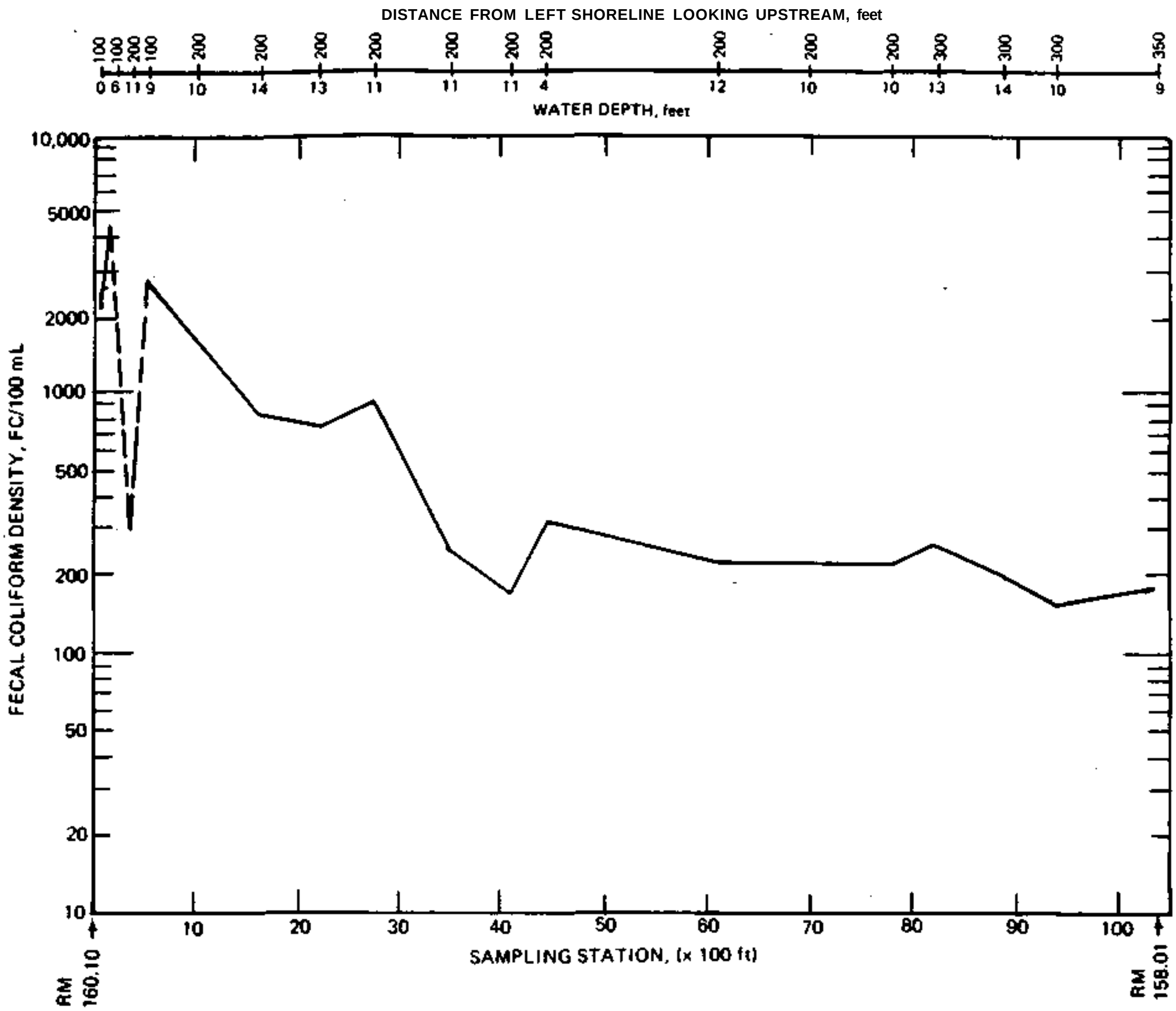

Figure 7. Longitudinal profiles of FC density, September 13 (effluent non-chlorinated)

increased to 1700 per 100 mL at St. 5+00 and stayed high in the study reach downstream. Generally, the two-step method produces higher FC counts than the standard one-step method, especially for chlorinated wastewater. The results of the September 13 run appear to show that the chlorination of wastewater effluent did not result in meeting the required river bacterial standard.

<u>September 18 Run</u> It can be seen from table 2 that during this run the effluent discharge was high (50 mgd) and the river flow was low. The effluent temperature was slightly greater than the river temperature. The effluent was not chlorinated on this date.

The effluent grab sample had 6,000 FC/100 mL. Figure 7 indicates that the upper reach of the study area had high FC

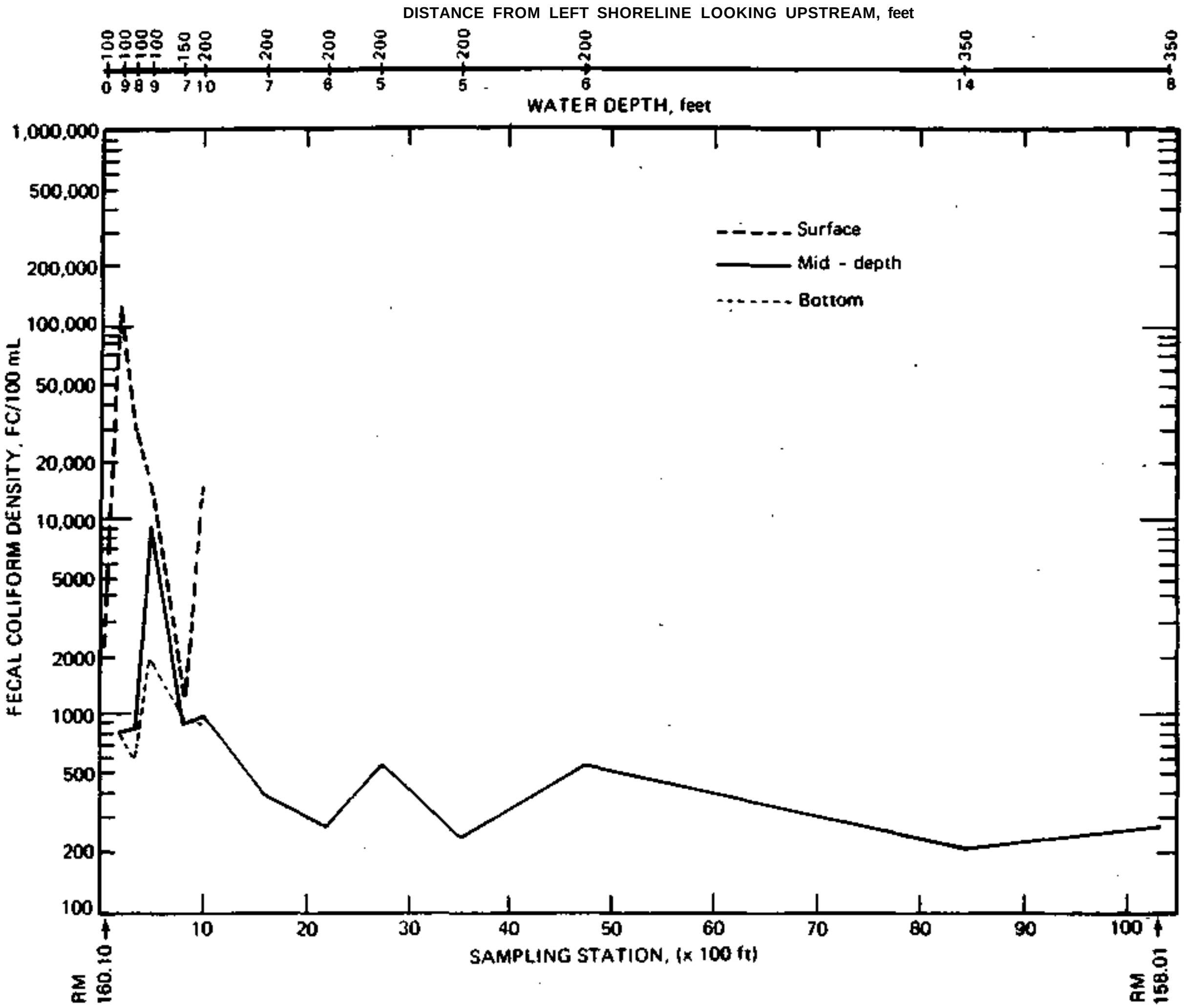

Figure 8. Longitudinal profilees of FC density, October 23 (effluent non-chlorinated)

counts. However, St. 3+50 had relatively low FC density. Through an error, the sample for this transect was collected at a point 200 feet offshore outside of the mixing zone instead of at a point 100 feet offshore. The FC densities at sampling locations in the lower reach below stations 35+00 were found to be fairly constant in the range of 160 to 320 FC/100 mL. The impact of the unchlorinated effluent appears to have extended to a distance of about 2600 feet from the outfall.

October 23 and 25 Runs. Surface, mid-depth, and near bottom water samples were collected for selected stations from 2+00 through 10+00. For these sampling stations, the water depths indicated in figures 8 and 9 (top abscissa) are the depths at which near bottom samples were taken.

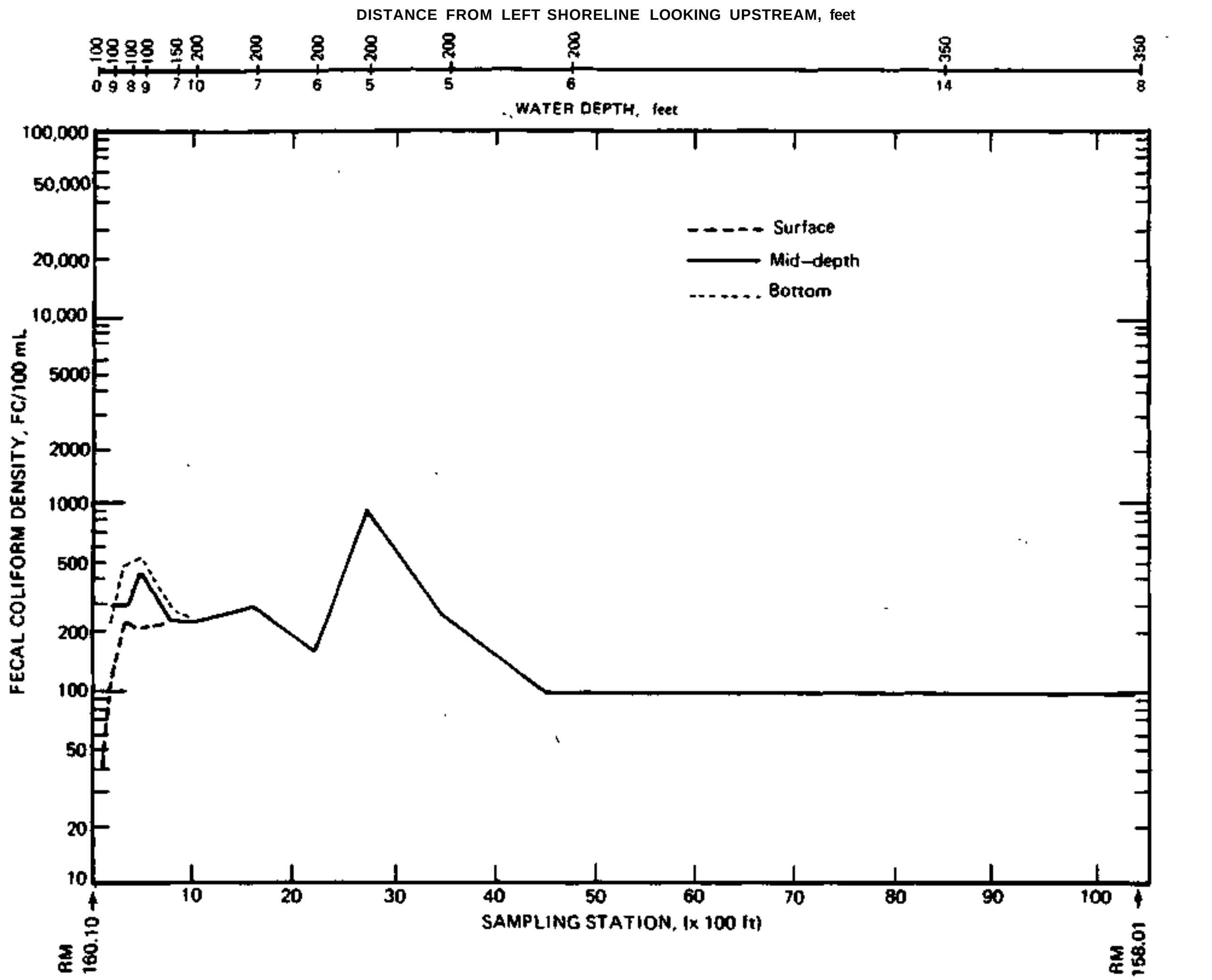

Figure 9. Longitudinal profiles of FC density, October 25 (effluent chlorinated)

On October 23, 1984, FC density for the non-chlorinated effluent was 140,000 FC/100 mL. Station 0+50 had 2200 FC/100 mL. It can be seen from figure 8 that the bacterial densities for the surface, mid-depth, and near bottom samples were different. FC counts for the surface waters were found to be significantly higher than those for the mid-depth and bottom waters. On this date the effluent temperature (20-21 CD was much greater than the river water temperature (15°C). The treatment plant discharge was probably confined to the upper portion of the river flow due to density differences. Poor mixing of the effluent and river water was experienced. This observation suggests that it is difficult to assess bacterial quality in a stream below an outfall based on one sample in a transect. More information is needed to establish guidelines for stream sanitation.

It is probable that this stratification in bacterial quality occurred much farther than at St. 10+00. Unfortunately, only mid-depth samples were collected from the lower reach. FC counts were less than 400/100 mL in mid-depth samples taken at stations beyond St. 47+00.

On October 25 there was a normal low flow operation with chlorinated effluent discharge from the GPSD plant. Fecal coliform densities for St. 0+50 and for the chlorinated effluent were 40 and 120 per 100 mL, respectively. The effluent temperature (25 C) was substantially higher than river water temperature (13-14.5 C). As on October 23, the mixing of the effluent discharge and the river water was probably confined mostly to the upper stratum on this date.

Figure 9 reveals that the chlorinated effluent had maximum impact on only four stations (St. 2+00 to St. 8+00). The surface layer in this reach had lower FC counts than the other two layers. At St. 10+00, FC counts for the three depth samples were essentially identical. The reason for the high FC count at St. 27+00 is not known.

TC and FC/TC Values

Lin and Evans (1980) reported that during the 5-year period from June 1971 through May 1976, the FC/TC values for the Illinois River at Peoria (RM 161.6), about 1.4 miles upstream of the effluent from the GPSD plant, ranged from 0.000 to 0.533, with a 5-year average of 0.071. This means that 7.1 percent of the total coliform consisted of fecal coliform. On the basis of monthly averages of the 5-year data, the FC/TC ratios were low in winter and in spring (December through May) while high values occurred in June (0.117), July (0.147), and September (0.114). The average for August was close to the 5-year average, and the mean FC/TC values for October and November were above the 5-year average.

Bacterial densities for the effluent of the GPSD facilities were determined on and after August 28, 1984. For the non-chlorinated effluent taken on September 11 and 13 and October 23, the FC/TC values were relatively steady between 0.12 and 0.17 (appendix). These values' were similar to those for the Illinois River at Peoria. For the chlorinated effluent, a wide range of FC/TC values (0.00 to 0.13) was observed. Strobel (1968) found that the relationship of FC and TC varied with the source of pollutant, level of wastewater treatment, characteristics of the receiving waters, and precipitation in the watershed.

July 24 Run. Data in the appendix (7/24/84) for the background station at RM 160.71 indicate that TC densities in the water column 100 feet from the shoreline were substantially higher than those at mid-channel (550 feet offshore). Samples collected from the two water columns at St. 5+00 had similar TC densities to those from RM 160.71, 100 feet offshore. In contrast to FC densities, TC densities in the study reach decreased with stream flow.

FC/TC values varied from 0.009 to 0.310. The low values in the range are due to either low FC counts, high TC counts, or a combination of both. There is no discernible pattern for FC/TC values for this date.

August 20 and 21 Runs. There was no wastewater effluent discharged to the river on August 20, 1984. The TC counts in the Illinois River water in the study reach were extremely low, with densities of 100 to 820 per 100 mL (appendix). The reason is unknown. However, the FC densities were found to be at normal levels. These gave high FC/TC values; i.e., about 23 to 85 percent of the total col i form was fecal coliform.

On August 21, 1984, 35 mgd of effluent was discharged to the Illinois River without chlorination. In a pattern similar to that for FC densities, the TC counts increased substantially to 58,000 per 100 mL at St. 2+00, decreased rapidly to 31,000 per 100 mL at St. 5+00, and then reduced gradually to 14,000 per 100 mL at St. 27+00. In this stretch of the river, the FC/TC values ranged from 0.16 down to 0.06. The river reaches between St. 35+00 and St. 70+00 and between St. 75+00 and St. 104+00 both had fairly constant TC counts (appendix, 8/21/1984). In these two sections of the river, the FC/TC values varied from 0.14 to 0.25.

August 28 and 30 Runs. On August 28, 1984 the unchlorinated effluent discharge was 45 mgd. The TC counts in the effluent at the beginning and at the end of river sample collections on this date were respectively 320,000 and 160,000 per 100 mL. The longitudinal profile of TC densities was found to be similar to the FC pattern (appendix). The TC counts rapidly decreased from 180,000 per 100 mL at St. 2+00 to 2900 per 100 mL at St. 46+00. The TC densities were generally low in the lower reach of the study area. The FC/TC values in the upper reach (St. 2+00 through St. 27+00) were generally low (below 0.10) while the ratios for the lower reach were generally higher.

The chlorinated effluent discharged to the Illinois River on August 30, 1984 contained only 60 TC/100 mL. On this date St. 2+00 had 100 TC/100 mL. The water sample at this station contained mostly chlorinated sewage effluent. The data presented in the appendix (8/30/84) reveal that TC values increased from 1600 per 100 mL at St. 5+00 to 2600 per 100 mL at St. 22+00 and then decreased at the downstream stations thereafter except at St. 104+00. The reason for the surge in the levels of the three indicator bacteria at St. 104+00 is unknown. The FC/TC ratios for all the sampling stations with the exceptions of St. 0+50 and St. 2+00 were between 0.10 and 0.32.

September 11 Run. The TC density in the unchlorinated effluent was 1,100,000 per 100 mL. At St. 2+00, unlike the pattern for FC density, the TC concentration decreased to 700,000 per 100 mL. St. 10+00 still had a high TC count (660,000/100 mL) because the effluent was also being discharged through ditch D at St. 9+00 Cfigure 2). The FC/TC values for the effluent discharge area (St. 2+00 to St. 10+00) were between 0.22 to 0.26.

It can be seen from the appendix (9/11/84) that there was a substantial reduction of TC densities between St. 10+00 and St. 16+00 (57,000 TC/100 mL). This resulted in a high FC/TC value (0.32) at St. 16+00. TC densities decreased from 84,000 to 41,000 per 100 mL in the river reach from St. 22+00 through St. 42+00. The reach between St. 46+00 and St. 89+00 had densities of 16,000 to 32,000 TC/100 mL. At St. 95+00 and St. 104+00, TC densities increased significantly. This might have been due to the aftergrowth of Aerobacter aerogens (Strobel, 1968). The FC/TC ratio decreased to about 0.10 or less for downstream stations below St. 27+00.

September 13 Run. The chlorinated effluent contained 92 TC/100 mL. Data in the appendix (9/13/84) show that, after the mixing of chlorinated effluent with the river water, the TC levels in the study area increased with downstream distance to a maximum of 16,000 TC/100 mL at St. 22+00 and stayed fairly steady (12,000 to 15,000 per 100 mL) through St. 76+00. The TC densities decreased thereafter.

High FC/TC values were generally observed around the chlorinated effluent discharge areas (St. 2+00 and St. 5+00). For other sampling locations, FC/TC values ranged from 0.11 to 0.30, and most were less than 0.20.

September 18 Run. On this date, the non-chlorinated effluent grab sample contained a low TC concentration (50,000 per 100 mL). The appendix (9/18/84) indicates that with the exception of St. 3+50, the TC densities in the river waters continuously decreased from 31,000 per 100 mL at St. 2+00 to 18,000 per 100 mL at St. 27+00. On the basis of the observed TC data, it appears that the impact of the non-chlorinated effluent discharge to the river extended up to St. 27+00. A similar conclusion can also be made on the basis of FC counts. The downstream stretch (St. 35+00 to St. 104+00) of the study area had 1800 - 5000 TC/100 mL.

The FC/TC ratios at all stations were found to be low, in most cases less than 0.10. They showed no general trend.

October 23 Run. The appendix (10/23/84) indicates that the unchlorinated grab sample contained 840,000 TC/100 mL. As with the FC densities, TC densities also showed stratification in the study area, with higher counts for the surface waters. A substantial reduction of TC concentration occurred at St. 16+00.

Downstream of this station there were no significant changes in TC densities among the sampling stations.

A3 shown in the appendix, the FC/TC values calculated for the samples collected on October 23, 1984 were generally less than 0.10 except for some upstream stations. There was no trend of FC/TC values for the samples at three different depths.

October 25 Run. The chlorinated effluent grab sample collected on October 25, 1984 had 2600 TC/100 mL. As previously stated, due to the temperature difference between the effluent (25 C) and the river water C13 - 14.5 C), the mixing of these two waters was limited to the upper stratum. It can be seen from the appendix (10/25/84) that for St. 2+00 through St. 10+00 the TC densities for the surface waters were lower than those for other depths. It seems that the chlorinated effluent tended to remain in the upper stratum of the river flow. The TC counts for St. 16+00 through St. 45+00 were high (>7300 per 100 mL).

The FC/TC values for the river samples collected downstream of the chlorinated effluent discharge were found to be very low (0.014 - 0.042) due to the low FC counts in combination with high TC densities. FC appears to be less resistant to chlorination than TC and FS.

FS and FC/FS Values

August 20 Run. FS concentrations for the river water samples collected on August 20, 1984 ranged from 16 per 100 mL at St. 80+00 to 370 per 100 mL at St., 10+00 (appendix), with a geometric mean of 69 per 100 mL. These values represent the background FS densities, since there was no wastewater effluent discharge from the GPSD facilities. The FS counts varied from station to station with no discernible trend.

On this date, the FC/FS values varied from 0.27 at St. 65+00 to 4.17 at St. 35+00 (appendix). Only one sampling location had FC/FS values greater than 4.0, and most of the stations had values less than 2.0.

August 28 and 30 Runs. The FS density in the non-chlorinated effluent discharge was very low (500 per 100 mL) on August 28, 1984. FS counts varied on this date from 80 to 210 per 100 mL between the outfall and St. 22+00. The FS counts were less than 80 per 100 mL for the other downstream stations. The FC/FS values for all stations were greater than 6.0 in the case of non-chlorinated effluent discharge. These data show that FS density is not a good indicator for evaluation of the impact of sewage treatment plant effluent on receiving waters.

On August 30, 1984, there was no FS detected in the samples of the chlorinated effluent or at St. 2+00. The FS densities for the other stations with the exception of St. 104+00 ranged from 30 to 74 per 100 mL Cappendix). The FC/FS values ranged from 2.6 to 7.3, which most likely represents the background levels for the Illinois River water.

September 11 Run. As shown in the appendix (9/11/84), the FS densities in the unchlorinated effluent and at St. 2+00 were 2700 and 1700 per 100 mL, respectively. As water travelled downstream the FS densities decreased to 170 counts per 100 mL at St. 42+00. Downstream of this station, with the exception of St. 104+00, the FS values in the lower reach of the sampling stations were between 130 and 210 per 100 mL.

The FC/FS values in the areas of non-chlorinated effluent discharges (St. 2+00 to St. 10+00) were extremely high (>100) . As can be seen in the appendix (9/11/84), the ratios decreased significantly at the downstream stations. However, there was no location which had FC/FS less than 4.0. It is clear that human wastes were the pollution source for the study area on this date.

September 13 Run. There was no FS detected in the chlorinated effluent and in the sample collected at St. 2+00. Inspection of the appendix (9/13/84) for the river reach between St. 5+00 and St. 42+00 indicates that FS counts were less than 100 per 100 mL. The FS densities increased in the lower reach of thestudyarea.

The FC/FS values were found to be higher for stations from St. 5+00 through St. 42+00, due to low FS counts. Only two locations (St. 95+00 and St. 104+00) had FC/FS values less than 4.0.

September 18 Run. It can be seen from the appendix (9/18/84) that the FS count in the non-chlorinated effluent was low (20/100 mL), which was the lowest FS density observed for all the samples collected on September 18, 1984. The grab sample of non-chlorinated effluent had a high FC/FS value of 300. The FS densities for the river stations varied from 35 to 140 per 100 mL without any general pattern. However, for the upper reach impacted by non-chlorinated effluent discharge (up to St. 27+00), the FC/FS values were generally high while the values were lower for the lower reach of the study area.

October 23 Run. The grab sample of non-chlorinated effluent contained a high concentration of FS (10,000/100 mL). However, the FS concentrations decreased as the effluent mixed with the river water. Near the non-chlorinated effluent discharge points (St. 2+00 through St. 5+00), the FS densities for the surface waters were greater than those for mid-depth and bottom waters (appendix, 10/23/84). The appendix also reveals that the FS densities for St. 8+00 and downstream stations on this date varied from 370 to 960 per 100 mL. The FC/FS values were high

(>8.0) from the outfall to St. 5+00. The remainder of the river samples generally had very low FC/FS values (<2.1).

October 25 Run. The chlorinated effluent grab sample had only 8 FS/100 mL. The appendix (10/25/84D indicates that the FS densities for samples at different depths and different stations showed trends similar to the density trends for both TC and FC. The FS counts for the stations below the chlorinated effluent discharge ranged from 60 to 460 per 100 mL.

The FC/FS values for the river samples were generally very low due to low FC densities after chlorination. The values were below 4.0 except at St. 27+00.

SUMMARY AND CONCLUSIONS

Fecal col i form, total coliform, and fecal streptococcus concentrations in the study area varied with water depth, transverse location, river mile, and date.

The goal in the selection of sampling points for the chosen transects was to obtain the maximum FC counts. This was a difficult goal to reach.

The results of this study show that the impact of non-chlorinated effluent discharges extended between 2600 and 6900 feet downstream of the outfall. The impact of the effluent discharge in the transverse direction was not determined. Station 0+50, 100 feet upstream of the outfall channels, showed high FC density when unchlorinated effluent was discharged at higher than average rates.

• Chlorinated effluents had very low or nondetectable FCs. However, with chlorinated effluent discharges, only a few river stations had FC counts less than 200 per 100 mL. In fact about 80 percent of the samples in the river downstream of the chlorinated effluents exceeded 200 FC/100 mL.

• The temperature difference between the effluent and river water was found to be an important factor in assessing the river bacterial quality.

• In order to obtain a complete picture, of chlorination effects on river FC densities, water samples should be collected from several depths in a sufficient number of water columns in a transect. It is needless to point out that with a larger number of sampling transects below the outfall, the river bacterial quality could have been better defined.

Among the three indicator bacteria, FC is the best indicator for evaluating the impacts of chlorination of treated wastewater effluent. For some occasions, the pattern of TC densities among stations was found to be similar to that of FC densities.

The majority of FC/TC values were found to be between 0.01 and 0.35. The values were' extremely low on October 25, 1984. In general, the values were low in the upper reaches of the river when these reaches were receiving chlorinated effluents.

FS densities in the effluent and the river water were generally low, even in non-chlorinated effluent. FS is therefore not suited for assessing the impact of sewage effluent discharges.

FC/FS ratio values in the upper reaches were extremely high when these reaches were receiving unchlorinated treatment plant discharges. For the evaluation of municipal wastewater effluent in receiving waters, FC/FS values serve very little purpose.

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Appendix . Bacteria Densities

Date	Transect	Station Ft. from shore	Ft. from surface	Bacteria density, per 100 mL TC	FC	FC/TC
7/24/84	RM 160.71	100	0	4,400	370	.084
			3	5,700	410	.072
			2	6,800	300	.044
			4	9,000	580	.064
	RM 160.71	550	0	900	12	.013
			3	350	20	.057
			8	300	93	.310
			17	300	33	.154
	5+00	100	0	3,400	540	.159
			3		1,600	-
			5	4,200	130	.031
			9	6,800	410	.060
	5+00	400	0	5,200	330	.063
			3	12,000	110	.009
			9	10,000	500	.050
			16	5,000	400	.080
	25+00	200	0	3,100	280	.090
	32+00	50	0	4,200	270	.064
			3	3,200	380	.119
	104+00	100	0	1,500	210	.140
			3	2,600	180	.069
			7	1,700	260	.153
			14	2,100	310	.148
	104+00	400	0	1,600	300	.188
			3	1,600	110	.069
			9	5,200	110	.021
			18	1,300	350	.269

Appendix. (Continued)

Date	Transect	Station: Ft. from shore	Station: Ft. from surface	Bacteria density, per 100 mL: TC	Bacteria density, per 100 mL: FC	Bacteria density, per 100 mL: FS	FC/TC	FC/FS
8/20/84	0+50	100	6	380	110	57	.289	1.9
	2+00	100	7	820	170	-	.207	-
	5+00	100	8	100	60	98	.600	.6
	10+00	100	7	200	120	370	.600	.3
	16+00	100	6	200	120	130	.600	.9
	22+00	200	10	300	90	49	.300	1.8
	28+00	200	7	200	170	130	.850	1.3
	35+00	200	11	300	150	36	.500	4.2
	43+00	200	7	240	120	45	.500	2.7
	50+00	200	7	170	68	54	.400	1.3
	57+00	200	10	100	77	50	.770	1.5
	65+00	200	11	150	60	220	.400	0.3
	73+00	200	10	150	52	35	.349	1.5
	80+00	400	12	160	60	16	.375	3.8
	88+00	400	13	130	30	60	.231	0.5
	96+00	400	10	180	64	58	.355	1.1
	104+00	400	9	130	62	80	.477	0.8

Appendix. (Continued)

Date	Station: Transect	Station: Ft. from shore	Station: Ft. from surface	Bacteria density, per 100 mL: TC	Bacteria density, per 100 mL: FC	FC/TC
8/21/84	0+50	100	6	3,500	610	.174
	2+00	100	7	58,000	9,200	.159
	5+00	100	10	31,000	3,000	.097
	10+00	100	0	25,000	2,300	.092
	16+00	100	6	20,000	1,700	.085
	22+00	200	10	16,000	1,600	.100
	27+00	200	7	14,000	900	.064
	35+00	200	11	4,000	1,000	.250
	44+00	200	8	5,500	1,100	.200
	48+00	200	6	7,600	1,000	.132
	63+00	200	12	4,400	800	.182
	70+00	200	10	3,100	600	.194
	75+00	200	10	1,700	350	.206
	82+00	300	12	1,400	350	.250
	89+00	300	13	2,500	350	.140
	95+00	300	10	1,700	250	.147
	104+00	350	8.5	1,200	220	.183

Appendix . (Continued)

Date	Transect	Station: Ft. from shore	Station: Ft. from surface	Bacteria density, per 100 mL: TC	Bacteria density, per 100 mL: FC	FS	FC/TC	FC/FS
8/28/84	Effluent 1			320,000	31,000	500	.097	62.0
	0+50	100	0	91,000	20,000	290	.220	69.0
	2+00	100	7	180,000	17,000	210	.094	81.0
	5+00	100	8	130,000	10,000	150	.077	.66.7
	10+00	200	9.6	67,000	2,500	80	.037	31.3
	16+00	200	12	61,000	2,100	150	.034	14.0
	22+00	200	11	13,000	1,300	60	.100	21.7
	27+00	200	12	9,800	850	80	.087	10.6
	35+00	200	7	4,500	690	56	.153	12.3
	42+00	200	8	25,000	560	40	.022	14.0
	46+00	200	5	2,900	390	50	.134	7.8
	65+00	200	12	1,100	390	52	.355	7.5
	70+00	200	10	3,300	610	60	.185	10.2
	76+00	200	10	-	-	-	-	-
	82+00	300	12	14,000	440	46	.031	9.6
	89+00	300	13	2,400	440	74	.183	6.0
	94+00	300	11	2,100	460	35	.219	13.1
	104+00	350	8	2,100	400	42	.190	9.5
	Effluent 2			160,000	21,000	-	.181	-

Appendix. (Continued)

Date	Station			Bacteria density, per 100 mL				
	Transect	Ft. from shore	Ft. from surface	TC	FC	FS	FC/TC	FC/FS
8/30/84	0+50	100	0	1,700	900	72	.529	12.5
	Eff Ts = 26°C			60	<1	<1	0	-
	2+00	100	7	100	<1	<1	0	-
	5+00	100	8	1,600	330	67	.206	4.9
	10+00	200	9	1,700	310	60	.182	5.2.
	16+00	200	11	1,300	220	48	.169	4.6
	22+00	200	11	2,600	270	59	.104	4.6
	27+00	200	12	2,200	280	45	.127	6.2
	35+00	200	9	1,200	190	74	.158	2.6
	42+00	200	8	1,100	200	62	.182	3.2
	46+00	200	5	1,100	210	60	.191	3.5
	65+00	200	12	1,200	310	52	.258	6.0
	70+00	200	10	1,100	260	76	.236	3.4
	76+00	200	10	800	220	30	.275	7.3
	82+00	300	12	620	200	61	.323	3.3
	89+00	300	13	720	180	37	.250	4.9
	94+00	300	11	860	210	64	.244	3.3
	104+00	350	8	3,800	810	110	.213	7.4

Appendix . (Continued)

Date	Transect	Station: Ft. from shore	Station: Ft. from surface	Bacteria density, per 100 mL: TC	Bacteria density, per 100 mL: FC	Bacteria density, per 100 mL: FS	FC/TC	FC/FS
9/11/84	0+50	100	0	79,000	13,000	320	.165	40.6
	Eff.			1,100,000	180,000	2,700	.164	66.7
	2+00	100	8	700,000	180,000	1,700	.257	105.9
	5+00	100	10	450,000	97,000	830	.215	116.9
	10+00	200	10	660,000	150,000	820	.227	182.9
	16+00	200	12	57,000	18,000	510	.316	35.3
	22+00	200	13	84,000	16,000	430	.191	37.2
	27+00	200	9	85,000	9,700	190	.114	51.1
	35+00	200	10	52,000	5,400	300	.104	18.0
	42+00	200	10	41,000	3,100	170	.076	18.2
	46+00	200	4	28,000	2,200	170	.079	12.9
	54+00	200	12	27,000	2,200	160	.081	13.8
	70+00	200	10	27,000	2,200	210	.081	10.5
	76+00	200	10	32,000	2,300	140	.072	16.4
	82+00	200	13	23,000	2,400	180	.104	13.3
	89+00	300	13	16,000	2,400	130	.150	18.5
	95+00	300	12	55,000	2,800	180	.051	15.6
	104+00	350	11	44,000	2,400	370	.055	6.5

Appendix. (Continued)

Date	Transect	Station Ft. from shore	Ft. from surface	Bacteria density, per 100 mL TC	FC	FS	FC/TC	FC/FS
9/13/84	0+50	100	0	7,500	650	100	.087	6.5
	Eff.			92	12	<1	.130	-
	2+00	100	8	870	310	<1	.356	-
	5+00	100	10	7,600	1,700	57	.224	29.8
	10+00	200	10	8,200	1,300	55	.159	23.6
	16+00	200	12	12,000	1,400	67	.117	20.9
	22+00	200	13	16,000	1,800	94	.113	19.2
	27+00	200	9	15,000	1,800	55	.120	32.7
	35+00	200	10	11,000	3,300	92	.300	35.9
	42+00	200	10	9,300	2,000	60	.215	33.3
	46+00	200	4	15,000	1,800	130	.120	13.9
	54+00	200	12	12,000	3,100	320	.258	9.7
	70+00	200	10	14,000	2,600	260	.186	10.0
	76+00	200	10	12,000	2,100	78	.175	26.9
	82+00	300	13	8,100	1,500	230	.185	6.5
	89+00	300	13	5,500	1,300	170	.235	7.7
	95+00	300	12	5,300	680	320	.128	2.1
	104+00	350	11	8,700	1,300	490	.149	2.7

Appendix . (Continued)

Date	Transect	Station: Ft. from shore	Station: Ft. from surface	Bacteria density, per 100 mL: TC	FC	FS	FC/TC	FC/FS
9/18/84	0+50	100	0	31,000	2,300	100	.074	23.0
	Eff.			50,000	6,000	20	.120	300.0
	2+00	100	6	31,000	4,700	140	.152	33.6
	3+50	200	11	5,000	300	85	.060	3.5
	5+00	100	9	25,000	3,400	100	.136	34.0
	10+00	200	10	20,000	-	85	-	-
	16+00	200	14	15,000	830	130	.055	6.4
	22+00	200	13	19,000	780	75	.041	10.4
	27+00	200	11	18,000	970	100	.054	9.7
	35+00	200	11	3,200	250	80	.078	3.1
	41+00	200	11	4,000	170	35	.043	4.9
	44+00	200	4	2,600	320	72	.123	4.4
	61+00	200	12	3,100	230	76	.074	3.0
	70+00	200	10	2,300	230	62	.100	3.7
	78+00	200	10	5,000	230	45	.046	5.1
	82+00	300	13	2,900	300	96	.103	3.1
	89+00	300	14	2,500	200	60	.080	3.3
	95+00	300	10	2,300	160	55	.070	2.9
	106+00	350	9	1,800	190	77	.106	2.5

Appendix .   (Continued)

Date	Station: Transect	Station: Ft. from shore	Station: Ft. from surface	Bacteria density, per 100 mL: TC	Bacteria density, per 100 mL: FC	Bacteria density, per 100 mL: FS	FC/TC	FC/FS
10/23/84	0+50	100	0	78,000	2,200	690	0.028	3.2
	Eff.			840,000	140,000	10,000	0.167	14.0
	2+00	100	0	780,000	120,000	2,500	0.153	48.0
			5	12,000	770	1,000	0.064	0.8
			9	34,000	790	1,500	0.023	0.5
	3+50	100	0	110,000	27,000	860	0.245'	31.4
			4	23,000	830	600	0.036	1.4
			8	14,000	590	700	0.042	0.8
	5+00	100	0	210,000	13,000	1,500	0.062	8.7
			5	80,000	9,000	970	0.113	9.3
			9	39,000	2,000	940	0.051	2.1
	8+00	150	0	25,000	1,400	410	0.056	3.4
			4	13,000	900	480	0.069	1.9
			7	14,000	1,000	630	0.070	1.6
	10+00	200	0	69,000	15,000	720	0.217	20.8
			5	13,000	1,000	960	0.077	1.0
			10	24,000	900	790	0.038	1.1
	16+00	200	7	8.400	490	540	0.058	0.9
	22+00	200	6	4,800	260	380	0.054	0.7
	27+00	200	5	8,500	570	590	0.067	1.0
	35+00	200	5	4,600	230	600	0.050	0.4
	47+00	200	6	11,000	550	420	0.050	1.3
	84+00	350	14	4,200	220	520	0.052	0.4
	104+00	350	8	5,800	260	370	0.045	0.7

Appendix . (Concluded)

	Station			Bacteria density, per 100 mL				
Date	Transect	Ft. from shore	Ft. from surface	TC	FC	FS	FC/TC	FC/FS
10/25/84	0+50	100	0	800	40	12	0.050	3.3
	Eff.			2,600	120	8	0.046	15.0
	2+00	100	0	4,800	120	60	0.025	2.0
			5	22,000	290	460	0.013	0.6
			9	9,400	220	130	0.023	1.7
	3+50	100	0	13,000	230	190	0.018	1.2
			4	13,000	290	250	0.022	1.2
			8	17,000	470	150	0.028	3.1
	5+00	100	0	15,000	210	230	0.014	0.9
			5	21,000	390	250	0.019	1.6
			9	20,000	460	190	0.023	2.4
	8+00	100	0	9,800	230	220	0.023	1.1
			4	11,000	230	210	0.021	1.1
			7	11,000	280	250	0.025	1.1
	10+00	200	0	12,000	230	230	0.019	1.0
			5	13,000	220	380	0.017	0.6
			10	33,000	240	260	0.007	0.9
	16+00	200	7	12,000	270	320	0.023	0.8
	22+00	200	6	8,400	150	140.	0.018	1.1
	27+00	200	5	25,000	930	190	0.037	4.9
	35+00	200	5	8,700	220	110	0.025	2.0
	45+00	350	6	7,300	100	83	0.014	1.2
	84+00	350	14	2,400	100	120	0.042	0.8
	104+00	350	8	3,300	100	90	0.030	1.1