Foth & Van Dyke

REPORT

1993 Fecal Coliform Study

Scope ID: 93R007

Racine Wastewater Utility
Racine, Wisconsin

November 1993

1993 Fecal Coliform Study

Scope ID: 93R007

Prepared for
Racine Wastewater Utility
Racine, Wisconsin

Prepared by
Foth & Van Dyke and Associates Inc.

November 1993

Acknowledgement

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Foth & Van Dyke

2737 S. Ridge Road
P.O. Box 19012
Green Bay, WI 54307-9012
414/497-2500

Engineers
Architects
Planners
Scientists

Foth & Van Dyke

2737 S. Ridge Road
P. O. Box 19012
Green Bay, WI 54307-9012
414/497-2500
FAX: 414/497-8516

November 17, 1993

Mr. Thomas Bunker
Racine Wastewater Utility
City Hall Annex, Room 227
800 Center Street
Racine, WI 53403

Dear Tom:

RE: 1993 Fecal Coliform Study

Foth & Van Dyke is pleased to present ten copies of the final report titled *1993 Fecal Coliform Study*, to the Racine Wastewater Utility. This document expands upon past investigations of the Racine Wastewater Utility and the City Health Department regarding the sources of fecal coliform, and offers recommendations on how to solve the beach-closing problem.

If after reviewing this document, you have any questions, please call us at your earliest possible convenience.

Sincerely,

Foth & Van Dyke

Gerald J. Berg
Project Manager

Stephen Marman, P.E.
Client Liaison

GJB1/SMM/lb

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Distribution

No. of Copies	Sent To
10	Thomas Bunker Racine Wastewater Utility City Hall Annex, Room 227 800 Center Street Racine, WI 53403
3	Gary Gylund State of Wisconsin Department of Administration Coastal Management Program 101 East Wilson Street, 6th Floor P. O. Box 7868 Madison, WI 53707-7868

1993 Fecal Coliform Study

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1 Background

Summertime fun and swimming are synonymous to many people. Unfortunately, elevated bacteria counts have forced the city of Racine, Wisconsin, to close their beaches during the height of the swimming season in each of the past three years. These beach closings are the result of elevated fecal coliform (FC) bacteria counts in the water. Fecal coliform bacteria ordinarily will not cause illness, but are associated with potential disease-causing organisms called pathogens. When the FC counts rise above a five-day geometric mean of 200 Colony-Forming Units (CFU) per 100 ml, the water is considered unsafe for recreation.

The most upsetting aspect of past beach closings was that they occurred during the month of August, when the water was the warmest for swimming. The most perplexing aspect of past beach closings was that they occurred during dry weather periods. One dry spell began on August 13 after 1.06 inches of rain fell and ended August 21. The beaches remained closed during that time. Typically beach closing are associated with rainfall because storm sewers become active. This is usually the case for Milwaukee and Chicago who have their beach closing incidents one to two days after a rainfall. Racine's specific situation is unusual in that the beach closings persisted eight days after a rainfall. Dry weather beach closings are not unusual for Racine.

In 1991, the Racine Wastewater Utility released an initial investigation identifying possible sources of the FC contamination. Sources identified include:

- Sewage - From sanitary sewers or the wastewater treatment plant (WWTP).
- Storm sewer runoff.
- Water from the Root River.
- Seagulls and other animals.
- Swimmers.
- Boaters.

Subsequently, the Racine Wastewater Utility requested the University of Wisconsin - Madison's department of environmental engineering perform a literature review to help the Utility gain a better understanding of the nature of FC. The City Health Department hired a summer intern to contact all of the health departments on the Great Lakes, in both the U.S. and Canada, to obtain information about other communities' standards and methods of testing. In 1993, Foth & Van Dyke was retained by the Racine Wastewater Utility to expand upon past investigations of the Racine Wastewater Utility and the City Health Department regarding the sources of FC and to make recommendations on how to solve the beach closing problem.

The City Health Department and Wastewater Utility's ultimate goal is to eliminate the FC problem so that the beaches can remain open during the summer. This report presents the data collected during the summer of 1993, discusses the potential sources, and recommends corrective measures and areas of further study.

2 Approach

The 1993 Fecal Coliform Study was a cooperative effort of the Racine Wastewater Utility and the City Health Department collecting water samples from four different sources: Lake Michigan, storm sewers and drainage ditches, the Root River, and sub-beach groundwater.

2.1 The Lake Transect Study

The Racine Wastewater Utility and the City Health Department had been testing the lake along the shore for several years, but had never done extensive testing away from shore. The lake transect study was commissioned by the Racine Wastewater Utility to test for bacteria, turbidity, and other parameters in the lake. The purpose of these tests was to determine how the FC were moving in the lake, and see if they were coming from a non-point source along the shore. A series of six east/west transects was established in Lake Michigan as shown in Figure 2-1. Positions were fixed using a Trimble TransPac GPS (global positioning system). Water samples were collected at the shore, 100 feet from shore, 500 feet from shore, and 1,000 feet from shore. Replicates were taken randomly with a ten percent frequency. Samples were collected from three depths (surface, mid-depth and bottom) where possible. Ten sets of samples were collected from June 29, 1993 to September 7, 1993. In addition to sampling at the transects, water samples were taken from four locations within the harbor, and at three storm sewers and two drainage ditches along the coast, as shown in Figure 2-1. Water samples were taken at three depths at each of the four sampling locations in the harbor, with one harbor replicate being sampled at random.

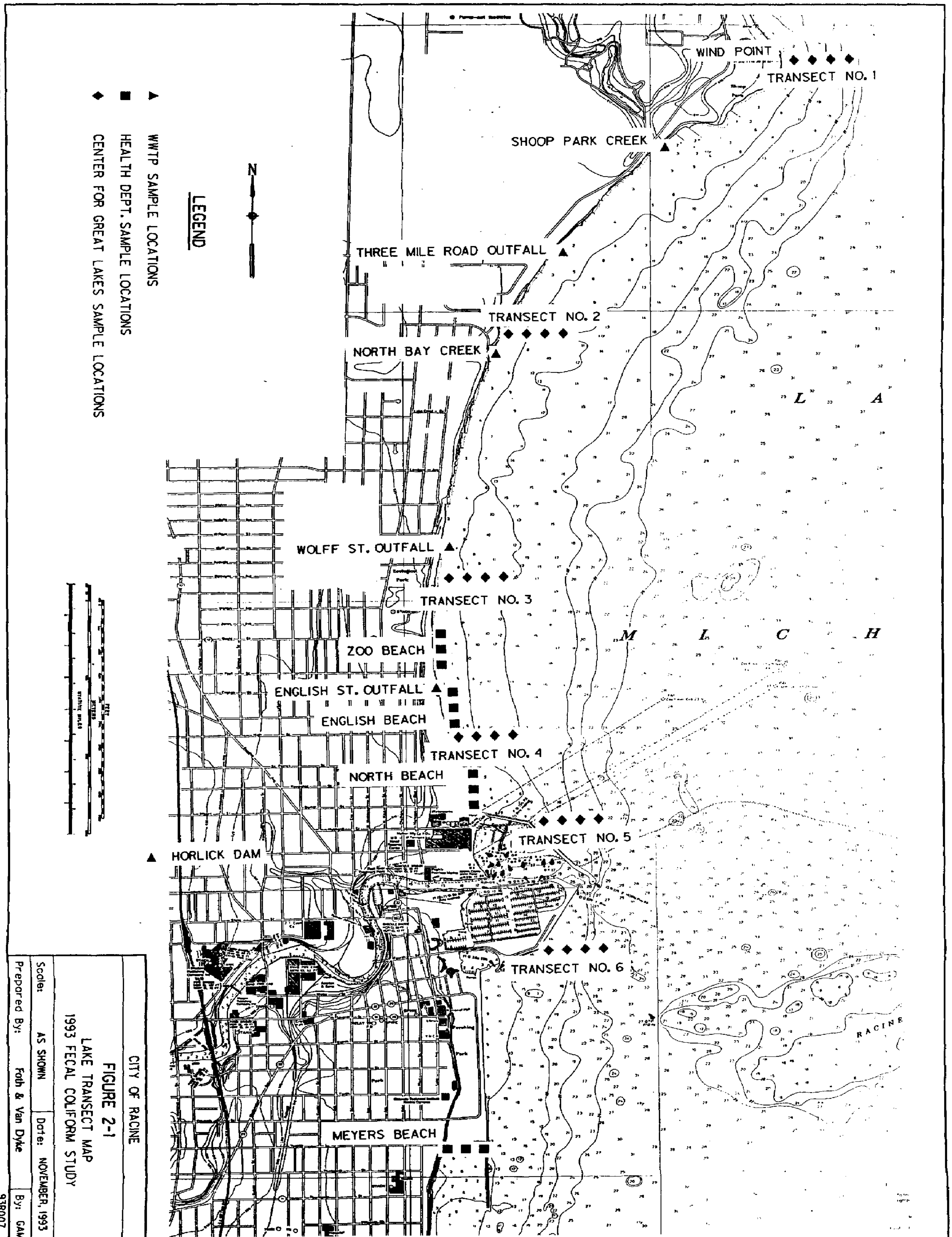
All samples were analyzed at Racine's WWTP for FC using the membrane filter technique as described in the 17th Edition of Standard Methods.[1] Lab replicates were also done with a ten percent frequency. The weekly sampling dates were designed to coincide with the City Health Department's bi-weekly sampling program of near-shore water adjacent to the beaches.

Surface water samples were collected in whirl pack bags and placed on ice when stored for more than one hour. Mid-depth and bottom samples collected in the lake transect study were collected using an acrylic, two-liter, vertical Van Dorn water bottle and transferred to whirlpack bags and put on ice. Water temperatures were recorded using an electronic temperature gage at each water sampling location and depth. Water samples were taken in the harbor using these same methods.

Current directions were recorded when surface water samples were collected. The data were obtained using flagging tape on a three-foot pole for shoreline stations or with flagging tape attached to an anchored float at off-shore stations.

The wind speed and direction were also recorded during the sampling program. Wind speed was measured using a hand-held anemometer and the direction was recorded using a compass.

[1] American Public Health Association, Standard Methods for the Examination of Water and Wastewater, 17th Edition, Washington, DC, 1989.



CITY OF RACINE

FIGURE 2-1

LAKE TRANSECT MAP

1993 FECAL COLIFORM STUDY

Scale:	AS SHOWN	Date:	NOVEMBER, 1993
Prepared By:	Foth & Van Dyke	By:	GAM

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Sediment samples were taken during three weekly sampling rounds, from August 7, 1993 through August 31, 1993. Sediment samples were taken at each of the 24 lake transect locations and four harbor locations using a Peterson dredge and a ponar dredge. Sediment samples were analyzed at two different labs. The Sommer-Frey lab in Milwaukee tested 17 samples and Racine's water treatment plant tested seven. Sediment samples were analyzed using a "most probable number" technique as described in the 17th Edition of Standard Methods.

2.2 Lake Michigan Beach Testing

The City Health Department continued it's routine water testing program for the Lake Michigan beaches. Water samples were taken 30 to 100 feet off shore at an approximate depth of three feet. Whirl-pack bags attached to the end of a three-foot rod were dipped into the water. Additional information such as air and water temperature, general wind direction and speed and estimated bird populations were noted. Split samples were analyzed by the City Health Department lab and WWTP lab.

2.3 Root River Testing

The City Health Department analyzed the Root River during summer 1993. Root River water samples were collected on a weekly basis. Surface water samples were collected using the same four-foot pole apparatus used in the City Health Department's lake sampling program. All samples were analyzed by the City Health Department lab. Current speed was determined by timing floating debris in midstream.

2.4 Sub-Beach Testing

Sub-beach water samples were obtained from holes which were dug in the sand at various distances away from shore. The holes were dug using a garden shovel at measured distances away from shore. The ground water was allowed to flow in from the sides and bottom of the hole and water samples were collected in whirl pack bags and analyzed at the WWTP.

3 Test Data

The test data obtained in the 1993 Fecal Coliform Study are summarized in this section. This includes data obtained by both the City Health Department and the Racine Wastewater Utility.

3.1 Lake Transect Study

The lake transect study cultured some 3,000 plates and recorded over 1,000 turbidity readings in the summer of 1993. The data are presented in Appendix A. Turbidity, which is a measure of solids in suspension, was largely associated with wave action and wind speed. The simple average for turbidity in all river and lake water samples was 4.4 nephelometric turbidity units (NTU). The simple average for FC in all river and lake water was 80.7/100 ml. It should be noted that these simple averages do not account for extreme values which may skew the results. The assumed background for turbidity would be 1.5 NTU and an assumed background FC count would be 10/100 ml. A curvilinear relationship between FC counts and turbidity was found in both lake and in river harbor water samples. This relationship was not found in storm sewer water or drainage ditch water.

Wind direction appeared to be the driving force behind the longshore currents in the lake. The wind direction and current direction were not always the same, however. The wind direction was somewhat variable on any given day, whereas the water current direction generally moved north or south along the coast. Very high FC counts were reported at Wind Point when the wind was from the N-NE. Shoreline counts of 624/100 ml on 6/29/93 and 630/100 ml on 8/10/93 with respective turbidity readings of 42 NTU and 18 NTU were observed when the wind direction came from the NE at 10 to 15 mph. The high FC counts were localized at Wind Point because the shoreline FC count at transect No. 2 was 15 and 40. No consistent FC loading pattern was observed during the lake transect study. The high readings were associated with increased wave activity which would increase the turbidity of the water.

FC counts in the harbor area were consistently higher than lake water. Plume water of the river was observed to flow out into the lake and dissipate with the longshore currents upon discharge into the lake. Bacterial counts typically dropped one full order of magnitude from the sampling station at Gas Light Pointe to the transect down current from the harbor mouth. The corresponding transect up current from the harbor mouth reported single digit counts during nine of ten sampling runs.

3.2 Lake Michigan Beach Testing

The City Health Department takes water samples off shore of the city beaches to assess the water quality of Lake Michigan. The beaches are closed if the geometric mean of five consecutive samples within a one-month period exceeds 200/100 ml or when any one test exceeds 1,000/100 ml. The bacterial levels in 1993 were below this standard for most of the summer, except for the week before the swimming season opened (6/8/93) and the last weekend of swimming season (8/27/93). The summer of 1993 had the most number of "open" swimming days in three years. The data collected during this period are shown in Table 3-1.

The beach sampling program used techniques and sampling sites similar to those used in previous years. Water was collected along two stretches of shoreline. The primary recreational beaches are located one-half mile north of the river/harbor and are subdivided into three beach

Table 3-1
Fecal Coliform Counts from City Health Department Lake Michigan Beach Testing

Date	Meyers #1	Meyers #2	Meyers #3	North #1	North #2	North #3	English #1	Engllish #2	English #3	Zoo #1	Zoo #2	Zoo #3	5 Day Geometric Means: Meyers Beach	North Beach	English Beach	Zoo Beach	3 Rec'l Beach
5/19/93	40	10	60	20	30	10	40	40	40	10	10	10	29	18	40	10	19
5/25/93	43	52	40	73	83	118	80	64	122	29	27	47	36	40	58	18	35
5/27/93	2000	2000	2000	1200	2100	1100	3400	224	120	168	228	108	315	132	115	38	83
6/1/93	69	51	96	12	15	15	10	36	13	9	8	9	64	75	71	26	52
6/3/93	76	76	84	460	960	500	480	425	390	445	550	490	137	114	102	47	82
6/8/93	960	740	1080	900	1730	2000	2200	2800	2000	2100	2100	1560	251	274	230	134	204
6/10/93	196	184	216	96	80	140	52	65	144	71	208	64	222	282	226	166	220
6/15/93	1	1	3	28	40	47	6	4	19	2	4	7	50	136	100	79	102
6/17/93	96	100	524	8	8	19	37	3	41	50	46	80	141	129	100	115	114
6/22/93	13	16	18	4	15	13	14	14	196	3	9	31	40	56	60	52	56
6/24/93	178	224	320	8	25	15	36	38	54	60	64	46	66	22	27	26	25
6/29/93	44	39	30	29	22	39	27	92	34	54	58	43	25	17	24	23	21
7/1/93	60	47	60	67	84	55	74	55	31	126	76	74	77	19	35	42	31
7/8/93	88	186	170	10	21	18	2	3	2	16	36	23	64	21	23	36	26
7/13/93	17	19	30	13	10	10	4	4	2	8	9	4	55	22	15	33	22
7/15/93	59	27	65	28	45	46	12	9	14	43	62	50	58	26	11	33	21
7/22/93	34	62	24	260	68	172	64	76	65	310	260	420	51	36	12	47	28
7/27/93	3	2	3	15	28	26	22	18	33	4	6	0	22	29	11	24	19
7/29/93	27	9	30	5	22	10	5	11	4	38	9	21	23	27	13	23	20
8/3/93	47	41	49	42	48	43	26	48	36	10	26	36	20	36	21	29	28
8/5/93	45	51	34	44	55	29	39	31	28	19	33	29	21	36	26	25	29
8/10/93	780	1080	970	7	13	4	240	162	92	194	64	130	48	20	30	20	23
8/12/93	56	102	68	330	180	128	730	480	950	1700	1600	1220	52	31	59	72	51
8/17/93	290	280	210	290	204	198	208	170	134	240	290	200	169	57	115	118	92
8/19/93	280	260	350	490	430	540	220	300	240	420	410	580	165	91	171	220	151
8/24/93	192	200	220	88	46	34	56	56	108	86	52	64	242	96	199	264	171
8/26/93	350	260	340	148	112	162	500	209	550	640	530	340	216	173	239	351	244
8/31/93	635	570	780	1330	2015	2700	570	1400	690	1500	1455	1385	319	273	248	349	287

areas: North beach, English beach, and Zoo beach. A second shoreline located 1 mile south of the river/harbor, known as Meyers beach, was also tested. Meyers beach is not considered a prime recreational beach and is mainly used as a boat launch and by jet skiers.

Water samples were taken on a biweekly basis until the geometric mean approached 200/100 ml. The frequency of the tests was then increased to a daily basis. Samples were split between the City Health Department lab and the WWTP lab on a biweekly basis during the entire summer to check for precision. The data reported in Table 3-1 are from the WWTP lab.

3.3 Root River Testing

The City Health Department tested the Root River at 15 different sites during the summer. The FC counts as reported by the City Health Department lab are listed in Table 3-2. A tributary, Hoods Creek, was also tested on a weekly basis. FC counts in the Root River increased after rain events and decreased exponentially with time after a rain event.

Bacterial levels increased and decreased with changes in current velocity. Bacterial levels increased as water speed increased and fell as the river water slowed. Horlick Dam and the Marina area, the slowest moving stretches of the river, typically had the lowest counts, whereas the rapids at Cedar Bend and the Memorial Street bridge had the highest.

3.4 Sub-Beach Testing

A unique approach to investigating potential sources of FC was to look at the water beneath the beach itself. This sub-beach water provided some very high counts, especially when the lake water counts exceeded the geometric mean of 200/100 ml. Data from these tests are listed in Table 3-3. Sampling locations were measured back from the edge of the waves. Relative locations would change slightly depending on the amount of wave action and erosion/deposition of sand on the beach. Lake water FC counts from 6/30/93 to 8/9/93 are estimates based on lake water samples taken by the City Health Department on the day before and the day after. Lake water FC counts from 8/12/93 to 8/29/93 were obtained from water samples taken on the same day that the sub-beach samples were collected.

The temperature of the sand was recorded on one occasion to develop a depth/temperature profile. The idea behind this was to see if the sub-beach water was warmed by the sun, perhaps affording the bacteria an "enteric like" environment for living and growth. The temperatures were taken on a sunny day in early August, air temperature was about 25°C. Temperatures were found to dissipate rapidly. The temperature on the surface of the sand was 40°C. It dropped to 28°C within the first two inches, and was a constant 23°C at six inches and below. The temperature needed to provide an "enteric like" environment would range from 37°C to 40°C. This zone would be very thin based on the observations listed above.

Surface beach sand was also analyzed for FC bacteria. Dry surface sand was collected on three occasions and analyzed for FC. One sample of sand was collected on 8/18/93. Two other sample pairs were collected on 8/28/93 and 8/29/93 before and after a rainstorm. A rain event of 0.16 inches occurred during the night of 8/28/93. A test was developed to evaluate the sand. One hundred grams of sand were washed in 100 ml of water. The wash water was then tested to determine the FC count. The data obtained from this test were variable, including one plate which was too numerous to count (TNTC) at 4,000 FC per gram of washed surface sand. All

Table 3-2
Fecal Coliform Counts from City Health Department Root River Testing

Sample Site	5/26/93	6/2/93	6/9/93	6/16/93	6/23/93	6/30/93	7/7/93	7/14/93	7/21/93	7/27/93	8/4/93	8/18/93	8/25/93
County Line	530	960	4100	1780	3000	4600	10700	1800	3800	300	200	2800	1200
7 Mile Rd.	450	650	4900	930	2700	3000	4000	7200	4900	500	100	2300	1700
Linwood Park	300	920	5200	1460	3600	6800	2400	2500	1900	700	200	600	1600
Johnson's Park	440	980	6400	920	3100	3100	14300	6500	1500	200	1600	800	700
Hwy. 31 & 4 Mile Rd.	140	870	4500	2900	1600	4700	1500	6400	1700	100	900	1100	1000
Armstrong Park	80	1030	9900	1130	7300	2900	800	2700	1000	1100	300	600	400
Horlick Dam	130	170	7100	1000	3000	700	400	900	600	100	100	100	100
Lincoln Park	350	360	6600	1040	1300	11600	3500	4700	11400	100	200	1500	500
Cedar Bend	730	400	12200	1890	2300	8400	4200	4200	1500	1300	600	2200	10600
Memorial Dr. Bridge	570	230	11600	2180	2200	19100	2300	16900	6000	2600	100	4300	2500
Western Publishing	470	280	6900	560	1200	11800	2300	14200	3200	700	100	1800	3000
Azarian Marina	1130	500	6800	510	800	5300	1400	15600	7500	1500	300	2500	1800
Western Yacht Club	460	190	11700	770	2000	3100	3000	13300	3800	1000	300	1500	500
Chartroom	480	90	6100	280	1100	1800	100	10300	900	300	300	100	300
Marina Pier	200	40	6000	180	500	9600	700	2900	400	100	400	100	100
Hoods Creek	1110	470	8800	2260	2100	8000	20000	12200	1000	700	700	1100	4100

Table 3-3
Fecal Coliform Counts from Sub-Beach Testing

Sample Site	Distance away from shore	6/30	7/6	7/21	8/5	8/9	8/12	8/18	8/20	8/28	8/29
Lake water FCs	50' into lake	15	16	145	41	7	197	264	733	10	420
	Wash zone						1033	624	6000	1340	540
North Beach - N	5'						28300		28400	1000000	53600
(High St.)	10'	198			1190		76200	500	37200	8500	7650
	15'		274	156		360	1770		1050		8000
	50'	9800	36	81		116	3200		54		310
	100'	56	16	2		2	40		58		330
Lake water FCs	50' into lake	15	16	145	41	7	197	128	3800	30	270
	Wash zone						1206	964	9700	420	730
North Beach -S	5'						13300		52400	14800	138800
(Kewaunee St.)	10'	7600			830		3200	22000	22400	8100	5800
	15'		580	6700		6000	21000		1200	120	3400
	50'	1000	172	192		388	854		1700		14400
	100'	584	66	116		6	1220		4600		80
Lake water FCs	50' into lake	17								70	260
English Beach	5'	288								6300	10000
Lake water FCs	50' into lake									30	160
Zoo Beach	5'									59200	9200
	10'									2100	6300
Lake water FCs	50' into lake					720		522			
Meyers Beach	10'					56		175			

tests were run on 8/30/93. The data from this study are listed in Table 3-4.

Table 3-4

Fecal Coliform Counts from Surface Sand Testing

Date Sampled	Location	Count/Gram of Sand
8/18/93	North Beach at Kewaunee Street	4,000
8/18/93	North Beach at High Street	556
8/28/93	North Beach at High Street	97
8/28/93	Zoo Beach	15
8/29/93	North Beach at High Street	72
8/29/93	Zoo Beach	180

4 Discussion

4.1 Bacterial Disappearance

Several valuable pieces of information were gathered from the lake transect study about the near-shore area of Racine. The relationship between dilution/disappearance and distance away from shore is one of the most valuable pieces of information obtained. This relationship has been noted before, but the relationship between dilution/disappearance and distance was never studied in detail. A study conducted by the Illinois EPA in Chicago (1986) found that four percent of the shoreline water samples exceeded 500/100 ml resulting in 33 beach closings. Water samples collected one mile away from shore, during this same time, were devoid of FC bacteria.[2] This study, however, did not take any samples within one mile. Another study, conducted by Zanoni, *et al.*, (1978), found that FC counts decreased with distance from shore.[3] Zanoni's study compared the water quality within Milwaukee's harbor breakwater 0.75 miles (3,960 feet) from shore and lake water beyond the breakwater. A shore sample was taken at the mouth of the Milwaukee river at the confluence of the Milwaukee, Menomonee and Kinnickinnic rivers adjacent to the Milwaukee Metropolitan Sewerage District, Jones Island WWTP. Harbor samples were collected at the breakwater and at an intermediate distance, approximately 0.25 miles (1,320 feet) apart. Lake water samples beyond the breakwall were taken at half mile intervals to a distance of two miles. Analysis of Zanoni's data shows a 50 to 95 percent reduction from the shore to the breakwater and a consistent 99 percent reduction (zero levels) just beyond the breakwall. This suggests that the breakwater was acting to "trap in" water with FC by reducing circulation and natural dilution to the lake.

The Racine lake transect study showed that the FC bacteria dissipated rapidly, and often fell to zero levels within 500 feet of shore. A graphical representation of the simple FC average for all water samples can be seen in Figure 4-1. The reduction of bacteria is due to several factors. Fecal coliform are not motile, thus their movement is controlled exclusively by the physical forces of nature. Higher counts would be expected along shore because warm-blooded animals which are sources for FC, are primarily terrestrial. Fecal coliform become mixed in and move with the warm water of the longshore currents. Over time, the longshore current temperature equilibrates with the lake and dilutes or mixes with the lake. During this time, however, some FC will die because of exposure to UV light or from starvation, some will remain viable but become non-culturable and some will settle out into bottom sediments. The dissipation rate in Racine may be higher than Milwaukee's because Milwaukee's breakwater reduces the dilution factor. Zanoni's study also used total coliform (TC), whereas Racine used FC. Death rates for TC and FC are roughly the same, although some TC species may live longer.

A similar trapping action was thought to occur at Racine as a result of a thermal bar. Temperature differences between offshore waters and the near shore waters can restrict the ability of the near shore waters to mix with the offshore waters. This isolation is referred to as a vertical thermocline or thermal bar. A thermocline is defined as a rapid change in water

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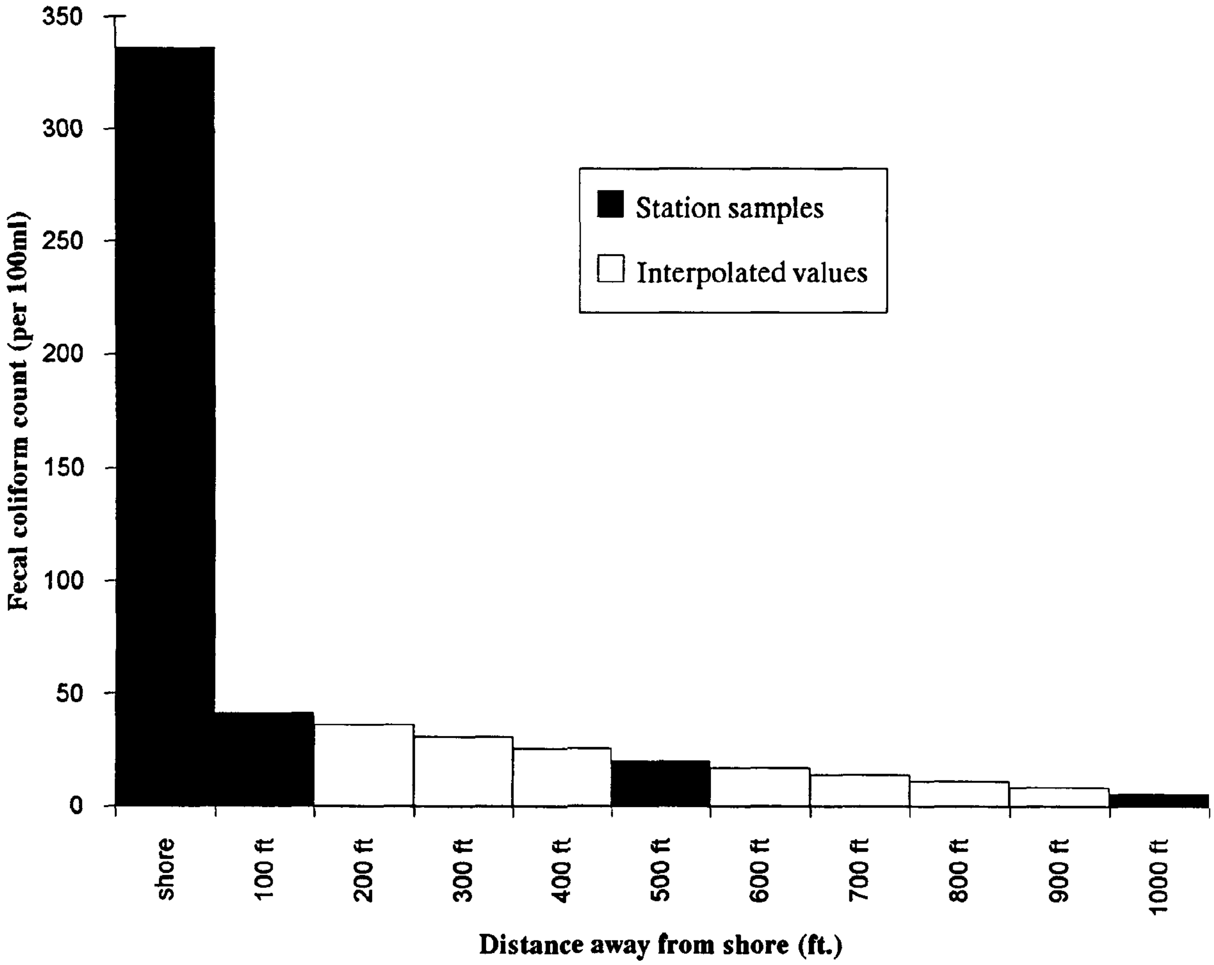
[2]Illinois Environmental Protection Agency, Lake Michigan Water Quality Report, 1986. February 1988.

[3]Zanoni, A.E., *et al.*, "An *In Situ* Determination of the Disappearance of Coliform in Lake Michigan". Journal Water Pollution Control Federation, February 1978.

Figure 4-1
Simple Average of Fecal Coliform Counts at Various Distances Away from Shore



temperature over a short distance. While the specific temperature change is not critical, a significant temperature change in a short distance will result in density differences in the water that are great enough to restrict mixing. This phenomenon has been reported to occur in lake Michigan by past researchers. This occurrence was also noted in the Racine Wastewater Utility's 1991 report. Visual observations by Utility staff noted that a color line extending from Wind Point to the harbor mouth was seen. This may have been the result of a vertical thermocline. This restriction could isolate the beach waters for Racine and trap the FC within the beach area. Weather conditions have to be favorable to set up a vertical thermocline. Warm air temperatures and low wind and wave action is needed to allow for this condition to be established.

The 1993 study was not able to document the formation of a vertical thermocline in the area of study. The data generated indicated that a one-degree Celsius drop in temperature occurred over a distance of 1,000 feet. This is not adequate to establish an isolation due to temperature/density differences. It should also be noted that there were very few beach closings this season. The lack of an established vertical thermocline may be one reason for this.

In addition, FC data illustrated that only very near shore water samples contained enough bacteria to present a problem. The waters isolated inside of a vertical thermocline should be homogeneous within this zone. Because of this, we would expect to see similar FC counts throughout the near shore zone. Based on the temperature data, if a vertical thermocline existed, it would have been located at a point greater than 1,000 feet from shore, placing all the sampling points within the isolated area. Only rarely have FC counts above 100 been reported in the 500 or 1,000-foot sampling points. This also suggests that if a vertical thermocline existed, it was not causing high near shore bacteria counts.

It is not likely that a vertical thermocline is a major cause of frequent beach closings. The weather conditions are typically not consistent enough for a vertical thermocline to present a long term problem. Furthermore, adequate mixing is available within such a zone to disperse or dilute the FC to a point that beach closings will not occur.

4.2 Longshore Current Plumes

The prevailing winds during the summer of 1993 were out of the west and north. Southerly moving longshore currents were the result. Sampling during weeks 1, 3, 9 and 10 were completed with southerly moving currents. Fecal coliform counts from the Milwaukee Metropolitan Sewerage District's South Shore WWTP and City of South Milwaukee's WWTP were reviewed to determine if their effluent could impact the water quality at Wind Point and at Racine's recreational beaches.

The South Shore WWTP is located 8.75 miles north of Wind Point and has a design capacity of 200 mgd. It uses chlorine to disinfect and sulfur dioxide gas to dechlorinate it's effluent. The FC geometric mean for the months of May and June of 1993 were 40/100 ml and 48/100 ml, respectively, with a maximum count of 5,000. The maximum count occurred after a three-inch rain event, the second highest count was 300 for the two-month period. Geometric means for the months of June, July and August of 1992 were 3/100 ml, 11/100 ml and 7/100 ml, respectively. The effluent quality is consistently good throughout the year. Records from the Jones Island WWTP, which is located 18.5 miles north of the Wind Point, were not reviewed.

The City of South Milwaukee's WWTP is located 9.5 miles north of Wind Point, and has a design capacity of 12 mgd with average dry weather flows of 3.5 mgd. The South Milwaukee WWTP uses chlorine to disinfect, and is planning to add dechlorination facilities to it's treatment plant in 1995. Effluent geometric mean FC counts for May, June and July of 1993 were 105/100 ml, 7,416/100 ml, and 8,867/100 ml, respectively, with a maximum of 49,000/100 ml. There were five sample dates where the effluent exceeded 20,000/100 ml. Thirty percent of South Milwaukee's effluent exceeded 10,000/100 ml. Geometric means for June, July and August of 1992 were 504/100 ml, 4,680/100 ml, and 4,298/100 ml, respectively. The South Milwaukee WWTP tests for FC roughly eight times per month.

A numerical calculation using Chick's law was performed to determine the effect that these two WWTP's effluent would have on Wind Point. Chick's Law uses a first order die off coefficient (k), which can be determined by:

$$k=(2.3/t) * \log(N1/N2)$$

where: k=die off coefficient to the natural logarithmic base
t=time in hours
N1=FC count at the beginning of the time period t
N2=FC count at the end of the time period t

It should be noted that this formula varies slightly from the one typically associated with Chick's law, $\ln(N2/N1) = -kt$. Both formulas generate the same results.

Chick's law is not ordinarily used as a substitute for a dilution/die off model in a lake. It is more commonly put to practice in wastewater treatment design. Zanoni used Chick's law as a general guide for estimating bacterial population disappearance and states that "it does provide a convenient means of comparing rates of die off in bacterial populations." The numbers obtained using Chick's law should only be used as a general estimate in the absence of numerical modeling.[4]

Using an average current of 0.3 miles per hour, and Zanoni's k value of $8.72 day^{-1}$, the South Shore WWTP would have a negligible effect on Wind Point. Applying these same parameters to South Milwaukee, one finds that an effluent would need 31 hours to travel the 9.5 miles to Wind Point. A count of 50,000/100 ml in the effluent would supply <1 fecal coliform per 100 ml to Wind Point. Using the strongest current observed at Wind Point during the transect study, 1.2 feet per second or 0.82 miles per hour, South Milwaukee's effluent would require 11.5 hours to travel to Wind Point. An effluent count of 50,000/100 ml would supply 760 FC to Wind Point. This could potentially result in a 205/100 ml count at the recreational beaches three miles further south.

Under these conditions, it would appear that the South Milwaukee WWTP could affect the water quality at Wind Point and possibly contribute to the FC counts at the recreational beaches. The 0.82 mph current, however, was rarely observed and was not seen within 1,000 feet of shore

[4]Zanoni, A.E., *et al.*, "An *In Situ* Determination of the Disappearance of Coliform in Lake Michigan". Journal Water Pollution Control Federation, February 1978.

during the ten weeks of testing. Additionally, the general current observed most often in the lake transect study was less than 0.1 mph. Appendix A lists and describes current magnitudes.

Chick's law was also applied to the effluent plume emanating from the Racine Wastewater Utility WWTP. The Utility's WWTP has a design capacity of 30 mgd and uses chlorine to disinfect. The WWTP presently does not dechlorinate and it's chlorine limit is 0.5 ppm. Design is currently underway to upgrade disinfection facilities and add dechlorination capabilities to help the plant meet its upcoming 1995 permit FC requirement of 400/100 ml, and residual chlorine limit of 37 ug/l. The plant's effluent is discharged 500 feet off-shore and is approximately 3.5 miles south of the recreational beaches. Using an average current of 0.3 miles per hour and Chick's law, one finds that an effluent FC count of 13,500 would be required to raise the FC count at the beach to 200/ 100 ml. This daily average was exceeded once during each of the past three summers (June-August): 162,000 CFU/100 ml on August 31, 1993, 20,000 CFU/100 ml on June 18, 1992 and 94,000 CFU/100 ml on August 8, 1991. Each of these high counts occurred after an intense rain event overloaded the system.

The Utility's WWTP 1993 monthly geometric mean FC counts for June, July and August were 345/100 ml, 204/100 ml, and 316/100 ml, respectively. Applying Chick's law to these counts results in FC counts at the recreational beaches of five or less FC. This suggests that the FC from the Utility's WWTP are not significantly affecting the recreational beaches. The lake transect study helped to verify this statement. The southernmost transect, transect No. 6, had single digit FC counts in weeks 6 and 8 when a northward moving current was present.

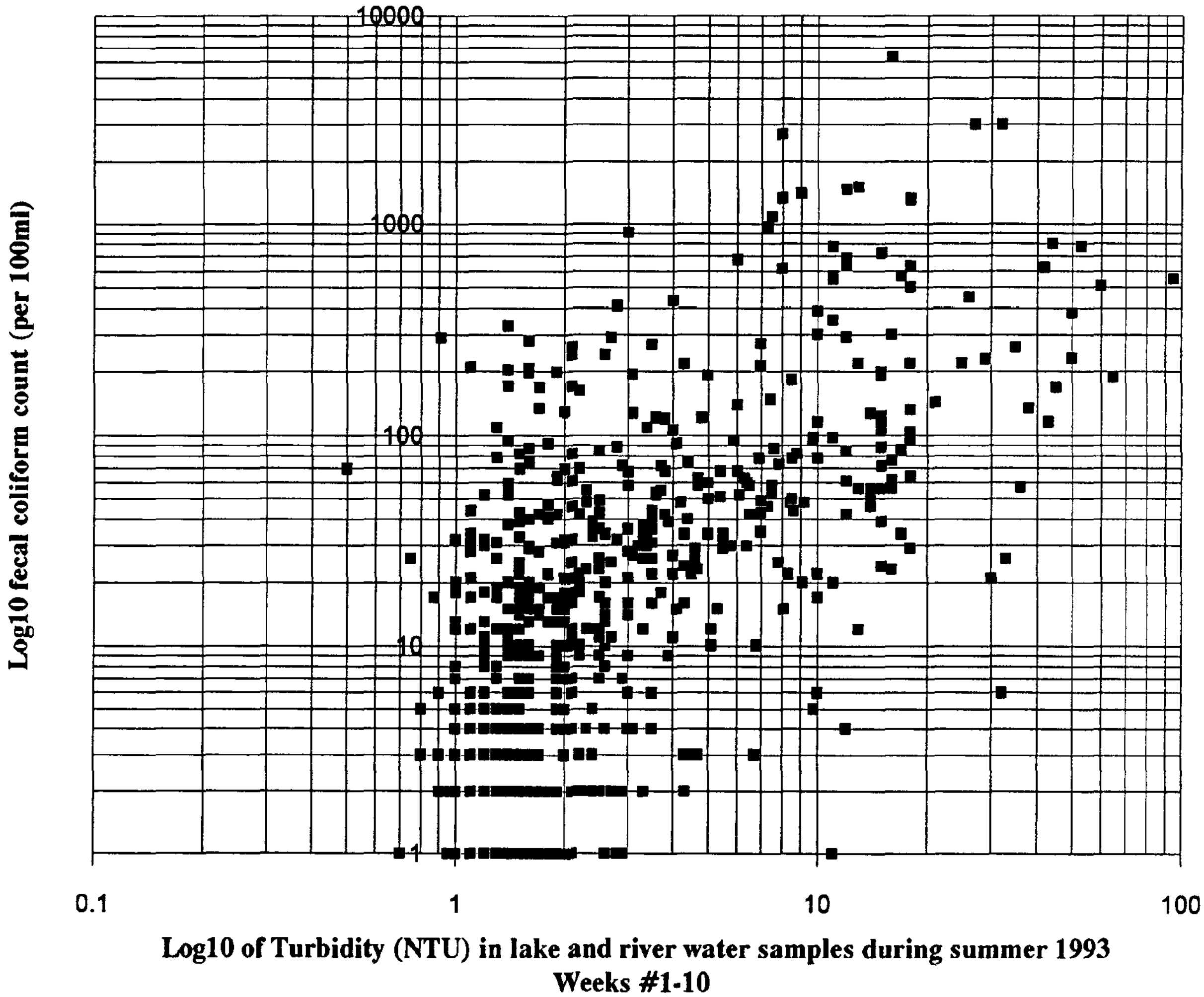
4.3 Turbidity and Sediments

Lab workers in the past had intuitively noticed that there was a relationship between turbidity and FC counts. They would base their sample dilutions on the clarity of the water before running their tests. This relationship was most evident at Wind Point where the clarity of the water would change dramatically depending on the local weather conditions. The geometric means of the shore water at Wind Point with non-westerly winds greater than 5 mph (weeks 1, 6 and 9) was 680/100 ml. Water samples had a geometric mean FC count of 19 at Wind Point when the non-westerly winds were 5 mph or less (weeks 2, 3, 4 and 7). Westerly winds were excluded from this observation because the shoreline blocks the wind from affecting the lake.

The lake transect study attempted to quantify this empirical relationship by running a turbidity test for each sample tested for FC bacterial. Graphs plotting FC counts versus turbidity readings were generated for each week of testing as shown in Appendix A. The data points used to develop the weekly graphs were plotted on log-log scale as shown in Figure 4-2. A statistical evaluation was done to determine the strength of the relationship between fecal coliform and turbidity in both lake and river/harbor water samples.

In order to determine the strength of the relationship between FC levels and turbidity levels measured in the lake and river/harbor water samples, the Pearson correlation coefficient was calculated. The correlation coefficient was calculated from the collective data set including weeks 1 through 10. The correlation coefficient falls between -1 and 1, and is a measure of linearity between two variables. A coefficient of -1 indicates a perfect negative correlation exists between two variables, i.e., as one variable increases, the other decreases. A coefficient of 1 indicates a perfect positive correlation between two variables, i.e., as one variable increases, the

Figure 4-2
Fecal Coliform Counts versus Turbidity Readings



other also increases. A coefficient of 0 indicates no correlation, indicating that the level of one variable has no relationship to the level of the other.

The Pearson correlation coefficient for the collective turbidity/FC data set, Weeks 1 through 10, was 0.314. This implies that a linear relationship between the two variables does exist, but it is not exceedingly strong. However, the Pearson correlation coefficient calculated on the log-transformed data, is 0.630. This implies that a strong relationship between the two variables does exist, but it is a curvilinear rather than a linear relationship. In both cases, Bartlett's Chi-Square test for significant correlation determined that the correlation between the two variables was significantly greater than zero. Output of the correlation coefficients and test of significance are given in Appendix B.

A curvilinear line fit to the data, along with the correlation coefficient, is illustrated in Figure 4-3. This line was found through regression techniques, and is given as $y = \text{Exp}(1.578)\ x^{1.208}$, where y represents fecal coliform and x represents turbidity. The regression analysis output is included in Appendix B. As can be seen, when plotted in the log scale, this equation appears as a straight line, emphasizing the log-linear relationship between the FC counts and turbidity in lake and river/harbor water samples.

The relation between FC counts and wind speed is the result of wave action, which resuspends sediments from the bottom of the lake. The weeks which had winds greater than 5 mph (weeks 1, 6 and 9) had turbidities averaging 35 NTU, whereas the weeks with wind less than 5 mph (weeks 2, 3, 4 and 7) had an average turbidity of 11 NTU. Fecal coliform counts will increase as wave height increases because more sediment is stirred up. Limnologists can gauge the area of benthic disturbance by knowing wave height. The height of the wave above the surface will be the depth to which the wave will affect the bottom. Fecal coliform bacteria have been shown to survive in sediments for up to two weeks.[5,6,7] Sediment samples taken on the lake transect study show the potential for large loadings from resuspension.

The winds greater than 5 mph were also associated with storm and rain events. Weeks 6, 8 and 9 had rainfall totals of 0.3 inches, 0.1 inches and 1.86 inches within 24 hours of sampling. The resulting geometric mean FC counts at Wind Point were 306 per 100 ml when samples were taken within 24 hours of a rain event and 30/100 ml on "dry weather" sampling dates. Water running over the ground picks up FC bacteria from droppings left by animals. The FC get washed into the lake along with mixed debris and particulate material. Fecal coliform bacteria attach themselves onto the particulate matter because they have a high surface affinity. The heavy particles and debris settle out quickly, but the smaller particles stay suspended longer

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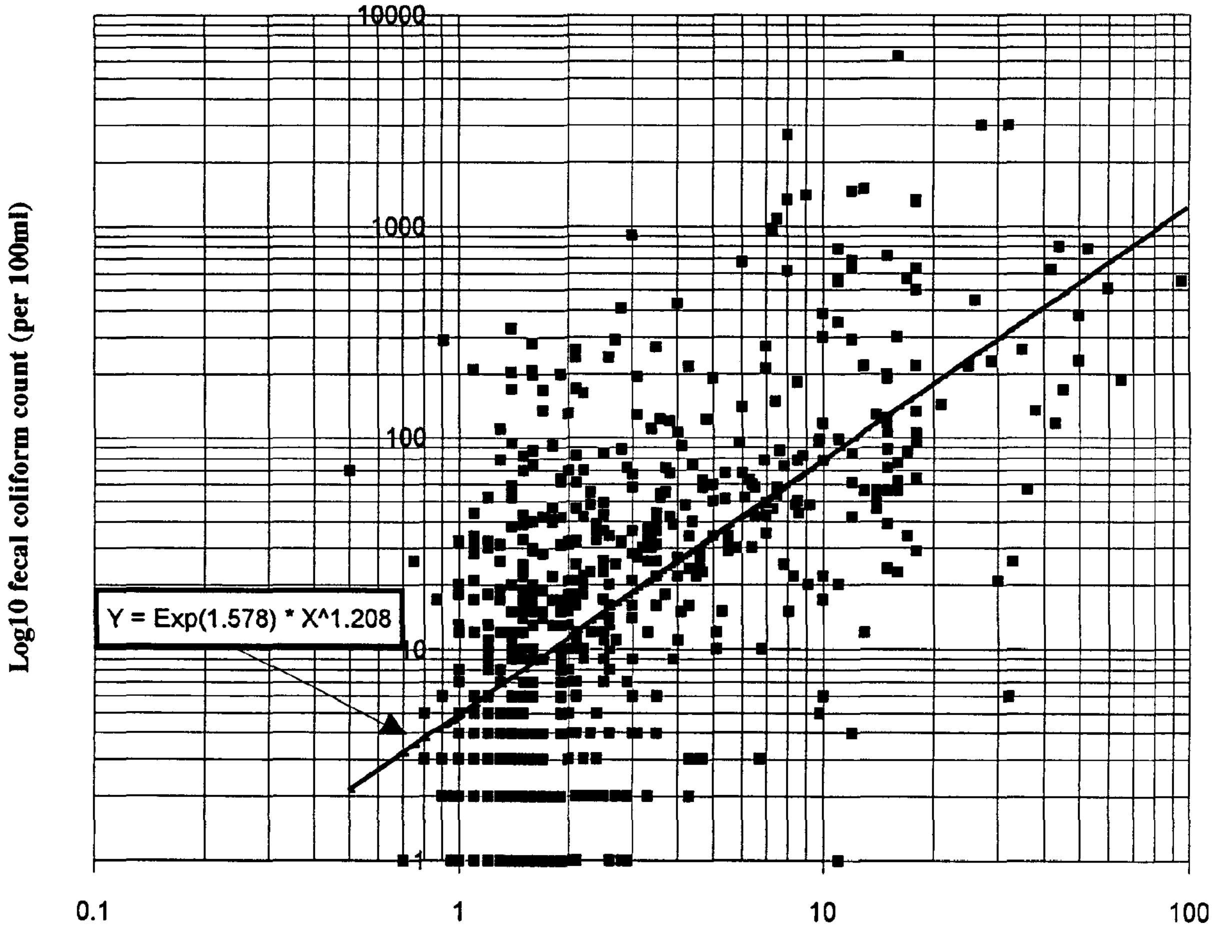
[5]Pommepuy, M., Guillaud, J.F., Dupray, E., Derrien, A., LeGuyader, F., and Cormier, M., "Enteric Bacterial Survival Factors", Water Science and Technology, v.25, No. 12, pp. 93-103, 1992.

[6]Marino, R.P., Gannon, J.J., "Survival of Fecal Coliform and Fecal Streptococci in Storm Drain Sediments". Water Research, v. 25, N. 9, September 1991.

[7]Burton, Jr., G.A., Gunnison, D., Lansa, G.R., "Survival of Pathogenic Bacteria in Various Freshwater Sediments", Applied and Environmental Microbiology, April 1987, v. 53, No. 4, pp. 633-638.

Figure 4-3
Curvilinear Line Fit to Fecal Coliform Counts and Turbidity Data



Log10 of Turbidity (NTU) in lake and river water samples during summer 1993
Weeks #1-10

Pearson Correlation Coefficient = 0.630

resulting in an increase in both FC and turbidity. Pommepuy, *et al.* (1992) also noted this relationship with turbidity. Storms could also increase the turbidity by eroding the "soft clay" cliffs north of Wind Point providing more particulate matter for the bacteria to cling to.[8]

4.4 River and Harbor

The Root River enters Lake Michigan in the heart of downtown Racine and all of the recreational beaches are within one mile north of its mouth. The Root River runs for 30 miles, drains an area of 190 square miles, and has an average flow rate of 155 ft^3/s or 100 mgd. Agriculture is the primary land use in it's drainage basin with field crops predominating over livestock. The final five miles are light residential, residential and commercial. The final mile of river is used as a docking area for some 200 pleasure craft. An additional 750 boats dock in the marina area which has been developed behind a breakwater which extends four tenths of a mile out into the lake. The mouth of the Root River is less than a mile to the south of the recreational beaches. The City Health Department decided to test the Root River because previous tests had identified high FC counts and because it, like all rivers, is a natural sink for terrestrial wastes. Fifteen locations, from the county line to the marina, were sampled weekly during the summer of 1993. FC counts ranged from 40/100 ml to 20,000/100 ml (Table 3-2).

Two relationships were found from these tests. First, there was a positive relationship between FC counts and wet weather. Rain events triggered sharp increases in the FC counts all along it's course. This relationship is shown in Figure 4-4 where the highest counts occur at or near time zero (the midpoint of a rainstorm). This plot shows that there is an exponential die-off of FC bacteria exists in the Root River. Four locations along the course of the river have been shown. The county line is a rural area located where the Root River enters Racine county. Horlick Dam is near the outskirts of the City. Memorial Drive Bridge is a very urban area and the Marina Pier is located near the mouth of the harbor.

These FC counts decreased exponentially as the bacteria died, settled to the bottom, or were washed out of the system. This figure also shows that the city has an impact on the bacterial quality of the river water. The points representing the sampling location at Memorial Dr. Bridge are always higher than the rural sampling location at the county line.

Second, there was a positive relationship between FC count and current velocity. Figure 4-5 shows how faster moving stretches of water had higher FC counts and corresponding slower currents have lower counts. It appears that the FC settle out with the particulate matter in the slow moving portions of the river and are resuspended in the rapids. This suggests that the final mile of the river and harbor area, where current velocities are less than 1 cm per second, acts like a clarifier. This allows the suspended particles that host FC to settle out before reaching the lake. Data from transects No. 5 and No. 6, which bracket the harbor to the north and the south, verify this. River water exiting the harbor mouth was observed to move either north or south, along with the prevailing currents in the lake. The FC counts would generally drop a full order of magnitude from Gas Light Pointe to the lake transects affected by the river plume. Fecal coliform counts at lake transects affected by the river plume never exceeded 60/100 ml.

[8]Pommepuy, M., Guillaud, J.F., Dupray, E., Derrien, A., LeGuyader, F., and Cormier, M., "Enteric Bacterial Survival Factors", Water Science and Technology, v. 25, No. 12, pp. 93-103, 1992.

Figure 4-4
Exponential Die Off of Fecal Coliform in the Root River after Rainstorm Events

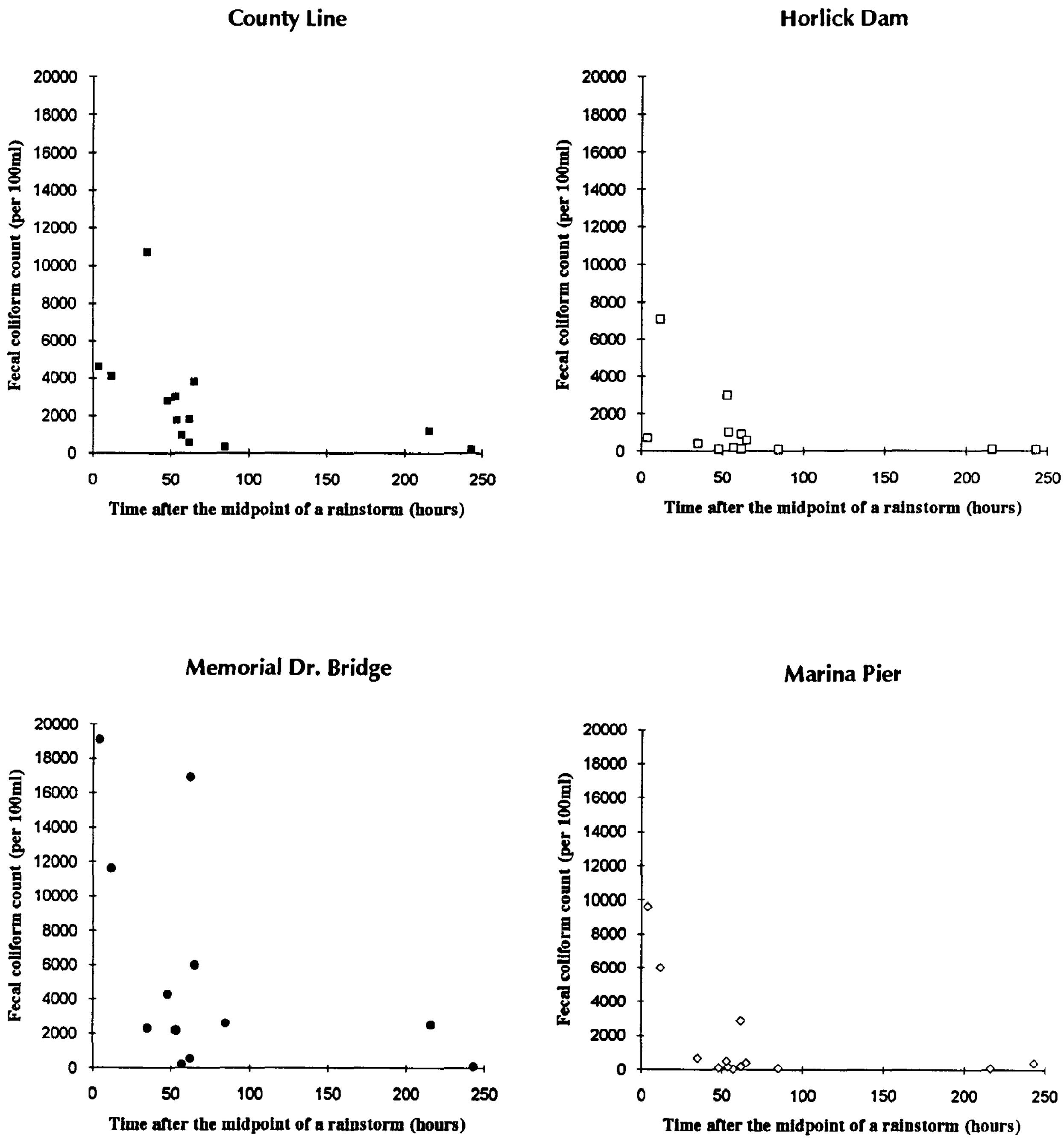
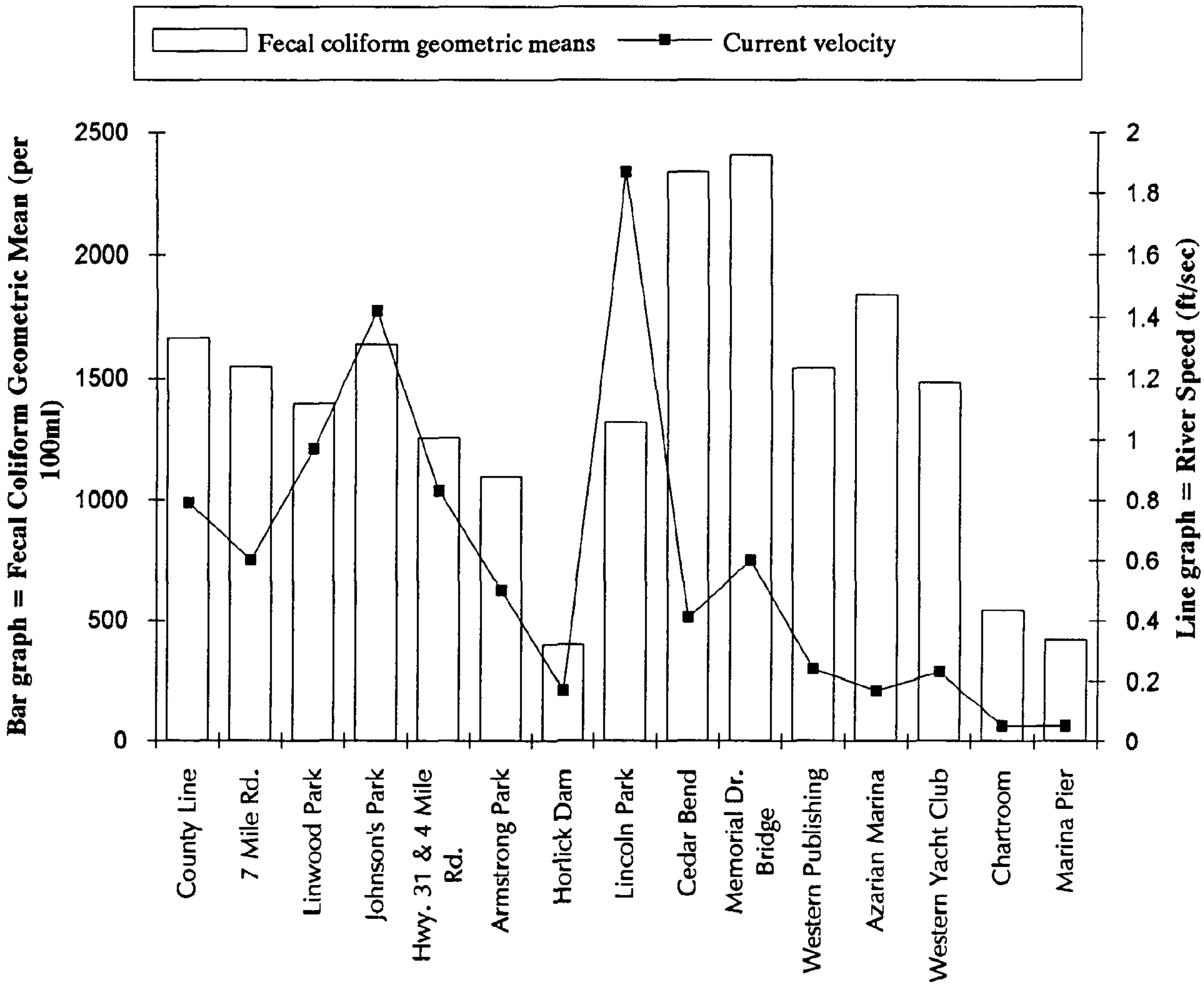


Figure 4-5
Relationship Between Fecal Coliform Count and Current Velocity in the Root River



Additional evidence of this natural cleansing effect came with a heavy rainstorm (1.86 inches recorded for the day) on August 30. Repair work was being done on lift station number 2, which is located 4.1 miles upstream from the mouth of the harbor (close to where Spring Street crosses the Root River). The increased sewage flow, from infiltration and inflow, overloaded the temporary pumping system dumping 222,000 gallons of raw sewage into the Root River from 5:30 p.m. to 8:00 p.m. It is reasonable to assume that some portion of this sewage slug would have been present in the lake the next morning when the lake transect study (week No. 9) sampled water in the harbor. The results show that the FC counts fell from 3,000 at Horlick Dam, to 1,320 at Gas Light Pointe, 616 at the Harbor mouth, and 268 in the densest area of the river plume in the lake. This is a significant reduction from the 8 million FC typically associated with raw sewage.

4.5 Storm Sewers

Storm sewers and drainage ditches dot the shoreline of Lake Michigan and the Root River. This effect of urbanization causes water quality problems because the ground and plants do not have an opportunity to filter street contaminants. Fecal coliform are one such contaminant, and have been shown to increase the counts in the river after rain events. Figure 4-6 shows that this relationship exists in Lake Michigan as well.

The summer of 1993 was a very wet summer. The month of June had 6.31 inches of precipitation fall in Racine. July was relatively dry with only 2.66 inches of rain, and August was wetter than previous years with 4.0 inches. It would be reasonable to expect, if storm sewers and drainage ditches are significant sources of FC on the beaches, that the beaches would have been closed more often than in previous years. This scenario was not observed, however, and 1993 brought more open days than either of the previous two drier years. This strongly suggests that there are other sources. Unlike Milwaukee and Chicago where beach closings can be closely linked to rainfall, Racine experiences beach closings in dry weather also. The affect of rain events can be seen in Table 4-1. This table documents FC counts taken before and after rain events of greater than 0.5 inch. Several rain events of greater than 0.5 inch have been omitted from this table because FC samples which bracket the rain event were not available. These FC data are the daily geometric means for samples collected at North Beach by the City Health Department.

Figure 4-6
Relationship Between Fecal Coliform Counts in Lake Michigan and Rainfall

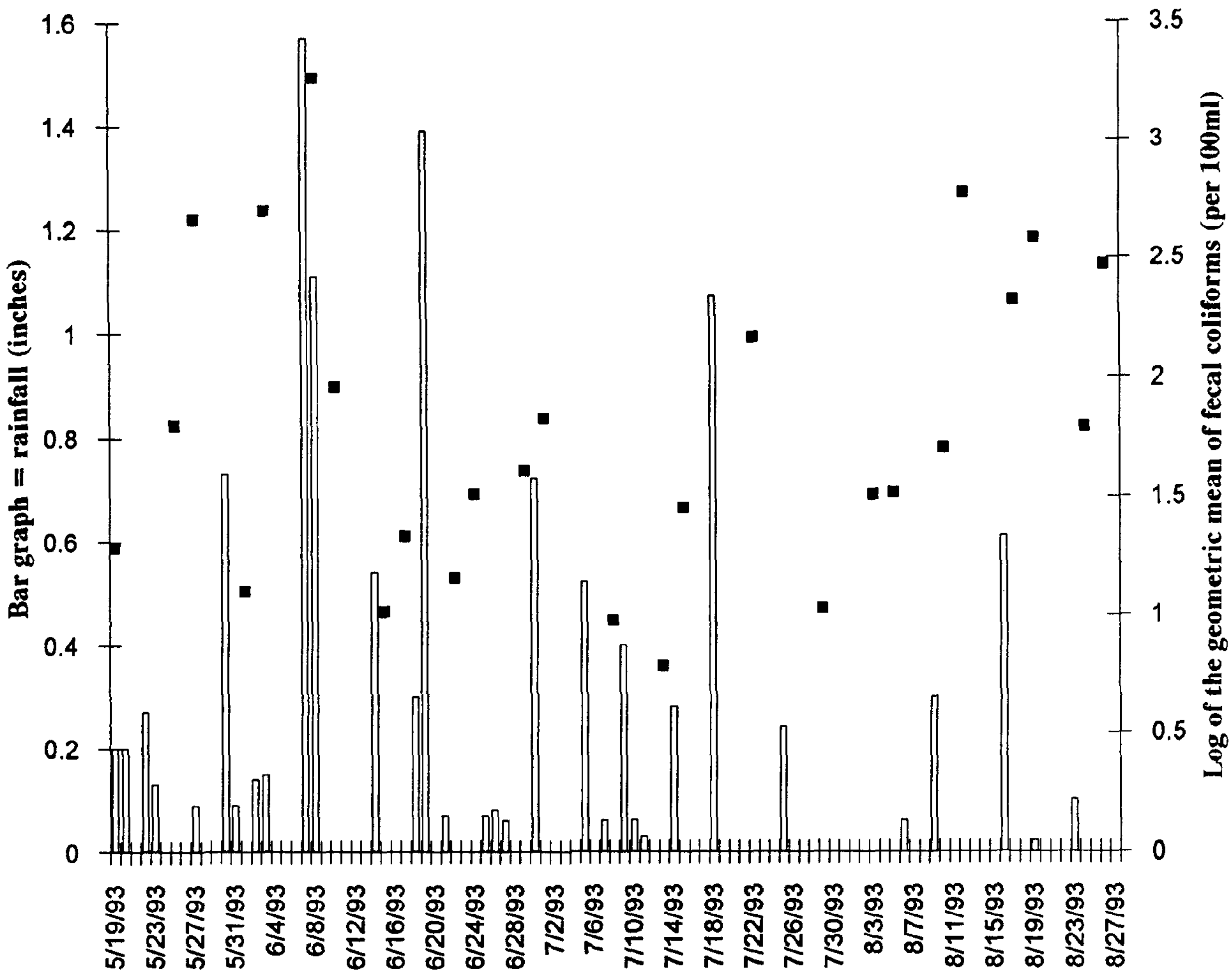


Table 4-1

Fecal Coliform Counts Before and After Rain Events

Rain (inches)	Date of Rain	Before Date	After Date	FC Count Before Rain	FC Count After Rain	▲ in FC Count
0.81	7/8/92	7/7/92	7/9/92	363	710	+347
1.23	8/26-27/92	8/25/92	8/27/92	421	952	+531
0.54	9/2/92	9/1/92	9/2/92	249	523	+274
0.73	5/30/93	5/27/93	6/1/93	1405	14	-1391
1.57	6/7/93	6/3/93	6/8/93	651	864	+213
0.54	6/14/93	6/11/93	6/15/93	119	95	-24
0.72	6/30/93	6/29/93	7/1/93	49	23	-26
0.61	8/15/93	8/12/93	8/17/93	197	227	+30
2.9	8/29-31/93	8/26/93	8/31/93	139	1895	+1756

The relationship between monthly rainfall totals and beach closures because of elevated FC counts is shown in Table 4-2.

Table 4-2

Rainfall-Related Beach Closures

Year	Month	Monthly Precipitation (inches)	Days Open/Total Possible	Beach Information (North Beach)
1991	June July August	2.74 3.24 2.40	51/82 Open 62% of the season	Beach closing information for 1991 is not well documented. Beaches said to have been closed for the month of August.
1992	June July August	1.09 4.69 3.81	42/82 Open 51% of the season	Open: 6/11 to 7/17; 8/11 to 8/13; 8/21 to 8/24. Closed: 7/17 to 8/11; 8/13 to 8/21; 8/24 to end of season.
1993	June July August	6.31 2.66 4.00	78/87 Open 90% of the season	Open: 6/15 (?) to 8/27, 9/2 (?) until end of season. Closed: 6/12 (?) to 6/15 (?); 8/27 to 9/2 (?)

The lake transect study sampled three storm outfalls and two drainage creeks to help define the source of bacteria. One storm outfall, the English Street outfall is consistently higher than it's companion outfalls. The English Street outfall is located in the middle of the recreational beaches. The outfall is an inverted siphon, and consequently retains water and sediments during dry weather periods and gets flushed out during storm events. The English Street storm line is a 60-inch double-brick-walled pipe draining 50 city blocks. A unique feature of the English Street storm sewer is that it is ten feet lower than the sanitary sewer. The English Street storm sewer originally served as a combined sanitary sewer draining directly into Lake Michigan. The pipe was converted to a storm sewer with overflows in the late 30s when the Utility's WWTP was completed. The overflows were capped in the mid 70s with the installation of false bottoms.

A television inspection of the storm sewer system for the English Street outfall was conducted by Visu-Sewer Clean and Seal, Inc. in 1992. Their report mentioned that "Bulkhead manhole (MH No. 2 at intersection of English Street and Chatham Street) appears to have infiltration from sanitary sewer above false floor" and "Light mineral deposits on walls (of MH No. 3 at the intersection of English Street and North Main) with light leaks, drips."[9] Conversations with the Utility's wastewater field operations crew suggested that the problem of leaks/infiltration at the manholes occur at all eight of the false bottomed manholes, from Michigan Boulevard to La Salle Street. On one occasion, a field operations crew put a temporary plug in the outlet of one of these manholes allowing the wastewater to back up in the manhole and influent pipe. Upon entering the storm sewer to observe the false bottom, wastewater was found streaming down the sides of the storm manholes "like a waterfall." A visual inspection of the false bottom at English Street and Chatham Street during a dry weather period in August of 1993 verified these earlier reports. There were six "steady streaming or dripping" leaks counted flowing around the edges of the false bottom. Fecal coliform content in the water dripping down from the false bottoms was 3.2 million/100 ml. The FC count upstream of the Chatham Street/English Street manhole was 520,000/100 ml, downstream was 1.6 million/100 ml. The flow was estimated roughly at 11 gallons per hour per manhole.

This sewage leak would account for the high FC counts at the English Street outfall. The sewage leak would also increase the FC counts in the sediments at the base of the inverted siphon. The beach FC counts would increase when these sediments are flushed out by a rain event. Wet weather beach closings are not uncommon for Racine or other communities monitoring FC as a measure of water quality. Milwaukee automatically closes it's beaches for one day after two-inch rain events. The City of Racine, however, has been hampered with beach closings during both dry and wet weather periods.

During dry weather conditions, the reduced flow from the English Street outfall forms a sand pit along the shoreline, creating a pond around the outfall structure. The reduced flow seeps into the sand and a direct flow to Lake Michigan is not present. The sand in this area becomes contaminated with FC. The occurrence of high dry weather FC counts may be attributable to wave action resuspending sediments from this area. Similar sediment resuspension was seen at Wind Point.

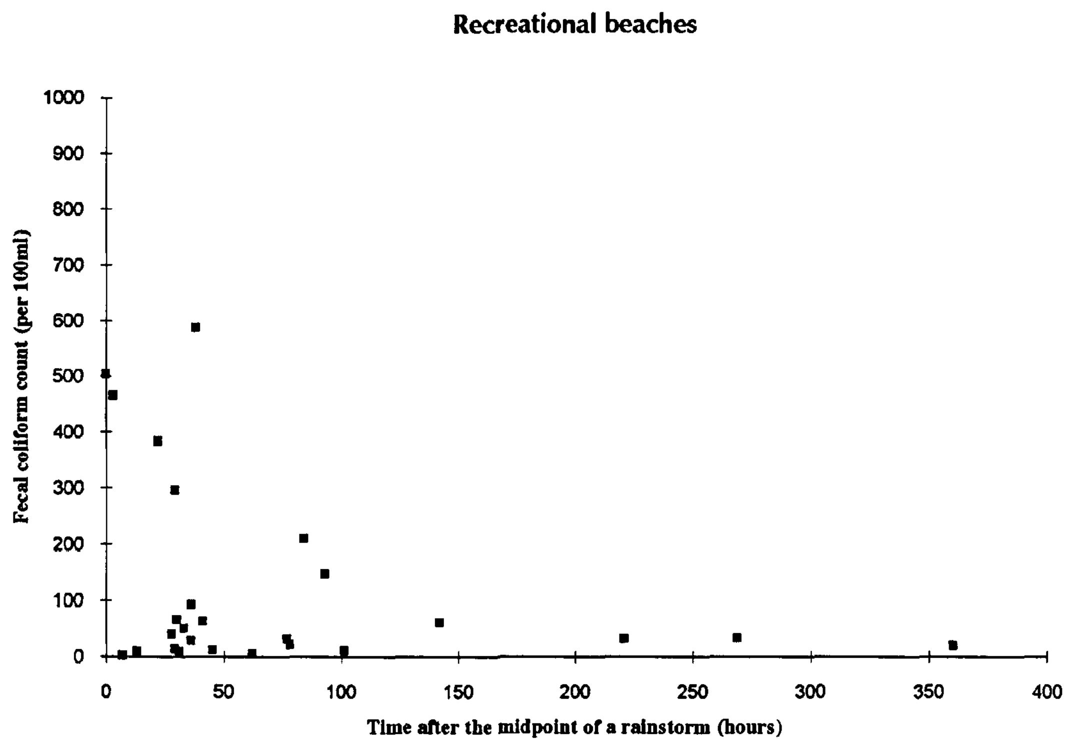
[9]Visu-Sewer Clean and Seal, Inc., Inspection Report conducted for the City of Racine, 4/8/93, p. 3.

Palmer, *et al.* (1987), found that vigorous mechanical mixing of beach area sediments (1 m^2 for one minute) could produce FC counts potentially as high as 1,410/100 ml. He concluded that loadings similar to his mechanical mixing experiment could be reproduced by waves or by bathers when the lake is calm.[10] Additionally, FC may live from two hours to two days in freshwater sediments. This may explain why counts will increase unexpectedly during dry weather periods. Figure 4-7 shows that the FC disappear exponentially in the lake water with time after rain events. Thus, it appears that FC are being flushed into the lake with storm water runoff initially increasing the FC count at the beaches, remaining in the sediments and being resuspended with wave action.

To study this theory further, sediment samples were taken at North beach, and at various other sampling locations associated with the lake transect and harbor surface water sampling points. These data are presented in Table 4-3. Sediment samples were collected using a ponar sampling device. The results given in Table 4-3 should not be used to draw relationships because the highest FC counts would be found at the top of the sand and the ponar device collects a mixed sample. The results do show, however, that FC were present at all transect sampling sites. Transect No. 4 (the transect at North Beach) showed the potential for high loadings from sediment resuspension with values of 160 mpn/g at the shore and 50 mpn/g 100 feet from shore. The count reported for Transect No. 6 at 1,000 feet, 1,000 mpn/g, shows that FC can and do survive in sediment for extended periods. This sample most likely shows carryover from an event that could have occurred seven days in advance of sampling.

[10]Palmer, M., "Bacterial Loadings from Resuspended Sediments in Recreational Beaches", Canadian Journal of Civil Engineering, v. 15, pp. 241-247, 1988.

Figure 4-7
Exponential Die Off of Fecal Coliform in Lake Michigan after Rainstorm Events



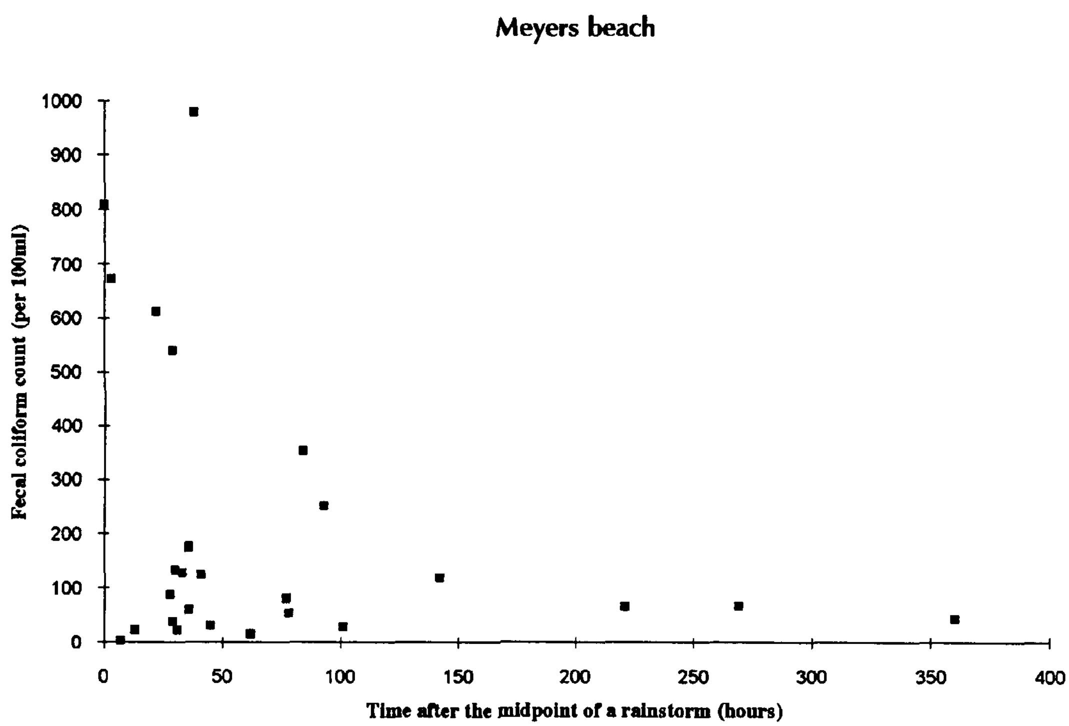


Table 4-3

Fecal Coliform Counts in Sediment Samples

Date	Location	Distance from Shore	MPN/Gram
7/21/93 Tested by Racine Water Utility	Harbor mouth	--	80
	Transect #6	500′	30
	Transect #4	shore	160
8/24/93 Tested by Sommer Frey Labs	Gas Light Pointe	--	460.0
	Marina	--	<3.0
	Harbor mouth	--	43.0
	Small boat launch	--	3.6
	Transect #2	shore	<3.0
	Transect #2	100′	21.0
	Transect #3	shore	<3.0
	Transect #3	100′	3.3
8/24/93 Tested by Racine Water Utility	Transect #4	shore	8
	Transect #4	100′	50
	Transect #4	500′	13
	Transect #4	1,000′	8
9/7/93 Tested by Sommer Frey Labs	Transect #1	shore	3.6
	Transect #1	100′	23.0
	Transect #1	500′	43.0
	Transect #1	1,000′	9.1
	Transect #5	100′	<3.0
	Transect #6	100′	9.1
	Transect #6	500′	<3.0
	Transect #6	1,000′	1,000.0
9/7/93 Tested by Racine Water Utility	Transect #5	100′	13
	Transect #5	500′	24
	Transect #5	1,000′	50

4.6 Seabirds

Ring-billed seagulls are an omnipresent feature of the Racine recreational beaches. An official count of their numbers at Racine has not been kept by the Wisconsin Department of Natural Resources (WDNR), but it is known that counts on the Great Lakes have been increasing annually. Ed Prins, president of the local Hoy Nature Club, keeps records on the species in Racine. Unfortunately, no population records are kept. According to his recollection, the number of ring billed seagulls in Racine has risen from 100 in the early eighties to 1,000+ in

1993. Mr. Prins also notes that the birds behavior seems to have changed somewhat over the years because they are allowing people to approach closer before taking to flight.[11]

Seagulls are a migratory bird and a protected species. Their population at the beach varies from day to day, but generally tends to rise during the course of the summer. Ring billed gulls are not bound to the shoreline like other shorebirds. They can often be found in farm fields, grass fields and parking lots. They are scavenger birds feeding on live and dead fish, insects, litter and rubbish at the dump. The birds are also fed by people on regular basis. People come to the beach with loaves of bread and feed the frenzied gulls. During the study, it was observed on one occasion that the birds were fed ten times in a two-hour period during a busy afternoon in early August. This could explain why the birds congregate at the recreational beaches leaving the rest of the Lake Michigan shoreline vacant.

Ring-billed gull droppings litter the beach, numbering as high as 20 droppings per 100 ft^2. Each gull dropping contains 71 million FC per gram, and each bird produces 1,770 million FC per day. Table 4-4 shows the relative contributions of FC from various animals.

Table 4-4

Sources for Fecal Coliform[12]

	Average Fecal Coliform (Millions)	
Animal	Per Gram of Feces	Per Day
Human	13.0	2,000
Chicken	1.3	240
Cow	0.23	5,400
Duck	33.0	11,000
Pig	3.3	8,900
Sheep	16.0	18,000
Seagull	71.1	1,770

It is obvious that the bacteria are deposited in large quantities on the sand's surface, but the mechanics of transport into the lake is not as straightforward. Fecal coliform bacteria have a very high surface affinity and the beach sand acts as a filter to prevent the movement of FC though the soil profile. Water beneath the beach was analyzed to determine whether or not the FC could pass through the sand. Results are listed in Table 3-3. These numbers show that there is a drop in FC with increased depth of sand (the sand at 50 feet and 100 feet was approximately three feet deep, and the sand at 10 feet to 15 feet was one foot deep). It appears as if there is some movement of FC downward though the soil profile. Gerhard Lee, soils professor emeritus, at the University of Wisconsin, says that the vertical and horizontal migration rates are roughly the same, for bacteria, but that the rate could be influenced by mechanical pumping, such as

[11]Personal communication between John Paul Hjelle and Ed Prins, Summer 1993.

[12]From: Haavaar, A.H., 1985 and Palmer, M., 1983.

wave action.[13] It is interesting to note that the FC counts are highest within 15 feet of shore. It is difficult to say whether the mechanical pumping action of the waves is drawing FC out of the sand, but it does appear that FC counts in the lake and sub-beach rise and fall with time.

Other mechanisms of transport are possible as well. Dust laden with FC may be blown into the water. Bird droppings left along the wash zone of the lake may increase the FC count as the waves draw the waste into the lake. Birds are also known to drop their feces into the lake as they fly over. Regardless of the mechanism of transport into the lake, the daily contribution 1.7 trillion FC dropped by the 1,000 birds living at the beach is a major source of FC in Lake Michigan.

It should also be noted that the highest concentrations in the sub-beach water occur within ten feet of shore. This is where children play, dig in the sand and build sand castles. The birds appear to be the primary source of FC. No other source was discovered to the near beach zone from the lake itself or from upgradient groundwater. There is also no published scientific evidence to suggest that FC can reproduce in beach sand. The threat to human health is somewhat reduced because many of the microorganisms found in bird droppings do not affect humans. The risk is not eliminated entirely, however, because seagulls are known to carry a high number of salmonella. Qualitatively speaking, for every ten pathogenic microorganisms associated with human waste, only one would be found in seagull waste. A quantitative relationship, however, cannot be drawn from the data generated in this study.

There are other shore birds living along the shores of Lake Michigan. Most notably are the Canada geese, mallard ducks and terns. The geese population is roughly 100 birds, and they live wild at the zoo. There are approximately 30 mallard ducks that live at the small boat launch. These two sources are not as significant loading sources. There are ten terns that live with the gull population on the beach. They do contribute to the FC loadings, but their numbers are so small, that they can not be considered the problem species.

4.7 Meyers Beach

Meyers beach is an isolated sand strip one mile south of the mouth of the Racine Harbor. A breakwall protects the area from the larger body of the lake. It is a very shallow inlet area, averaging three feet deep, and is used primarily as a jet ski area. Very few people use Meyers beach to swim at because a dense mat of algae is typically present and washes up against the shore. Additionally, there are very few seagulls living on Meyers beach.

Meyers beach was not studied extensively as part of the lake transect study. Samples were taken by the City Health Department, and found to run consistently higher than those at the recreational beaches. Figure 4-7 not only shows that the FC disappear at an exponential rate after a rainstorm, but that Meyers beach has a consistently higher FC count than it's recreational beach counterparts. It was originally thought that FC from the WWTP were affecting the beach when southerly winds prevailed. An analysis of the chloride content in the effluent from the WWTP and the level of chlorides in the Meyers beach area found no evidence to support an affect on the water quality. It may be just as likely that the breakwater protecting the beach is

[13]Personal communication, John Paul Hjelle and Gerhard Lee.

reducing the circulation of the inlet area, raising FC counts by reducing dilution as seen in the Milwaukee study by Zanoni. Without further evidence, an accurate analysis cannot be made.

5 Conclusions and Recommendations

The purpose of the 1993 Fecal Coliform Study is to expand upon the past investigations of the Racine Wastewater Utility and the City Health Department regarding the sources of fecal coliform and to make recommendations on how to eliminate the fecal coliform problem so that the beaches can remain open during the summer.

Several conclusions can be drawn from this study:

- FC bacteria dissipate rapidly away from shore and often fall to zero levels within 500 feet of shore.

- Because of effective disinfection at the Milwaukee Metropolitan Sewerage District's South Shore WWTP, it is an unlikely contributor to high FC counts on Racine's beaches.

- Because of ineffective disinfection at the City of South Milwaukee's WWTP, it could be a contributor to high FC counts on Racine's beaches under certain rare conditions. With new disinfection and dechlorination facilities scheduled to go on line in 1995, the South Milwaukee WWTP would no longer be a likely contributor.

- The Racine Wastewater Utility WWTP is not a significant contributor to high FC counts on Racine's beaches. With new disinfection and dechlorination facilities scheduled to go on line in 1995, the Utility's WWTP will no longer be a potential contributor.

- A log-linear relationship exists between fecal coliform counts and turbidity indicating that FC counts will increase with increase in turbidity and vice-versa.

- Wind speed will increase wave action and thereby turbidity.

- Rain events triggered sharp increases in FC counts all along the course of the Root River.

- FC counts were higher in faster moving stretches of the Root River and lower in corresponding slower currents. This can also be linked to turbidity and sediment suspension.

- Storm sewers and drainage ditches with the exception of the English Street Outfall did not appear to be a significant FC source.

- The English Street storm sewer had consistently higher FC counts than the other storm sewer outfalls due to sewage infiltration.

- The English Street outfall is a likely source of high FC counts during dry weather as well as wet weather.

- Fecal coliform bacteria were present in sediments at all lake transect sampling points.

- Seagulls are a major source of FC with a daily contribution of 1.7 trillion FC dropped by the 1,000 birds living at the beach.

- Meyers beach was not studied extensively as part of the lake transect study because of its infrequent use.

Based on the conclusions of the study the following recommendations are made:

- Chick's Law was used to estimate the affect of the South Shore WWTP, South Milwaukee's WWTP and Racine Wastewater Utility WWTP on Racine's recreational beaches in lieu of running a dilution die-off model. Because South Milwaukee and the Racine Wastewater Utility are in the midst of disinfection and dechlorination facilities upgrades scheduled to be completed in 1995, it would be of limited benefit to run a dilution die-off model and further evaluate the effect of these point source discharges.

- The relationship between wind speed and wave action was not investigated in detail in this study. Further quantification of the affect of wind speed on wave action and turbidity due to resuspension of sediments may prove a useful tool in the future for predicting FC levels along the shoreline.

- Based on the observed relationship between FC count and current velocity, it appears that the final mile of the Root River where current velocities are less than 1 cm per second acts as a clarifier where suspended solids can accumulate. Because the Root River is a natural sink for the drainage basin, it receives much of the non-point source pollution in the area. It is recommended that further study of the Root River be done to gain a better understanding of the nature of the sediments and how they can affect the lake under various weather conditions.

- The English Street stormwater and outfall was identified as a significant source of fecal coliform due to sewage leaks. Possible repairs to the English Street storm line include grouting the sanitary or storm sewer pipes, slip lining the sanitary and/or the storm sewer pipes and/or repairing the false bottoms in the storm sewer system manholes. Each of these measures could be an effective measure to plug the leaks running into the storm sewer and thus reduce the amount of sanitary wastes entering the storm sewer system. Moving the English Street outfall or chlorinating its effluent are other potential measures to reduce the bacterial flow out of the outfall. The relative merits of each of these corrective measures should be the topic of a separate study.

- The ring-billed seagulls were identified as a significant source of FC counts. The ring-billed gulls congregate at North Beach and are fed frequently by visitors. Disrupting this food supply will force the gulls to search elsewhere for their sustenance. This could be accomplished through a city ordinance prohibiting feeding of wildlife on the beaches. A public awareness program would also have to be instituted to improve the effectiveness of the ordinance. Rather that trying to drive the birds from the recreational beaches it may be possible to attract them to another area by providing a sanctuary with a food source. This should be considered depending upon the success of the ordinance. Scaring tactics are also a potential method for dealing with the seagulls, for example, the use of patrol vehicles or dogs. The most important time for scaring the birds is in the early summer, before their numbers and thus their droppings build up the FC levels in the sand. Other bird scaring tactics include the use of audio broadcasts of the gull distress call and use of owl statues. It has been noted by authors writing on these topics that the gulls eventually get used to the artificial scaring and ignore it.

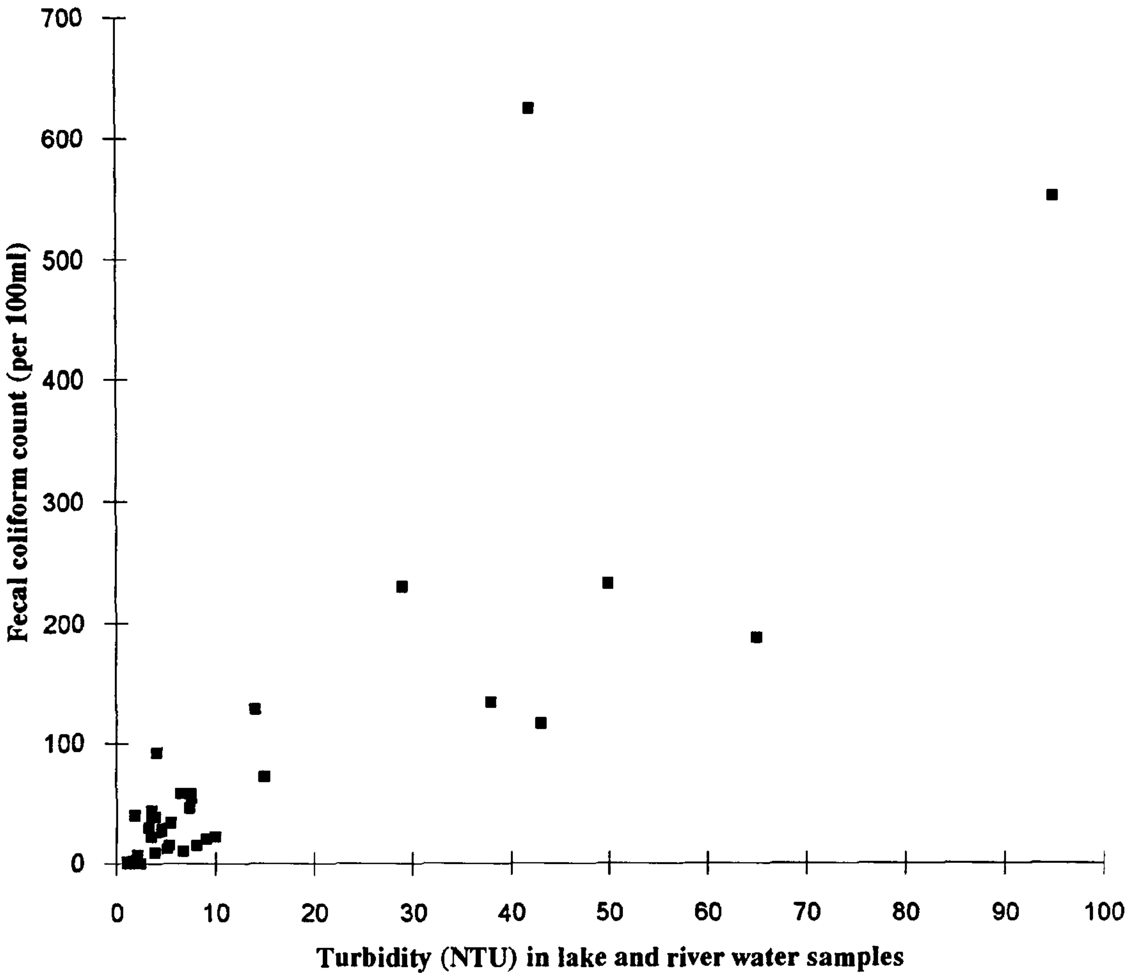
- A detailed investigation of Meyers Beach was not done as part of this study because of its limited value as a recreational beach. It may be of benefit to verify if the breakwater protecting the beach is reducing the circulation and thereby raising the FC counts. This study could corroborate the results of the Root River evaluation.

The 1993 Fecal Coliform Study is an important step in the process of eliminating the FC problem and accomplishing the goal of keeping the beaches open during the summer. Correction of the English Street sewer and attempts to discourage the seagulls will go a long way toward that end. A better understanding of the relationship between FC in sediment, in the Root River, and Lake Michigan and the effect of resuspending sediments due to wave action, will move the Racine Wastewater Utility and the City Health Department closer to their goals.

Appendix A

Lake Transect Study Data

Week No. 1 - June 29, 1993
Fecal coliform vs. Turbidity



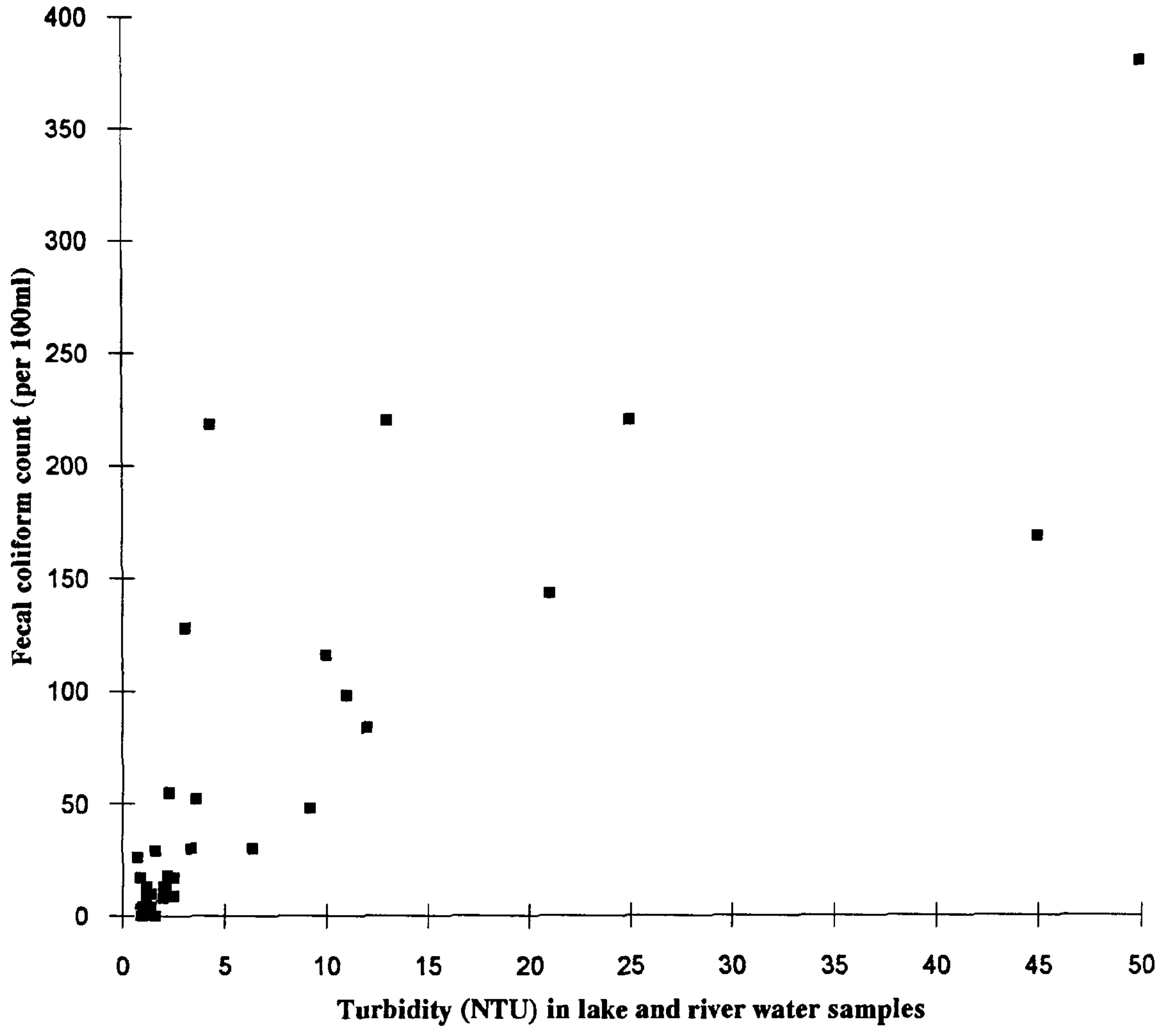
Week No. 1 - June 29, 1993
Fecal Coliform Bacteria and Turbidity Data

		Fecal coliform count (per 1				Turbidity in water (NTU)				Replicate sample done in lab or field
Sample site	**Location**	**Shore**	**100'**	**500'**	**1000'**	**Shore**	**100'**	**500'**	**1000'**	FC count/turbidity (field only)
Transect No. 1	Surface	624	N/C	232	10	42		43	6.8	
(@ Wind Point)	Mid Depth		N/C	134	20			38	9.1	
"	Bottom		N/C	116	22			50	10	
Shoop Park Creek	Mouth	548				5.5				
3 Mile Outfall	Outfall	<2				2.8				
Transect No. 2	Surface	15	0	0	0	5.3	2.1	1.8	1	Lab replicate @ 500' surface=0
(@ North Bay Creek)	Mid Depth		4	0	0		2.1	1.5	1.3	Field replicate @ 100' mid=1/2.3
"	Bottom		0	1	1		1.9	1.4	1.3	Lab replicate @ 500' bot.=0
North Bay Creek	Mouth	1536				3.6				
Wolff St. Outfall	Outfall	680				1.4				
Transect No. 3	Surface	11	1	0	0		1.5	1.2	1.4	Field replicate @ 100' surface=0/1.6
(@ Zoo/High St.)	Mid Depth		0	1	1		1.4	1.3	1	Lab replicate @ 100' surface=1
"	Bottom		2	1	0		1.7	1.7	1.1	
Zoo beach	0' off shore	54				7.5				
"	"	58				7.5				Lab replicate @ Zoo beach #2= 46
"	"	46				7.3				Lab replicate @ Zoo beach #3=43
English St. Outfall	Outfall	2400				2.8				
English Beach	0' off shore	27				4.6				
	"	92				4.1				
	"	34				5.5				
Transect No. 4	Surface	40	0	0	N/C	1.4	2.3	1.7		
(@ North Beach/	Mid Depth		N/C	0	N/C			1.5		Lab replicate @ 500' bottom=0
Romayne Ave.)	Bottom		3	1	N/C		2.5	2		
North Beach	0' Off Shore	29				4.6				
	"	22				3.5				
	"	39				3.9				
Transect No. 5	Surface	7	N/C	N/C	N/C	2.1				Lab replicate @ shore=4
orth of Harbor Mout	Mid Depth		N/C	N/C	N/C					
	Bottom		N/C	N/C	N/C					
		Fecal coliform count (per 1				Turbidity in water (NTU)				Replicate sample done in lab or field
Sample location	**Depth**	**Shore**	**100'**	**500'**	**1000'**	**Shore**	**100'**	**500'**	**1000'**	FC count/turbidity (field only)
Transect No. 6	Surface	<2	N/C	0	N/C	1.7		1.5		
	Mid depth		N/C	N/C	N/C					
	Bottom		N/C	N/C	N/C					
Meyers Beach	0' Off shore	44				3.5				
	"	39				3.5				
	"	30				3.2				
Harbor Area		**Surf.**	**Mid.**	**Bot.**		**Surf.**	**Mid.**	**Bot.**		
Horlick Dam		230				29				
Gas Light Pointe		72	128	550		15	14	95		
Marina		58	22	188		6.5	10	65		Lab replicate @ mid=20
Harbor Mouth		9	12	15		3.9	5.1	8.1		
Small Boat Launch		0	15	3		1.8	1.5	2.5		Field replicate @ mid=1/1.5

Week No. 1 - June 29, 1993
Field Conditions

Transect/ Station	Time	Water Depth (ft)	Wind		Current		Water Temperature (°C)			Comments
			Speed (mph)	Direction	Direction	Magnitude	Surface	Middepth	Bottom	
1A		shore					14.5	-	-	algal masses on beach and in water
1B										no sampling conducted, too rough
1C							14.5	14.5	14.5	
1D		23	7	NE	S		14	14	13	
2A										sample taken by Racine
2B	1300	7	9	NE	S		14	14	14	rep at mid depth
2C	1315	10			S		14.2	14	14	
2D	1325	15	12	NE	S		14.2	14	13.8	
3A										sample taken by Racine
3B	1340	6					14.5	14.5	14.5	rep at surface
3C	1345	7			S		14.5	14.5	14.5	
3D	1355	14			N		14.5	14.5	14.2	
4A										sample taken by Racine
4B	1510	2			S		15.2	-	-	water 2' deep with 2-4 foot waves
4C	1500	5			S		15.1	14.5	14.5	
4D										no sampling conducted
5A										sample taken by Racine
5B										no sampling conducted
5C										no sampling conducted
5D										no sampling conducted
6A										sample taken by Racine
6B										no sampling conducted
6C			12-15	NE	-	-	14	14	14	surface sample only, no anchoring
6D										no sampling conducted
H1	1535	19			upstream		17.5	14	12.5	
H2	1600	26			out of har		13.8	13.5	13.5	
H3	1550	19			W		16.5	14.5	13	
H4	1615	14			into harb		14	13.8	13	rep at surface

Week No. 2 - July 13, 1993
Fecal coliform vs. Turbidity



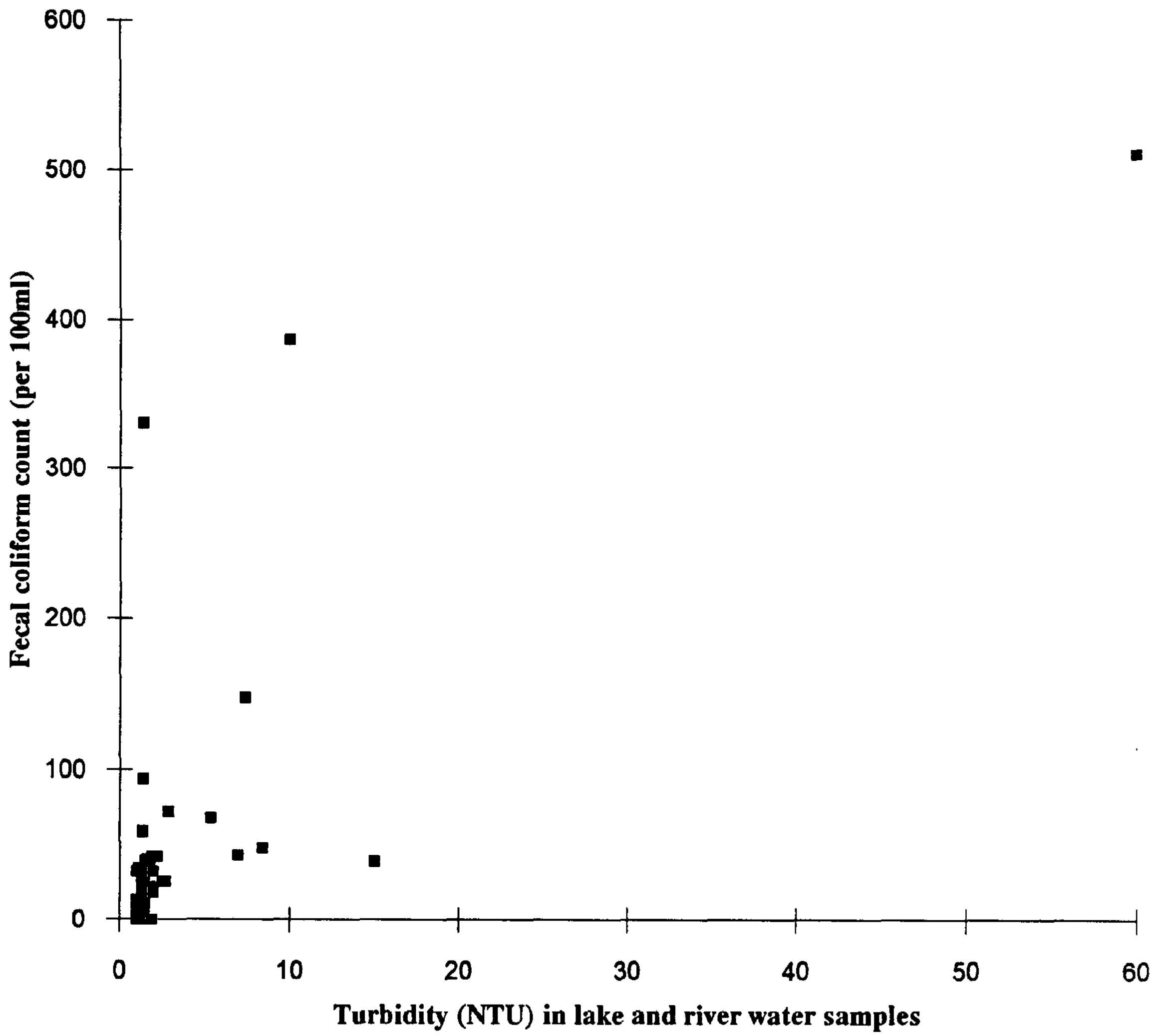
Week No. 2 - July 13, 1993
Fecal Coliform Bacteria and Turbidity Data

		Fecal coliform count (per 1				*Turbidity in water (NTU)*				*Replicate sample done in lab or field*
Sample site	**Location**	**Shore**	**100'**	**500'**	**1000'**	**Shore**	**100'**	**500'**	**1000'**	*FC count/turbidity (field only)*
Transect No. 1	Surface	13	2	0	0	2	1.1	0.9	0.9	Field replicate @ 100' surface=0/0.9
(@ Wind Point)	Mid Depth		0	2	4		1.1	1		
"	Bottom		1	3	4		1.1	1.3	1	Lab replicate @ 500' bottom=1
Shoop Park Creek	Mouth	620				5.9				
3 Mile Outfall	Outfall	>3456				3				
Transect No. 2	Surface	3	1	1	0	1.2	1.1	1	1.1	Lab replicate @ 500' surface=0
@ North Bay Creek	Mid Depth		N/C	0	0			1.1	1.1	Field replicate @ 500' mid=0/1.0
"	Bottom		1	1	0		1.1	1.1	1.2	
North Bay Creek	Mouth	N/C								
Wolff St. Outfall	Outfall	360				1.5				
Transect No. 3	Surface	29	3	0	0	1.6	0.9	0.96	0.96	
(@ Zoo/High St.)	Mid Depth		0	0	0		1	0.98	0.98	
"	Bottom		3	0	0		1.2	0.91	1	
Zoo beach	' off shor	8				1.9				
"	"	9				1.2				
"	"	4				1.2				
nglish St. Outfal	Outfall	9400				1.5				
English Beach	' off shor	4				1.4				
"	"	4				1.3				
"	"	2				1.4				
Transect No. 4	Surface	9	2	0	0	2.5	0.96	1.2	0.96	Lab replicate @ shore=7
(@ North Beach/	Mid Depth		N/C	0	0			1.1	0.98	Lab replicate of field replicate=0
Romayne Ave.)	Bottom		0	0	0		1	1.1	1.1	Field replicate @ 1000' bottom=0/1.0
North Beach	' Off Shor	13				1.2				
"	"	10				2.1				
"	"	10				1.4				
Transect No. 5	Surface	0	0	0	0	1.1	1.1	1	0.95	Lab replicate @ shore=0
@ bend in breakwa	Mid Depth		0	0	0		1.1	0.94	1.2	Field replicate @ 100' mid=0/1.3
uth of harbor mou	Bottom		0	0	0		1	1	1.6	
		Fecal coliform count (per 1				*Turbidity in water (NTU)*				*Replicate sample done in lab or field*
Sample location	**Depth**	**Shore**	**100'**	**500'**	**1000'**	**Shore**	**100'**	**500'**	**1000'**	*FC count/turbidity (field only)*
Transect No. 6	Surface	18	10	52	0	2.2	2.1	3.6	0.92	Field replicate @ 500' surface=18/2.9
bend in breakwal	Mid depth		12	17	0		2.1	2.5	1	Lab replicate @ shore=13
uth of harbor mou	Bottom		8	0	13		2	1.4	1.2	
Meyers Beach	' Off shor	17				0.87				
"	"	26				0.75				Lab replicate @ Meyers #2 replicate=1
"	"	30				3.4				
Harbor Area		**Surf.**	**Mid.**	**Bot.**		**Surf.**	**Mid.**	**Bot.**		
Horlick Dam		379				50				Lab replicate @ Horlick Dam=351
Gas Light Pointe		220	84	168		25	12	45		
Marina		220	98	143		13	11	21		Lab replicate @ Harbor mouth bottom=4
Harbor Mouth		116	30	48		10	6.4	9.2		Field replicate @ surface=20/7.8
Small Boat Launch		55	128	218		2.3	3.1	4.3		

Week No. 2 - July 13, 1993
Field Conditions

Transect/ Station	Time	Water Depth (ft)	Wind		Current		Water Temperature (°C)			Comments
			Speed (mph)	Direction	Direction	Magnitude	Surface	Middepth	Bottom	
1A	945	shore	2-3	SSE	S	slight	17.0	-	-	
1B	-	2	5-6	S	S	med. strong	16.0	-	15.8	rep at sfc
1C	-	10	7	S	N		14.8	14.1	14.0	
1D	1145	26	7-8	S	S	strong	16.1	12.0	10.8	
2A	1010	shore	0-2	SE	N	slight	17.0			
2B	-	3	5	S	N	med. strong	15.6	-	14.8	
2C	-	10	6-7	S	N		15.0	14.0	13.0	rep at mid depth
2D	1225	12	5-6	S	N		15.0	14.0	12.1	
3A	1025	shore	light	variable	none	wave dominated	14.8			
3B	-	5	5-6	S	N		15.5	15.0	14.9	
3C	-	9	5-6	S	N	med. strong	15.0	14.8	14.2	
3D	1255	14	6-7	S	N		14.7	13.5	13.0	
4A	1040	shore	light	variable	S	slight	16.5			1300+ gulls on lake, many were on shore
4B		2	0-1	variable	N	slight	15.0	-	15.0	
4C		7	2-3	N	N		14.5	13.9	13.6	
4D	1440	14	0-2	S	N	v. strong	15.7	14.1	13.8	rep at mid depth
5A	1500	brkwall	2-3	NNE	parallel to wall		15.0	-	-	wave dominated current
5B		12	5-6	NNE	N		14.7	14.0	13.5	rep at mid depth
5C		17	5-6	NNE	S	slight	15.5	14.8	13.5	variable winds affect current determination
5D	1515	24	5-6	NNE	NNE		15.1	13.5	12.5	
6A	1550	brkwall	6-7	NNE	none	see note	16.0	-	-	current dominated by waves from south, inshore of river plume
6B		19	7-8	NNE	S	see note	15.0	13.5	12.0	boat drifting, in river plume which was moving south
6C		20	7-8	NNE	S	see note	15.0	13.5	11.5	boat drifting, river plume moving south. rep @ sfc
6D	1610	24	7-8	NNE	S	see note	14.5	13.0	11.2	river plume moving south
H1	1410	19	3	S	downstrm		21.5	16.0	13.0	
H2	1350	30	light	variable	out	strong	14.8	13.2	13.2	rep at sfc
H3	1425	19	4-5	S	none		20.2	14.9	12.3	
H4	1340	13	2-3	S	into harb		14.9	14.5	14.0	

Week No. 3 - July 20, 1993
Fecal coliform vs. Turbidity



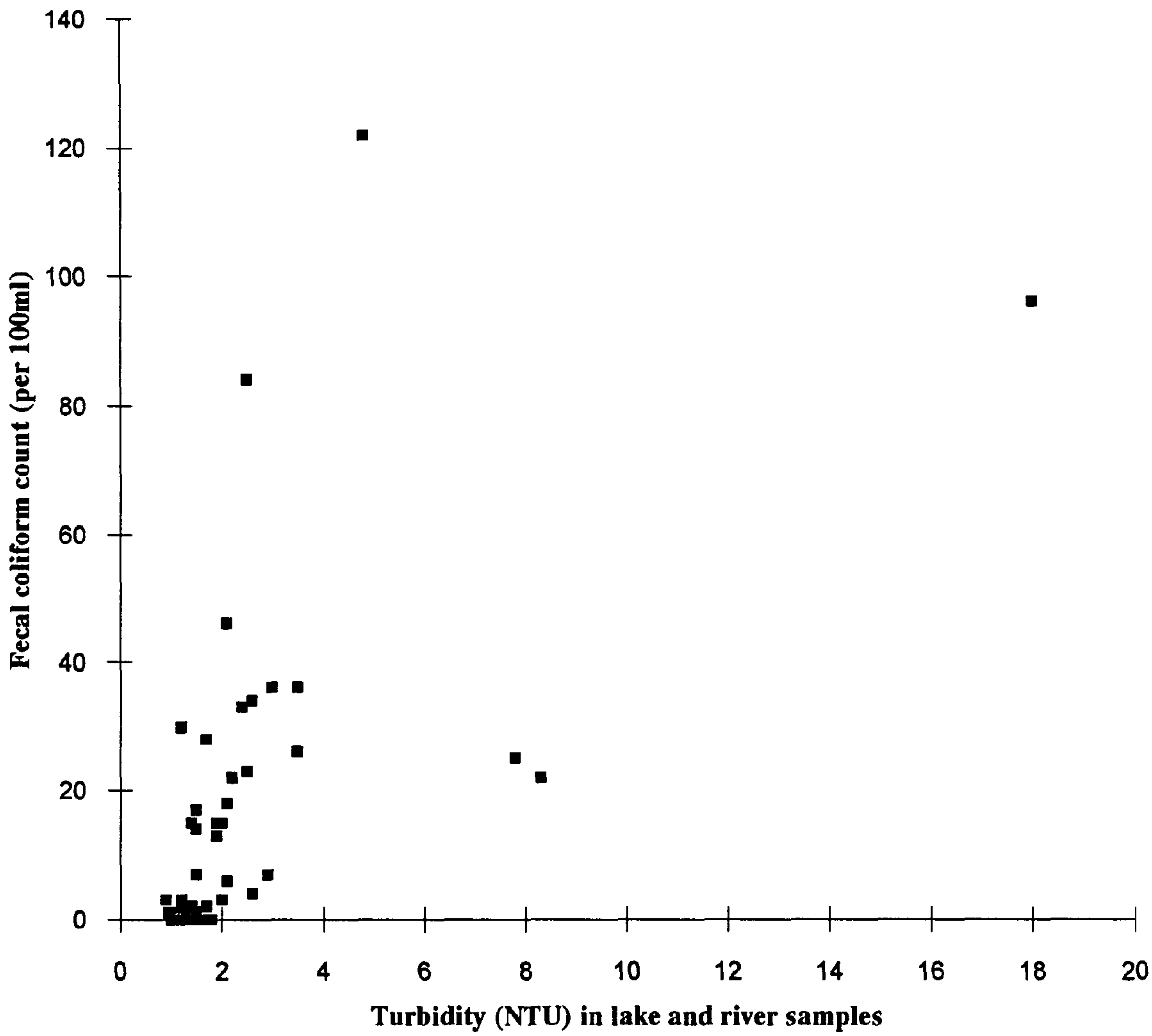
Week No. 3 - July 20, 1993
Fecal Coliform Bacteria and Turbidity Data

		Fecal coliform count (per 1				Turbidity in water (NTU)				Replicate sample done in lab or field
Sample site	**Location**	**Shore**	**100'**	**500'**	**1000'**	**Shore**	**100'**	**500'**	**1000'**	FC count/turbidity (field only)
Transect No. 1	Surface	43	25	1	0	7	2.7	1.5	1.1	Lab replicate @ 100' surface=17
(@ Wind Point)	Mid Depth		N/A	0	1			1.4	1.3	
"	Bottom		25	0	0		2.5	1.3	1.3	Field replicate @ 100' bottom=23/2.
Shoop Park Creek	Mouth	230				5				
3 Mile Outfall	Outfall	208				3				
Transect No. 2	Surface	2	1	0	0	1.4	1.4	1.3	1.4	Lab replicate @ 500' mid.=0
(@ North Bay Creek)	Mid Depth		0	0	0		1.4	1.3	1.3	Field replicate @ 1000' mid.=0/1.3
"	Bottom		0	0	0		1.3	1.3	1.5	
North Bay Creek	Mouth	N/A								
Wolff St. Outfall	Outfall	376				1.4				
Transect No. 3	Surface	330	32	0	0	1.4	1	1	1	Lab replicate @ 500' surface=0
(@ Zoo/High St.)	Mid Depth		N/A	1	0			1.3	1	
"	Bottom		34	0	0		1.1	1.3	1.3	Field replicate @ 100' bottom=30/1.
Zoo beach	' off shor	39				1.5				
"	"	33				1.5				
"	"	40				1.6				
English St. Outfall	Outfall	49000				2				
English Beach	' off shor	12				1.4				
"	"	22				1.8				
"	"	17				1.5				
Transect No. 4	Surface	21	4	0	0	2	1.5	1.2	1.1	Lab replicate @ 1000' surface=0
(@ North Beach/	Mid Depth		N/A	0	0			1	1.9	
Romayne Ave.)	Bottom		0	0	0		1.4	1	1.1	Field replicate @ 100' bottom=0/1.3
North Beach	' Off Shor	25				1.5				
"	"	19				1.5				
"	"	26				1.3				
Transect No. 5	Surface	2	3	3	3	1.2	1	1	1	Lab replicate @ 1000' surface=0
(@ bend in breakwall	Mid Depth		3	0	2		1.2	1.1	1.1	
orth of harbor mouth	Bottom		8	4	8		1	1.3	1.3	
		Fecal coliform count (per 1				Turbidity in water (NTU)				Replicate sample done in lab or field
Sample location	**Depth**	**Shore**	**100'**	**500'**	**1000'**	**Shore**	**100'**	**500'**	**1000'**	FC count/turbidity (field only)
Transect No. 6	Surface	11	31	59	32	1.2	1.3	1.4	2	Lab replicate @ 100' surface=31
@ bend in breakwall	Mid depth		12	19	3		1.3	1.3	1.2	
outh of harbor mouth	Bottom		4	10	5		1.2	1.5	1.3	
Meyers Beach	' Off shor	13				1				
"	"	10				1.2				
"	"	22				1.5				
Harbor Area		**Surf.**	**Mid.**	**Bot.**		**Surf.**	**Mid.**	**Bot.**		
Horlick Dam		510				60				
Gas Light Pointe		386	68	48		10	5.4	8.4		Field replicate @ surface=197/11.0
Marina		72	148	39		2.9	7.4	15		
Harbor Mouth		5	40	42		1.4	1.8	2.2		Lab replicate @ bottom=26
Small Boat Launch		18	42	94		2	1.9	1.4		Lab replicate @ bottom=52

Week No. 3 - July 20, 1993
Field Conditions

Transect/ Station	Time	Water Depth (ft)	Wind		Current		Water Temperature (°C)			Comments
			Speed (mph)	Direction	Direction	Magnitude	Surface	Middepth	Bottom	
1A	1105	shore	2-3	N	S		18.0	-	-	
1B	1136	3	light	variable	S	slight	15.8	-	16.0	rep at bottom
1C	1129	13	light	variable	S	strong	15.0	15.0	15.0	
1D	1115	25	light	variable	S	v. strong	15.7	15.0	14.0	1.2 ft/sec
2A	1147	2	6-7	N	S	slight	12.5	-	-	
2B	1217	4	4-5	NE	SW		16.0	15.5	14.9	
2C	1210	9	6-7	NE	SSW		14.9	14.2	13.1	
2D	1157	12	6-7	NNE	SW		14.5	14.0	12.5	rep at mid depth
3A	1227	shore	2-3	NE	SW	slight	15.2	-	-	
3B	1247	2	light	variable	note	slight	16.0	-	15.0	current parallel to beach, rep at bot
3C	1242	6	4-5	NE	SSW		15.0	15.0	13.9	
3D	1237	13	5-6	NE	WSW		15.0	14.7	13.5	
4A	1300	shore	2-3	NE	none		18.5	-	-	
4B	1335	2	4-5	SE	N	slight	17.2	-	16.1	rep at bottom
4C	1327	5	4-5	SE	SW		15.3	15.1	14.8	
4D	1320	15	2-3	ENE	SSE	med. strong	16.0	15.1	14.8	
5A	930	brkwall	5-6	NW	S	v. slight	12.8	-	-	
5B	957	12	5-6	NW	SSE		13.0	12.5	12.5	
5C	945	16	3-4	NW	S		12.8	12.1	11.8	
5D	937	23	6-7	NW	S		12.8	10.1	11.1	
6A	1006	brkwall	6-7	NNE	note		-	-	-	current parallel to wall
6B	1029	19	4-5	NNW	SW		11.5	9.9	9.0	
6C	1015	20	8-9	N	S		11.0	9.5	8.9	
6D	1007	25	5-6	NNE	S		12.0	8.5	8.1	
H1	1405	19	6-7	SE	downstrm	slight	21.5	13.6	10.5	rep at surface
H2	1418	29	4-5	SE	out	strong	14.7	13.9	10.1	
H3	1356	19	4-5	SE	none		19.0	13.3	10.8	
H4	1428	13	light	variable	into harb		14.0	12.0	10.6	

Week No. 4 - July 27, 1993
Fecal coliform vs. Turbidity



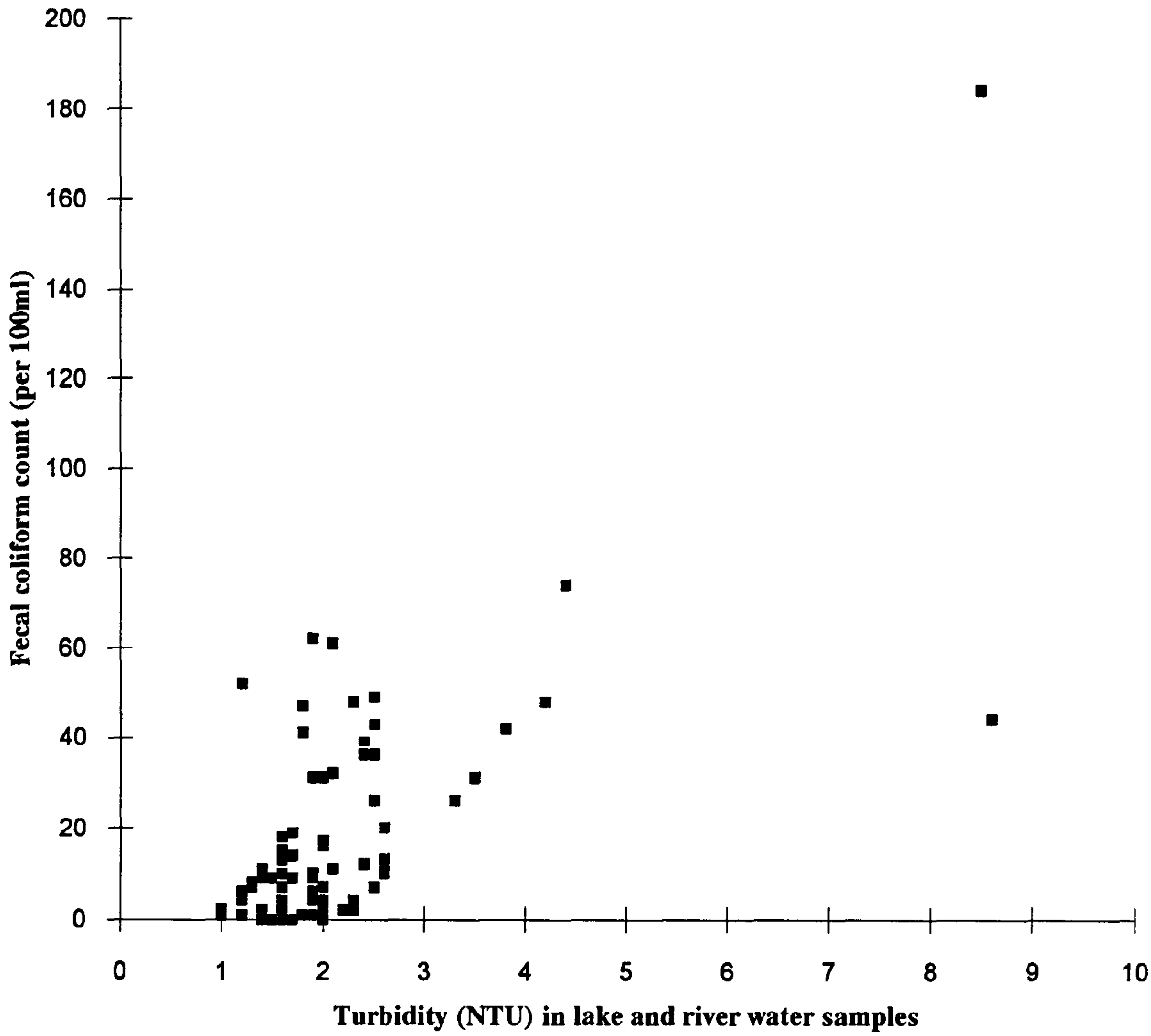
Week No. 4 - July 27, 1993
Fecal Coliform Bacteria and Turbidity Data

		Fecal coliform count (per 1				Turbidity in water (NTU)				Replicate sample done in lab or field
Sample site	**Location**	**Shore**	**100'**	**500'**	**1000'**	**Shore**	**100'**	**500'**	**1000'**	FC count/turbidity (field only)
Transect No. 1	Surface	260	72	14	5	35	3.7	3	0.8	
(@ Wind Point)	Mid Depth		N/A	5	0			2.4	1	Field replicate @ 500' mid=14/2.5
"	Bottom		68	11	0		3.8	2.7	1.2	Lab replicate @ 1000' bottom=1
Shoop Park Creek	Mouth	264				2.5				Lab replicate @ SPC=238
3 Mile Outfall	Outfall	8200				7				
Transect No. 2	Surface	40	5	2	1	1.6	1	1.1	1.2	Field replicate @ 500' surface=2/1
(@ North Bay Creek)	Mid Depth		38	2	2		1.4	1.1	1.1	Lab replicate @ 1000' surface=2
"	Bottom		17	3	1		1.3	1.1	1.2	
North Bay Creek	Mouth	N/A								
Wolff St. Outfall	Outfall	4200				1.6				
Transect No. 3	Surface	410	70	20	3	2.8	2.2	1	1.1	Field replicate @ 500' surface=17/
(@ Zoo/High St.)	Mid Depth		12	N/A	0		1	1.1	1.2	Lab replicate @ 1000' mid=0
"	Bottom		87	17	2		1.6	1.1	1.2	
Zoo beach	' off shor	249				2.6				
"	"	290				2.7				
"	"	200				1.9				LAb replicate @ Zoo beach #3=179
English St. Outfall	Outfall	12000				1.5				
English Beach	' off shor	208				1.6				
"	"	170				2.1				
"	"	134				1.7				
Transect No. 4	Surface	910	79	13	0	3	1.3	1	1	Field replicate @ shore surface=53
(@ North Beach/	Mid Depth		N/A	12	0			1	1.1	Lab replicate of field replicate
Romayne Ave.)	Bottom		110	4	18		1.3	1	1.2	
North Beach	' Off Shor	204				1.4				
"	"	198				1.6				
"	"	170				1.4				
Transect No. 5	Surface	33	44	4	0	1.1	1.1	1	1.1	
@ bend in breakwal	Mid Depth		32	18	1		1.2	1	1	Lab replicate @ 100' bottom=43
rth of harbor mout	Bottom		31	12	7		1.1	1.5	1.5	Field replicate @ 100' bottom=43/1
		Fecal coliform count (per 1				Turbidity in water (NTU)				Replicate sample done in lab or field
Sample location	**Depth**	**Shore**	**100'**	**500'**	**1000'**	**Shore**	**100'**	**500'**	**1000'**	FC count/turbidity (field only)
Transect No. 6	Surface	5	12	9	3	1.3	1.1	1.2	1.2	ield replicate @ 500' surface=6/1.
@ bend in breakwall	Mid depth		7	5	3		1.3	1.3	1.5	Lab replicate @ 1000'surface=3
uth of harbor mout	Bottom		3	7	0		1	2	1.5	
Meyers Beach	' Off shor	290				0.91				
"	"	280				1.6				
"	"	210				1.1				
Harbor Area		**Surf.**	**Mid.**	**Bot.**		**Surf.**	**Mid.**	**Bot.**		
Horlick Dam		260				2.1				
Gas Light Pointe		98	68	120		9.8	6	3.8		
Marina		53	78	104		3.6	6.9	18		
Harbor Mouth		15	34	7		4.1	4.3	1.9		Field replicate @ HM surface=8/2.3
Small Boat Launch		168	75	110		1.7	1.6	3.4		Lab replicate @SBL surface=166

Week No. 4 - July 27, 1993
Field Conditions

Transect/ Station	Time	Water Depth (ft)	Wind		Current		Water Temperature (°C)			Comments
			Speed (mph)	Direction	Direction	Magnitude	Surface	Middepth	Bottom	
1A	1132	1	0-2	S	S	slight	13.2	-	-	rep at surface
1B	1155	3	2-3	SSE	S	slight	11.0	-	11.0	
1C	1150	8	2-3	SSE	N	strong	10.0	10.0	9.5	
1D	1142	26	4-5	SSE	N	strong	10.1	9.0	8.5	
2A	1205	2	light	variable	none		10.2	-	-	
2B	1225	6	4-5	SE	N	slight	10.0	9.8	10.0	
2C	1217	11	0-2	E	NNW	med. strong	11.0	8.5	8.5	rep at surface, slight rain
2D	1212	13	light	variable	N	med. strong	11.0	8.5	8.0	
3A	1235	2	5-6	SSE	S	slight	11.5	-	-	
3B	1250	5	7-8	SE	N		10.0	9.5	9.0	rep at surface
3C	1245	7	7-8	SE	N	strong	9.5	9.0	9.0	
3D	1240	14	8-9	SE	N	strong	10.0	8.8	8.2	
4A	1005	shore	light	variable	S	slight	14.0	-	-	
4B	1027	2	0-2	SE	none		11.0	-	10.0	
4C	1020	7	2-3	W	NW		10.0	8.9	8.5	rep at bottom
4D	1015	16	light	variable	N	slight	13.0	10.0	8.5	
5A	930	brkwall	light	variable	none		14.0	-	-	
5B	955	12	4-5	W	NW	v. slight	10.0	8.9	8.2	rep at surface
5C	947	16	4-5	W	NW	slight	9.5	8.5	7.8	
5D	937	23	4-5	W	NW	slight	12.0	9.0	8.0	
6A	1052	2	light	variable	SW	slight	10.5	-	-	
6B	1115	19	2-3	SE	NNE	med. strong	11.0	8.8	8.8	
6C	1107	20	5-6	SE	N	med. strong	11.0	8.9	8.5	rep at bottom
6D	1058	29	5-6	SE	N	slight	11.5	9.1	8.5	
H1	1335	18	8-10	SE	downstrm	slight	17.0	11.5	9.5	
H2	1402	28	7-8	SSE	into harb		14.5	10.8	10.2	rep at surface
H3	1345	19	9-10	SE	NNE	slight	17.0	10.0	10.0	
H4	1414	15	8-9	S	out	med. strong	10.2	10.4	10.7	

Week No. 5 - August 3, 1993
Fecal coliform vs. Turbidity



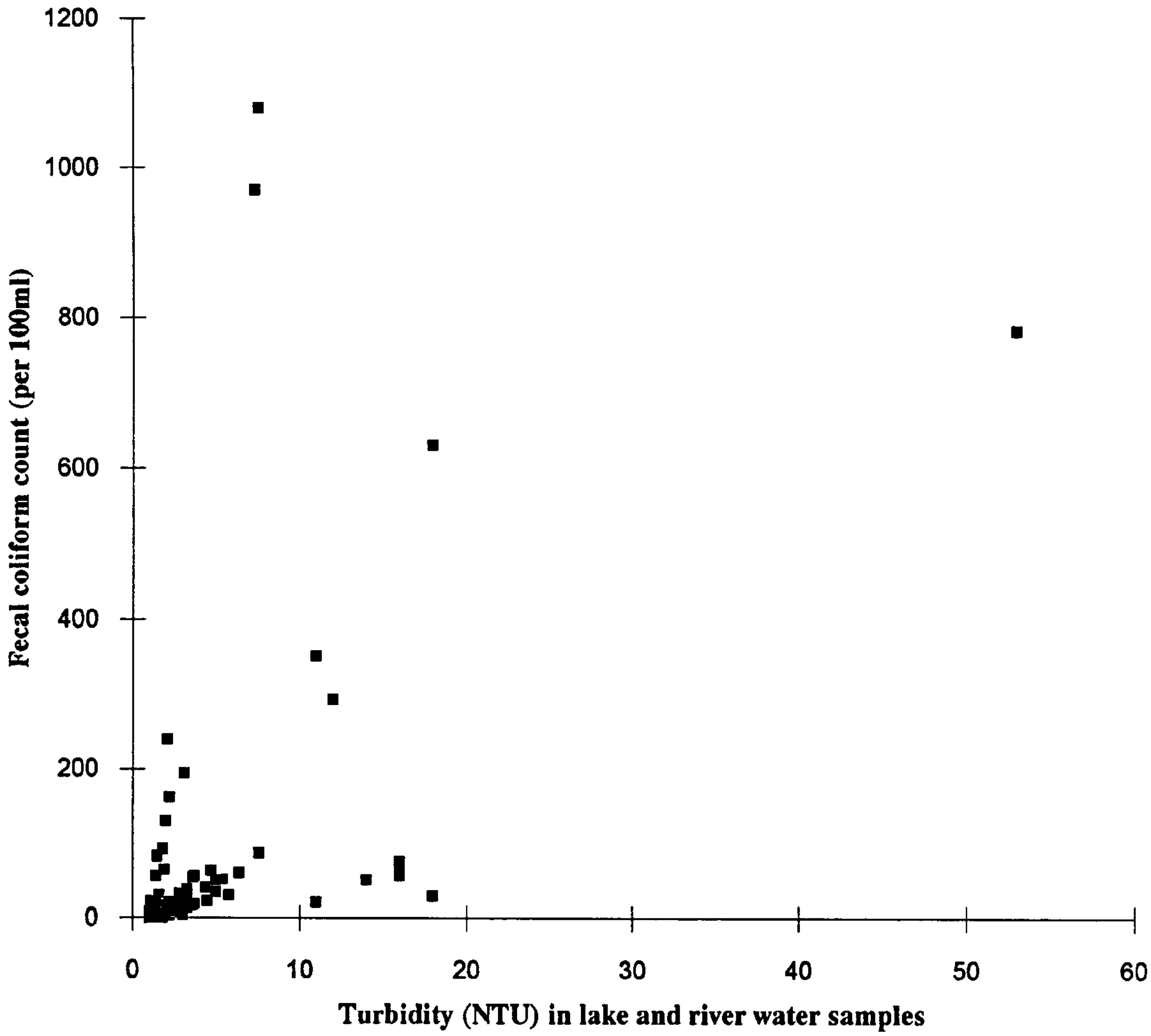
Week No. 5 - August 3, 1993
Fecal Coliform Bacteria and Turbidity Data

		Fecal coliform count (per 1				*Turbidity in water (NTU)*				*Replicate sample done in lab or field*
Sample site	**Location**	**Shore**	**100'**	**500'**	**1000'**	**Shore**	**100'**	**500'**	**1000'**	*FC count/turbidity (field only)*
Transect No. 1	Surface	74	9	0	0	4.4	1.7	1.6	1.6	
(@ Wind Point)	Mid Depth		N/A	1	3			1.9	1.6	Lab replicate @ 500' bottom=3
"	Bottom		31	0	7		1.9	1.6	1.3	Field replicate @ 100' bottom=25/1.7
Shoop Park Creek	Mouth	1150				5				
3 Mile Outfall	Outfall	104				1.5				
Transect No. 2	Surface	18	7	2	2	1.6	1.6	1.4	1.6	Lab replicate @ 1000' surface=3
(@ North Bay Creek	Mid Depth		3	11	6		1.6	2.1	1.2	Field replicate @ 500' mid=4/1.4
"	Bottom		10	9	8		1.6	1.5	1.3	
North Bay Creek	Mouth	N/A								
Wolff St. Outfall	Outfall	1220				1.3				Lab replicate @ Wolff St. Outfall=1000
Transect No. 3	Surface	61	62	16	10	2.1	1.9	2	1.9	Field replicate @ shore surface=31/2.3
(@ Zoo/High St.)	Mid Depth		32	31	19		2.1	2	1.7	Lab replicate @ shore surface=57
"	Bottom		39	14	15		2.4	1.7	1.6	
Zoo beach	' off shor	10				2.6				
"	"	26				3.3				
"	"	36				2.4				
English St. Outfal	Outfall	21000				1.8				
English Beach	' off shor	26				2.5				
"	"	48				2.3				
"	"	36				2.5				
Transect No. 4	Surface	17	6	4	0	2	1.9	1.9	2	
(@ North Beach/	Mid Depth		N/A	7	1			2	2	Lab replicate @ 1000' mid.=2
Romayne Ave.)	Bottom		16	9	5		2	1.9	1.9	Field replicate @ 1000' bottom=18/1.7
North Beach	' Off Shor	42				3.8				
"	"	48				4.2				
"	"	43				2.5				
Transect No. 5	Surface	4	0	3	0	1.6	2	2	2	
@ bend in breakwal	Mid Depth		2	0	4		2.3	2	2	Field replicate @ 500' mid.=5/2.4
rth of harbor mout	Bottom		4	12	11		2.3	2.4	2.6	Lab replicate @ 500' mid.=0/2.4
		Fecal coliform count (per 1				*Turbidity in water (NTU)*				*Replicate sample done in lab or field*
Sample location	**Depth**	**Shore**	**100'**	**500'**	**1000'**	**Shore**	**100'**	**500'**	**1000'**	*FC count/turbidity (field only)*
Transect No. 6	Surface	4	5	0	0	1.2	1.2	1.4	1.7	Field replicate @ shore surface=1/1.0
@ bend in breakwal	Mid depth		1	0	0		1.4	1.5	1.5	
uth of harbor mout	Bottom		2	1	1		1	1.2	1	
Meyers Beach	' Off shor	47				1.8				
"	"	41				1.8				
"	"	49				2.5				Lab replicate @ Meyers #3=56
Harbor Area		**Surf.**	**Mid.**	**Bot.**		**Surf.**	**Mid.**	**Bot.**		
Horlick Dam		184				8.5				
Gas Light Pointe		31	17	52		3.5	2	1.2		
Marina		7	13	44		2.5	2.6	8.6		Field replicate @ M surface=9/2.6
Harbor Mouth		9	1	2		1.4	1.8	2.2		Lab replicate @ HM mid.=0
Small Boat Launch		20	13	11		2.6	1.6	1.4		

Week No. 5 - August 3, 1993
Field Conditions

Transect/ Station	Time	Water Depth (ft)	Wind		Current		Water Temperature (°C)			Comments
			Speed (mph)	Direction	Direction	Magnitude	Surface	Middepth	Bottom	
1A	1150	shore	10+	W	none		17.5	-	-	algal masses on beach and along shore
1B	1210	3	10+	W	SE		16.5	-	16.5	rep at bottom
1C	1205	9	10+	WSW	SE		16.5	16.4	16.0	
1D	1157	26	10+	WSW	ESE		16.5	16.0	15.2	
2A	1225	2	light	variable	NE	slight	15.5	-	-	S swell, 200+ gulls on site
2B	1243	6	light	variable	S	slight	15.5	15.2	14.8	
2C	1238	10	10+	W	E		15.0	15.0	15.0	rep at mid depth
2D	1230	14	10+	W	E		15.5	14.2	14.2	
3A	1252	2	10+	W	none		18.0	-	-	rep at sfc, 200+ gulls on site
3B	1310	5	10+	W	E		16.0	15.8	16.0	
3C	1305	8	10+	W	E	med. strong	16.0	15.1	15.6	
3D	1258	13	10+	W	E		16.0	15.2	15.2	
4A	1010	shore	light	variable	N	slight	15.8	-	-	1000+ gulls on beach and near shore
4B	1015	1.5	10-15	W	SE		15.0	-	15.0	done on foot
4C	1025	7	10-15	W	E		16.0	15.8	15.0	
4D	1030	16	10-15	W	E	med. strong	16.0	15.8	14.0	rep at bottom
5A	930	brkwall	10-15	W	none		17.0	-	-	
5B	1001	12	10-15	W	SE		15.5	15.1	14.7	
5C	955	16	10-15	W	E		16.0	15.2	14.5	rep at mid depth
5D	940	22	10-15	W	E	offshore	16.0	15.5	14.0	
6A	1042	brkwall	light	variable	N	slight	15.8	-	-	rep at surface
6B	1105	19	10+	W	N	strong	14.1	13.5	12.5	rain, gusty winds
6C	1055	21	10+	W	E		15.0	14.2	12.0	gusty winds
6D	1048	26	10+	W	E		15.1	14.8	11.5	gusty winds
H1	1345	18	5-10	W	downstrm		17.3	14.9	13.8	gusty winds
H2	1404	29	10+	WSW	upstream	med. strong	17.0	15.5	13.0	
H3	1351	18	10+	W	S		17.0	14.6	14.0	rep at surface
H4	1412	12	10+	W	N		16.6	15.2	14.1	current into harbor

Week No. 6 - August 10, 1993
Fecal coliform vs. Turbidity



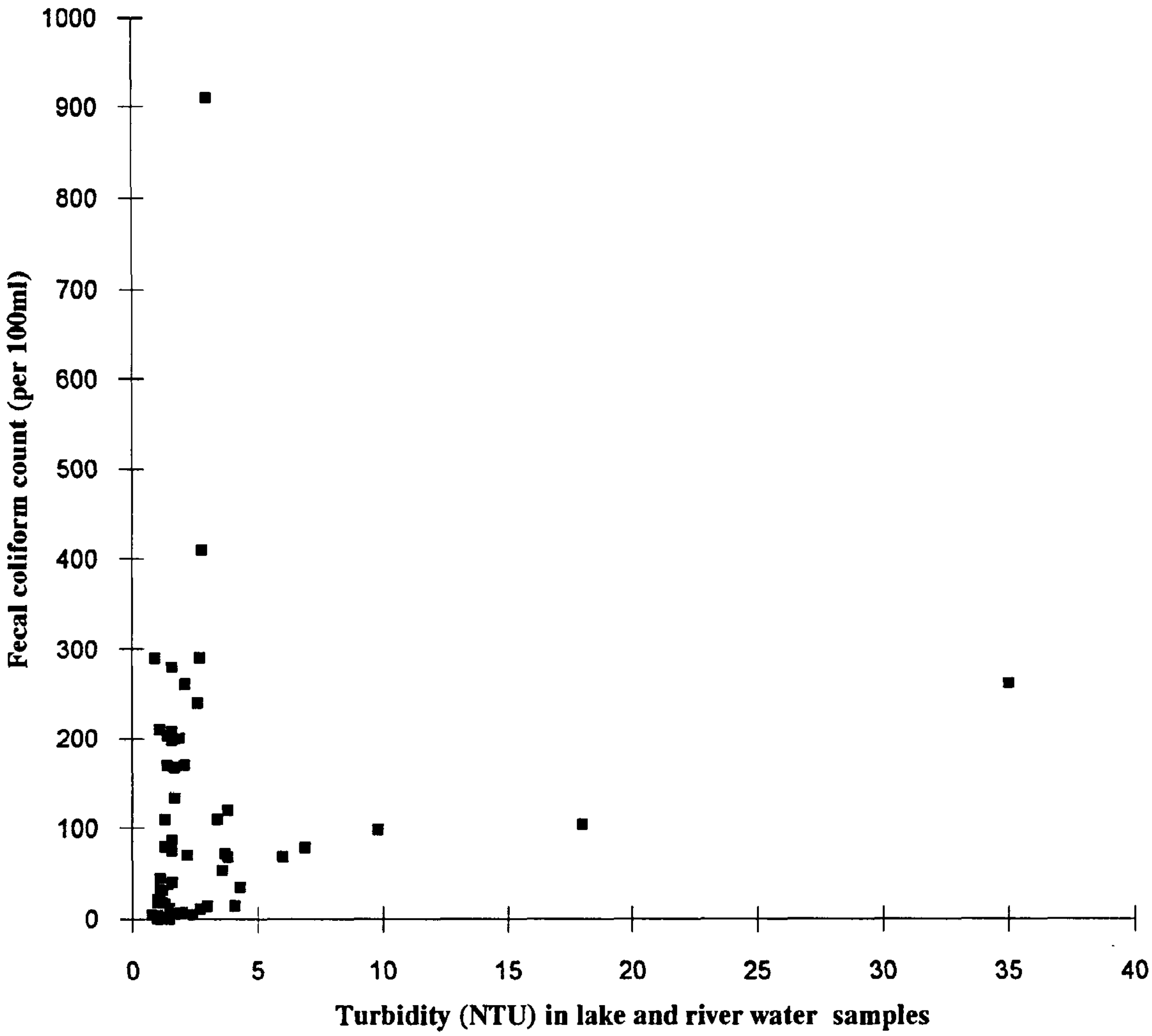
Week No. 6 - August 10, 1993
Fecal Coliform Bacteria and Turbidity Data

		Fecal coliform count (per 1				*Turbidity in water (NTU)*				*Replicate sample done in lab or field*
Sample site	**Location**	**Shore**	**100'**	**500'**	**1000'**	**Shore**	**100'**	**500'**	**1000'**	*FC count/turbidity (field only)*
Transect No. 1	Surface	630	293	18	9	18	12	3.7	1.6	Lab replicate @ 500' surface=41
(@ Wind Point)	Mid Depth		N/A	54	5			3.6	1.1	Field replicate @ 500' mid.=41/3.7
"	Bottom		351	55	3		11	3.7	1.2	
Shoop Park Creek	Mouth	350				4				
3 Mile Outfall	Outfall	120				19				
Transect No. 2	Surface	40	34	10	7	4.4	5	2	1.3	Field replicate @ shore surface=44/5.6
(@ North Bay Creek)	Mid Depth		30	30	55		5.8	1.6	1.4	
"	Bottom		22	20	9		4.5	1.6	2.2	Lab replicate @ 1000' bottom=6
North Bay Creek	Mouth	N/A								
Wolff St. Outfall	Outfall	955				19				
Transect No. 3	Surface	51	16	2	3	5.4	3	1.8	1.5	Lab replicate @ 100' surface=13
(@ Zoo/High St.)	Mid Depth		16	1	3		3.5	1.8	1.4	
"	Bottom		6	7	12		3	1.6	2.3	Field replicate @ 1000' bottom=12/1.8
Zoo beach	' off shor	194				3.1				
"	"	64				1.9				
"	"	130				2				
English St. Outfall	Outfall	98000				4.4				
English Beach	' off shor	240				2.1				
"	"	162				2.2				Lab replicate @ English Beach #2=172
"	"	92				1.8				
Transect No. 4	Surface	82	21	5	7	1.5	1.1	1.2	1	
(@ North Beach/	Mid Depth		N/A	9	6			1.4	1.6	Field replicate @ 1000' mid.=2/1.1
Romayne Ave.)	Bottom		N/A	28	20			3	2.2	Lab replicate @ 500' bottom=18
North Beach	' Off Shor	7				1.5				
"	"	13				1.8				
"	"	4				3				
Transect No. 5	Surface	6	5	4	1	1.1	1.5	1.5	1.4	
(@ bend in breakwal	Mid Depth		17	5	0		1.8	1.4	1	Lab replicate @ 100' bottom=16
orth of harbor mout	Bottom		21	16	32		3	2.6	2.8	Field replicate @ 100' bottom=13/2.6
		Fecal coliform count (per 1				*Turbidity in water (NTU)*				*Replicate sample done in lab or field*
Sample location	**Depth**	**Shore**	**100'**	**500'**	**1000'**	**Shore**	**100'**	**500'**	**1000'**	*FC count/turbidity (field only)*
Transect No. 6	Surface	9	3	21	1	3	2.2	2.1	1.2	Field replicate @ 100' surface=13/2.1
@ bend in breakwall	Mid depth		11	17	16		2.5	1.9	2.1	Lab replicate @ 100' surface=13
outh of harbor mout	Bottom		12	8	4		3.3	2.6	1.7	
Meyers Beach	' Off shor	780				53				
"	"	1080				7.5				
"	"	970				7.3				
Harbor Area		**Surf.**	**Mid.**	**Bot.**		**Surf.**	**Mid.**	**Bot.**		
Horlick Dam		50				14				
Gas Light Pointe		60	76	62		6.4	16	16		Lab replicate @ GLP surface=104
Marina		56	29	20		16	18	11		
Harbor Mouth		87	50	63		7.6	5	4.7		
Small Boat Launch		27	37	33		3.1	3.3	3.3		Field replicate @ SBL surface=104/14

Week No. 6 - August 10, 1993
Field Conditions

Transect/ Station	Time	Water Depth (ft)	Wind		Current		Water Temperature (°C)			Comments
			Speed (mph)	Direction	Direction	Magnitude	Surface	Middepth	Bottom	
1A	1225	shore	3-4	S	S	wave dominated	15.5	-	-	
1B	1300	3	7-8	S	N		15.0	-	15.0	
1C	1250	7	7-8	S	N	mod. strong	15.0	14.8	13.8	rep @ mid depth
1D	1242	26	3-4	S	N		14.0	13.0	12.5	
2A	1308	shore	5-6	S	N		15.0	-	-	rep @ sfc
2B	1325	4	8-9	S	N	slight (see note)	14.6	14.5	14.5	swell influenced
2C	1320	11	L	V	N	see note	14.0	13.1	13.0	swell influenced
2D	1313	17	7-8	SW	N		13.7	13.0	13.0	
3A	1340	shore	6-7	S	N	parallel to beach	16.3	-	-	in spite of wave action
3B	1400	4	8-10	S	N		13.0	13.0	13.0	
3C	1353	8	20	S	N		13.2	13.0	12.0	
3D	1345	15	10-12	S	N		13.8	12.5	12.5	rep @ bottom
4A	1015	shore	blocked	-	N	slight	15.5	-	-	wave dominated
4B	1030	2	L	V	NW	slight	13.0	-	-	wave dominated
4C	1035	7	7-8	SW	NNW		13.0	13.0	13.0	
4D	1045	15	2-3	S	N	swell dominated	12.8	11.5	11.5	rep @ mid depth
5A	945	brkwall	blocked	-	N	wave dominated	12.8	-	-	
5B	1007	13	blocked	-	N	slight	12.0	11.5	12.1	swell obscures current, rep @ bot
5C	1000	16	7-8	S	N		12.5	12.0	11.5	
5D	950	24	7-8	S	N	swell dominated	-	-	-	no temps measured
6A	1110	brkwall	blocked	-	-	swell dominated	11.5	-	-	
6B	1140	18	7-8	S	N	strong	13.3	12.5	12.0	rep @ sfc
6C	1132	20	8-9	S	N	wave dominated	13.3	12.2	12.0	
6D	1120	27	9-10	S	SW		12.9	11.0	9.8	
H1	1425	18	5-6	S	downstrm		18.0	14.9	12.2	rep @ sfc
H2	1447	28	8-10	S	out		16.5	15.0	13.8	
H3	1437	19	8-10	S	N	slight	18.2	15.0	13.0	
H4	1456	19	8-10	S	S	slight	14.0	14.0	14.0	

Week No. 7 - August 17, 1993
Fecal coliform vs. Turbidity



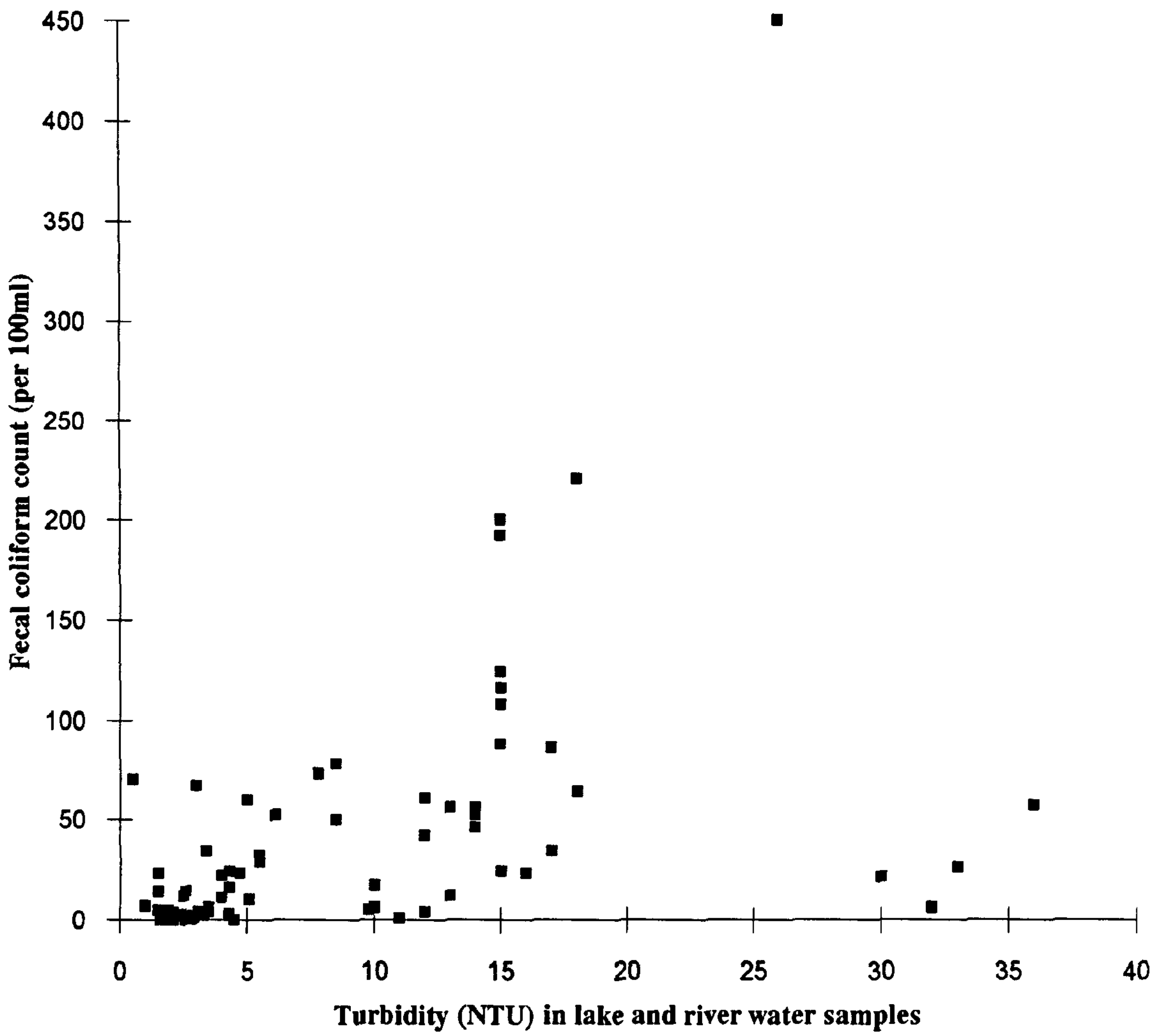
Week No. 7 - August 17, 1993
Fecal Coliform Bacteria and Turbidity Data

		Fecal coliform count (per 1				*Turbidity in water (NTU)*				*Replicate sample done in lab or field*
Sample site	**Location**	**Shore**	**100'**	**500'**	**1000'**	**Shore**	**100'**	**500'**	**1000'**	*FC count/turbidity (field only)*
Transect No. 1	Surface	260	72	14	5	35	3.7	3	0.8	
(@ Wind Point)	Mid Depth		N/A	5	0			2.4	1	Field replicate @ 500 mid=14/2.5
"	Bottom		68	11	0		3.8	2.7	1.2	Lab replicate @ 1000' bottom=1
Shoop Park Creek	Mouth	264				2.5				Lab replicate @ SPC=238
3 Mile Outfall	Outfall	8200				7				
Transect No. 2	Surface	40	5	2	1	1.6	1	1.1	1.2	Field replicate @ 500' surface=2/1.2
(@ North Bay Creek	Mid Depth		38	2	2		1.4	1.1	1.1	Lab replicate @ 1000' surface=2
"	Bottom		17	3	1		1.3	1.1	1.2	
North Bay Creek	Mouth	N/A								
Wolff St. Outfall	Outfall	4200				1.6				
Transect No. 3	Surface	410	70	20	3	2.8	2.2	1	1.1	Field replicate @ 500' surface=17/1.5
(@ Zoo/High St.)	Mid Depth		12	N/A	0		1	1.1	1.2	Lab replicate @ 1000' mid=0
"	Bottom		87	17	2		1.6	1.1	1.2	
Zoo beach	' off shor	240				2.6				
"	"	290				2.7				
"	"	200				1.9				Lab replicate @ Zoo Beach #3=179
English St. Outfal	Outfall	12000				1.5				
English Beach	' off shor	208				1.6				
"	"	170				2.1				
"	"	134				1.7				
Transect No. 4	Surface	910	79	13	0	3	1.3	1	1	Field replicate @ shore surface=531/3
(@ North Beach/	Mid Depth		N/A	12	0			1	1.1	Lab replicate of Field replicate=529
Romayne Ave.)	Bottom		110	4	18		1.3	1	1.2	
North Beach	' Off Shor	204				1.4				
"	"	198				1.6				
"	"	170				1.4				
Transect No. 5	Surface	33	44	4	0	1.1	1.1	1	1.1	
@ bend in breakwal	Mid Depth		32	18	1		1.2	1	1	Lab replicate @ 100' bottom=43
rth of harbor mout	Bottom		31	12	7		1.1	1.5	1.5	Field replicate @ 100' bottom=43/1.2
		Fecal coliform count (per 1				*Turbidity in water (NTU)*				*Replicate sample done in lab or field*
Sample location	**Depth**	**Shore**	**100'**	**500'**	**1000'**	**Shore**	**100'**	**500'**	**1000'**	*FC count/turbidity (field only)*
Transect No. 6	Surface	5	12	9	3	1.3	1.1	1.2	1.2	Field replicate @ 500' surface=6/1.0
@ bend in breakwal	Mid depth		7	5	3		1.3	1.3	1.5	Lab replicate @ 1000' surface=3
uth of harbor mout	Bottom		3	7	0		1	2	1.5	
Meyers Beach	' Off shor	290				0.91				
"	"	280				1.6				
"	"	210				1.1				
Harbor Area		**Surf.**	**Mid.**	**Bot.**		**Surf.**	**Mid.**	**Bot.**		
Horlick Dam		260				2.1				
Gas Light Pointe		98	68	120		9.8	6	3.8		
Marina		53	78	104		3.6	6.9	18		
Harbor Mouth		15	34	7		4.1	4.3	1.9		Field replicate @ HM surface=8/2.3
Small Boat Launch		168	75	110		1.7	1.6	3.4		Lab replicate @ SBL surface=166

Week No. 7 - August 17, 1993
Field Conditions

Transect/ Station	Time	Water Depth (ft)	Wind		Current		Water Temperature (°C)			Comments
			Speed (mph)	Direction	Direction	Magnitude	Surface	Middepth	Bottom	
1A	1222	shore	Winds for this date were light and variable approx. 0-3 mph through-out the entire sampling period. Direction was difficult to deter-mine but was predomi-nately NE or N.	N	SSW		16.3	-	-	
1B	1255	3		NNE	SE		20.5	-	20.5	
1C		8		N	S		20.0	20.0	20.0	rep @ mid depth
1D	1237	30		N	N		19.5	19.0	16.0	
2A	1305	shore		N	S		19.0	-	-	rep @ sfc
2B		4		NE	SE		19.0	18.5	18.0	
2C		10		N	E		19.5	19.5	16.0	
2D	1320	12		N	E		19.0	18.5	16.0	
3A	1350	shore		NE	N		21.0	-	-	
3B		3		NE	SSE		20.5	-	20.5	
3C		7		NE	ESE		20.0	20.0	20.0	rep @ sfc
3D		13		NE	-		20.0	19.0	16.0	
4A	1055	shore		-	-		20.5	-	-	rep @ sfc
4B		2		NNE	SSW		19.0	-	-	
4C		8		NNE	S		19.2	19.0	18.5	
4D	1111	15		NNE	SSW		20.0	18.5	16.5	
5A	-	brkwall		V	E		20.0	-	-	
5B	-	13		NNW	SE		19.0	18.7	17.2	rep @ bot
5C	1037	15		N	SSE		18.5	17.5	14.0	
5D	1028	24		NNW	E		18.0	18.0	12.0	
6A	940	brkwall		N	N		18.5	-	-	
6B		18					19.5	19.0	17.5	
6C		20			N		19.0	18.5	17.5	rep @ sfc
6D		27			N		19.5	17.0	11.5	
H1	1444	19		NE	downstrm		22.0	17.0	17.0	
H2		29		N	SE		20.5	18.0	16.0	rep @ sfc
H3	1450	18		NE	E		20.5	18.0	16.0	
H4	1515	12		NE	SE		20.0	20.0	18.0	

Week No. 8 - August 24, 1993
Fecal coliforn vs. Turbidity



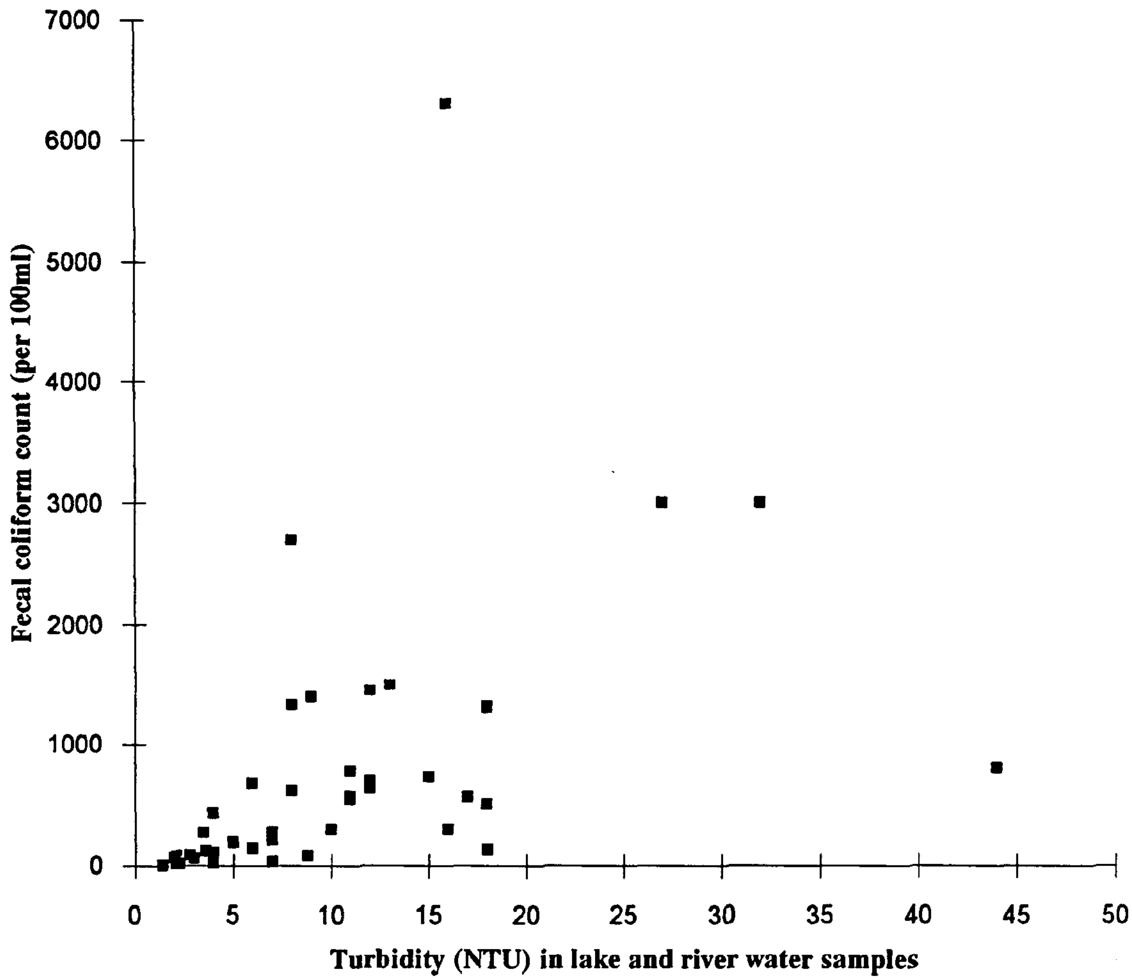
Week No. 8 - August 24, 1993
Fecal Coliform Bacteria and Turbidity Data

		Fecal coliform count (per 1				Turbidity in water (NTU)				Replicate sample done in lab or field
Sample site	**Location**	**Shore**	**100'**	**500'**	**1000'**	**Shore**	**100'**	**500'**	**1000'**	FC count/turbidity (field only)
Transect No. 1	Surface	57	12	17	73	36	13	10	7.8	Lab replicate @ 1000' surface=52
(@ Wind Point)	Mid Depth		N/A	42	12			12	2.5	
"	Bottom		23	10	5		16	5.1	1.9	
Shoop Park Creek	Mouth	1280				30				
3 Mile Outfall	Outfall	4600				0.8				Lab replicate @ 3 mile OF=284
Transect No. 2	Surface	26	6	2	4	33	10	4.3	3.5	
(@ North Bay Creek)	Mid Depth		N/A	2	0			2.7	2	
"	Bottom		1	4	3		11	3.1	2	Lab replicate @ 500' bottom=4
North Bay Creek	Mouth	N/A								
Wolff St. Outfall	Outfall	10000				1				
Transect No. 3	Surface	4	5	6	0	12	9.8	3.5	2.8	
(@ Zoo/High St.)	Mid Depth		0	6	1		4.5	32	2.9	Lab replicate @ 500' mid.=7
"	Bottom		3	14	0		4.3	2.6	2.6	
Zoo beach	' off shor	86				17				
"	"	52				14				
"	"	64				18				Lab replicate @ Zoo #3=80
English St. Outfall	Outfall	120000				12				
English Beach	' off shor	56				13				
"	"	56				14				
"	"	108				15				
Transect No. 4	Surface	450	124	23	2	26	15	4.7	3.3	Lab replicate @ 100' surface=136
(@ North Beach/	Mid Depth		N/A	24	2			4.3	2.1	
Romayne Ave.)	Bottom		116	22	3		15	4	2.4	
North Beach	' Off Shor	88				15				
"	"	46				14				
"	"	34				17				
Transect No. 5	Surface	11	3	1	5	4	2.2	2.8	1.5	
(@ bend in breakwal	Mid Depth		16	23	3		4.3	1.5	1.7	Lab replicate @ 1000' mid.=2
orth of harbor mout	Bottom		32	34	0		5.5	3.4	1.8	
		Fecal coliform count (per 1				Turbidity in water (NTU)				Replicate sample done in lab or field
Sample location	**Depth**	**Shore**	**100'**	**500'**	**1000'**	**Shore**	**100'**	**500'**	**1000'**	FC count/turbidity (field only)
Transect No. 6	Surface	1	1	0	2	2	2	2.1	2.5	
@ bend in breakwall	Mid depth		1	1	1		2.1	2.6	2.9	Lab replicate @ 500' mid.=0
outh of harbor mout	Bottom		0	1	0		1.6	1.6	2.1	
Meyers Beach	' Off shor	192				15				
"	"	200				15				
"	"	220				18				
Harbor Area		**Surf.**	**Mid.**	**Bot.**		**Surf.**	**Mid.**	**Bot.**		
Horlick Dam		24				15				
Gas Light Pointe		50	29	21		8.5	5.5	30		
Marina		67	78	61		3	8.5	12		
Harbor Mouth		52	60	4		6.1	5	2.1		Lab replicate @ HM surface=42
Small Boat Launch		42	14	7		1.5	1	0.5		

Week No. 8 - August 24, 1993
Field Conditions

Transect/ Station	Time	Water Depth (ft)	Wind		Current		Water Temperature (°C)			Comments
			Speed (mph)	Direction	Direction	Magnitude	Surface	Middepth	Bottom	
1A	1145	shore	0-2	blocked	N	med. strong	19.1	-	-	
1B	1220	2	0-2	blocked	N		17.5	-	17.5	rep @ sfc
1C	1210	12	9-10		N		18.0	16.5	16.8	
1D	1154	28	10-15		E		17.5	17.0	14.0	
2A	1240	shore	4-5	blocked	N		16.6	-	-	rep @ sfc
2B	1305	5	5-6	SW	N	slight	16.5	-	16.0	
2C	1255	10	9-10	W	N		16.8	15.5	16.0	
2D	1247	14	5-6	W	NE	mod strong	17.0	16.0	15.5	
3A	1315	shore	blocked		none		22.0	-	-	
3B	1340	6	7-8	W	N		16.8	16.4	16.5	
3C	1335	7	9-10	W	N		16.0	15.8	16.0	rep @ mid depth
3D	1325	14	8-9	W	N		16.5	15.8	16.0	
4A	1040	shore	9-10	SW	parr to shore		19.5	-	-	
4B	1047	2	7-8	SW	N		16.5	-	16.1	
4C	1055	7	9-10	SW	N		16.1	16.0	15.0	rep @ mid depth
4D	1105	14	10+	SW	N		16.0	14.9	15.0	
5A	1000	brkwall	9-10	SW	parr to wall	v. slight	17.0	-	-	
5B	1025	12	9-10	SW	E	slight	15.2	15.0	15.1	
5C	1019	16	9-10	SW	N		15.0	14.5	14.5	rep @ bottom
5D	1007	34	9-10	SW	N		16.0	15.5	14.0	
6A	1440	brkwall	4-5	W (note)	E (note)		15.8	-	-	current parr to wall, rep @ sfc
6B	1515	18	9-10	W	E (note)		15.8	15.1	15.5	current parr to wall
6C	1510	21	10+	W	NE		15.7	15.5	15.0	
6D	1505	25	10+	W	NNE		16.0	16.0	15.5	immed. S of river plume
H1	1358	19	10-12	W	downstrm	strong	22.1	18.0	16.3	
H2	1450	29	5-6 (note)	W	out	strong	22.2	21.0	15.9	
H3	1410	18	8-9	W	N		21.5	19.9	17.0	rep @ bottom
H4	1522	10	8-9	W	out		20.8	19.0	16.0	

Week No. 9 - August 31, 1993
Fecal coliform vs. Turbidity



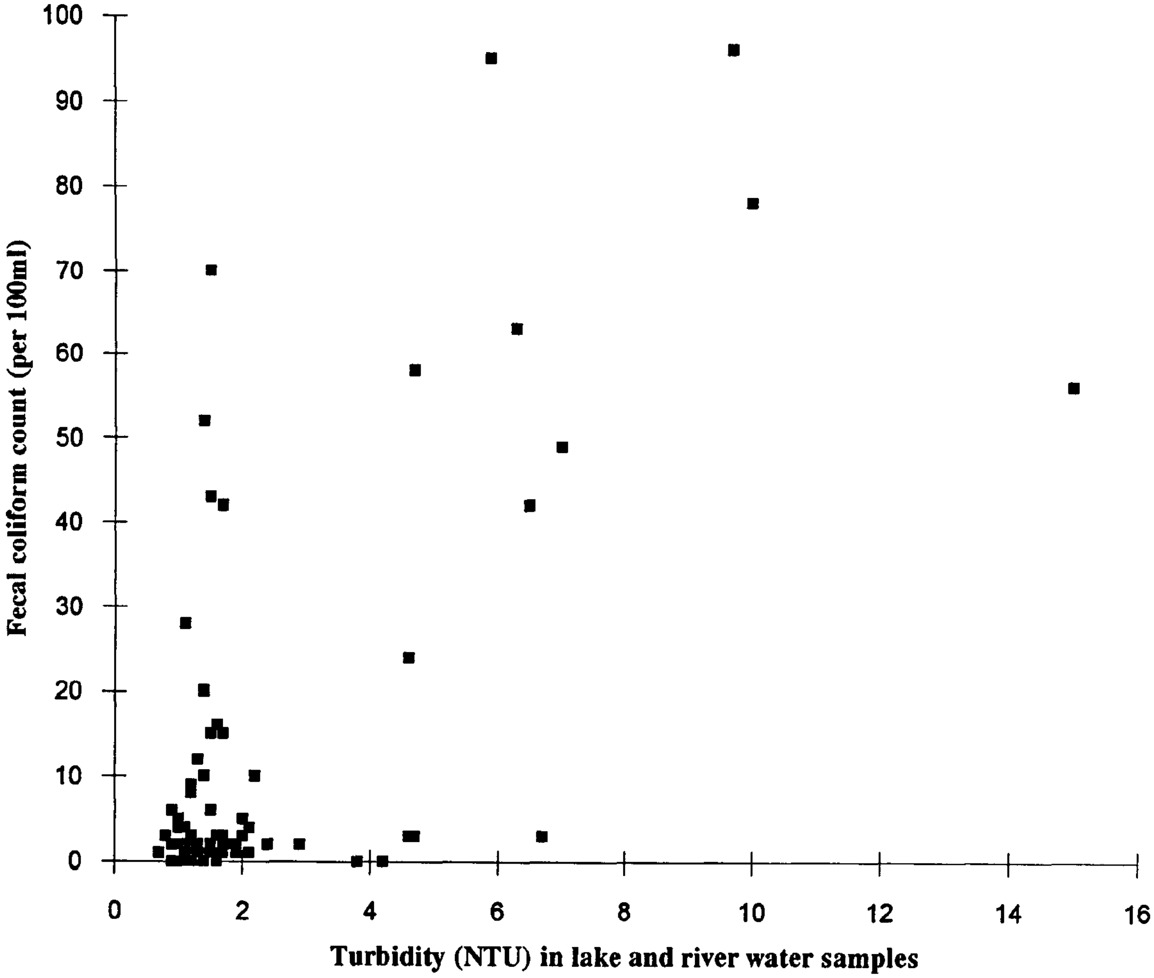
Week No. 9 - August 31, 1993
Fecal Coliform Bacteria and Turbidity Data

		Fecal coliform count (per 1				*Turbidity in water (NTU)*				*Replicate sample done in lab or field*
Sample site	**Location**	**Shore**	**100'**	**500'**	**1000'**	**Shore**	**100'**	**500'**	**1000'**	*FC count/turbidity (field only)*
Transect No. 1	Surface	800		132	25	44		18	2.1	
(@ Wind Point)	Mid Depth									
"	Bottom									
Shoop Park Creek	Mouth	1280				6				
3 Mile Outfall	Outfall	4600				1.1				Lab replicate @ 3 mile OF=4100
Transect No. 2	Surface	300	82	88	70	16	8.8	2.8	2	Field replicate @ 100' surface=68/4
(@ North Bay Creek)	Mid Depth									
"	Bottom									
North Bay Creek	Mouth	N/A								
Wolff St. Outfall	Outfall	11600				5				
Transect No. 3	Surface	3000	122	82	23	27	3.6	2.1	2.3	Lab replicate @ 1000' surface=24
(@ Zoo/High St.)	Mid Depth									
"	Bottom									
Zoo beach	' off shor	1500				13				
"	"	1455				12				
"	"	1305				18				Lab replicate @ Zoo #3=1385
English St. Outfall	Outfall	26000				5				
English Beach	' off shor	570				11				
"	"	1400				9				
"	"	690				12				
Transect No. 4	Surface	6300		140	35	16	10	6	7	
(@ North Beach/	Mid Depth									
Romayne Ave.)	Bottom									
North Beach	' Off Shor	1330				8				
"	"	N/A								
"	"	2700				8				
Transect No. 5	Surface	N/A	106	58	27		4	3	4	Lab replicate @ 500' surface=68
(@ bend in breakwal	Mid Depth				41					
orth of harbor mout	Bottom				244					
		Fecal coliform count (per 1				*Turbidity in water (NTU)*				*Replicate sample done in lab or field*
Sample location	**Depth**	**Shore**	**100'**	**500'**	**1000'**	**Shore**	**100'**	**500'**	**1000'**	*FC count/turbidity (field only)*
Transect No. 6	Surface	N/A	106	268	6	9	4	3.5	1.4	
@ bend in breakwall	Mid depth									
outh of harbor mout	Bottom									
Meyers Beach	' Off shor	635				12				
"	"	570				17				
"	"	780				11				
Harbor Area		**Surf.**	**Mid.**	**Bot.**		**Surf.**	**Mid.**	**Bot.**		
Horlick Dam		3000				32				
Gas Light Pointe		1320	728	504		18	15	18		
Marina		544	300	568		11	10	17		
Harbor Mouth		616	676	212		8	6	7		Lab replicate @ HM bottom=228
Small Boat Launch		432	192	272		4	5	7		

Week No. 9 - August 31, 1993
Field Conditions

Transect/ Station	Time	Water Depth (ft)	Wind		Current		Water Temperature (°C)			Comments
			Speed (mph)	Direction	Direction	Magnitude	Surface	Middepth	Bottom	
1A	-	Due to sea state, depths could not be taken at any of the lake stations.	Due to sea state, wind speed and direction were not measured at most of the lake stations. Winds were consistently N to NE at about 10-15 mph throughout the sampling period.		Due to sea state, currents were not measured at most stations. The predominant current appeared to be southerly, as indicated by the plume of turbid water moving south from wind point and the movement of turbid water near the harbor areas south.		-	Due to sea state, temperatures below the surface were not taken at most stations.		
1B	-						-			
1C	-						-			station inside turbid plume
1D	1200						17.0			station just outside turbid plume
2A	-						-			
2B	-						15.5			
2C	-						15.0			rep @ sfc
2D	1155						16.0			
3A	-						-			
3B	-						-			station in turbid zone near shore
3C	-						17.0			
3D	1140						16.0			
4A	-						-			
4B	-						-			
4C	-						16.0			
4D	1130						17.0			
5A	-						-			
5B	-						16.0			
5C	-						-			
5D	955	*	10-12	N	S	strong	17.0			waves inhibited depth sounder
6A	-		see note above		see note above		-			
6B	-						14.0			
6C	-						15.0			station in river plume
6D	1115						17.0	17.0	16.5	station 50 feet outside of river plume
H1	1015	18	blocked		downstrm	strong	20.8	18.0	15.2	
H2	1025	21	10-12	N	varied	see note	17.0	16.5	16.0	eddies in harbor mouth
H3	1020	18	10-15	N	none		20.8	18.2	17.0	
H4	1035	11	blocked		S		16.0	15.0	14.5	

Week No. 10 - September 7, 1993
Fecal Coliform Bacteria vs. Turbidity



Week No. 10 - September 7, 1993
Fecal Coliform Bacteria and Turbidity Data

		Fecal coliform count (per 1				*Turbidity in water (NTU)*				*Replicate sample done in lab or field*
Sample site	**Location**	**Shore**	**100'**	**500'**	**1000'**	**Shore**	**100'**	**500'**	**1000'**	*FC count/turbidity (field only)*
Transect No. 1	Surface	3	3	0	1	6.7	4.6	4.2	1.7	Field replicate 1 EM=4/4.8
(@ Wind Point)	Mid Depth		N/A	0	0			3.8	1.3	
"	Bottom		3	1	0		4.7	1.6	1.1	
Shoop Park Creek	Mouth	128				2.3				
3 Mile Outfall	Outfall	4				4.1				
Transect No. 2	Surface	3	2	1	1	2	1.7	1.2	1.3	Field replicate 2 EM=2/1.2
(@ North Bay Creek)	Mid Depth		1	3	1		2.1	1.6	1.4	
"	Bottom		1	0	2		1.9	1.6	1.8	Lab replicate @ 1000' bottom=1
North Bay Creek	Mouth	N/A								
Wolff St. Outfall	Outfall	28				1				
Transect No. 3	Surface	4	5	2	0	2.1	2	1.5	0.9	Field replicate 3 EM=2/2.0
(@ Zoo/High St.)	Mid Depth		N/A	2	1			1.3	1.3	
"	Bottom		1	1	0		2.1	1.5	1	
Zoo beach	' off shor	52				1.4				
"	"	43				1.5				
"	"	70				1.5				
English St. Outfall	Outfall	10400				1.4				
English Beach	' off shor	3				1.2				
"	"	0				1.2				
"	"	8				1.2				
Transect No. 4	Surface	42	28	4	1	1.7	1.1	1	1.1	Field replicate 4 EM=1/1.2
(@ North Beach/	Mid Depth		N/A	2	0			1.2	1.2	
Romayne Ave.)	Bottom		N/A	0	1			1.2	1.5	Lab replicate @ 1000' bottom=3
North Beach	' Off Shor	15				1.5				
"	"	12				1.3				
"	"	6				1.5				
Transect No. 5	Surface	5	2	1	1	1	1	1.2	1.1	Field replicate 5 EM=1/1.1
(@ bend in breakwall	Mid Depth		4	0	0		1.1	1.2	1.4	
orth of harbor mouth	Bottom		2	9	2		1.1	1.2	1.9	Lab replicate @ 1000' bottom=3
		Fecal coliform count (per 1				*Turbidity in water (NTU)*				*Replicate sample done in lab or field*
Sample location	**Depth**	**Shore**	**100'**	**500'**	**1000'**	**Shore**	**100'**	**500'**	**1000'**	*FC count/turbidity (field only)*
Transect No. 6	Surface	3	1	2	0	0.8	0.7	2.9	0.9	Field replicate 6 EM=1/1.0
@ bend in breakwall	Mid depth		2	2	3		1	0.9	1.7	
outh of harbor mouth	Bottom		10	6	2		2.2	0.9	2.4	Lab replicate @ 1000' bottom=5
Meyers Beach	' Off shor	16				1.6				
"	"	20				1.4				
"	"	15				1.7				
Harbor Area		**Surf.**	**Mid.**	**Bot.**		**Surf.**	**Mid.**	**Bot.**		
Horlick Dam		30				20				
Gas Light Pointe		96	78	56		9.7	10	15		Field replicate H EM=4/2.0
Marina		63	58	49		6.3	4.7	7		
Harbor Mouth		3	24	42		1.2	4.6	6.5		
Small Boat Launch		8	10	95		1.2	1.4	5.9		Lab replicate @ SBL bottom=96

Week No. 10 - September 7, 1993
Field Conditions

Transect/ Station	Time	Water Depth (ft)	Wind		Current		Water Temperature (°C)			Comments
			Speed (mph)	Direction	Direction	Magnitude	Surface	Middepth	Bottom	
1A	1150	shore	blocked		none		18.5	-	-	rock bottom, pockets of sand
1B	1222	3	blocked		SW	slight	18.0	-	17.5	rep @ sfc, hard rock bottom
1C	1212	8	6-7	W	SSE		17.8	17.2	17.0	hard rock bottom
1D	1200	26	5-6	W	SE	strong	17.4	17.3	17.4	hard rock bottom
2A	1224	shore	blocked		none	wave dominated	18.0	-	-	
2B	1252	5	blocked		E	slight	18.0	18.0	18.0	
2C	1245	10	blocked		SW	v. slight	17.9	17.9	17.5	rep @ mid depth
2D	1240	14	10-15	W	E		17.8	17.2	17.2	
3A	1300	shore	blocked		none		18.0	-	-	
3B	1315	4	blocked		S	slight	19.0	-	18.2	rep @ bottom
3C	1310	8	8-10	W	SE	slight	18.0	18.0	18.0	
3D	1305	13	10-15	W	S		17.5	17.7	17.5	
4A	1058	shore	blocked		S	see note	17.0	-	-	current parallel to beach
4B	1104	2	4-5	W	none		17.0	-	-	
4C	1108	8	6-7	W	SE		17.8	17.5	17.2	rep @ bottom
4D	1114	15	4-5	SW	W	slight	17.9	17.5	17.5	
5A	1025	brkwall	blocked		NNW	see note	18.0	-	-	no sediment collected, current parallel to breakwall
5B	1048	12	4-5	W	SE		16.8	16.2	16.0	rep @ sfc, rep mud sample taken
5C	1040	14	7-8	W	SE		17.2	17.0	15.8	
5D	1030	21	7-8	W	SE		18.0	18.0	17.5	
6A	948	brkwall	blocked		none		18.6	-	-	no sediment collected
6B	1015	19	5-6	WSW	none		17.0	17.0	16.0	
6C	1008	20	7-8	WSW	NE	slight	17.5	17.2	17.0	
6D	954	26	7-8	WSW	NNE		17.5	17.0	16.8	rep @ mid depth
H1	1332	18	blocked		downstrm	slight	17.8	17.0	17.0	
H2	1348	30	10-15	NW	downstrm		18.0	17.0	16.2	
H3	1340	18	blocked		none		17.5	17.0	16.5	
H4	1355	13	blocked		N (in)	strong	17.4	17.5	16.8	rep @ sfc

Appendix B

Statistical Evaluation of Fecal Coliform/Turbidity Relationship

Correlation Coefficients

Collective Data Set -Number of Observations: 606

Pearson Correlation Matrix

	FCCOUNT	TURBIDIT
FCCOUNT	1.000	
TURBIDIT	0.314	1.000

Significant Test

Bartlett Chi-Square Statistic: 62.495 DF = 1 Prob = .000

Correlation Coefficients
Log-Transformed Data Set

Collective Data Set - Number of Observations: 606

Pearson Correlation Matrix

	LOGFC	LOGTURB
LOGFC	1.000	
LOGTURB	0.630	1.000

Significant Test

Bartlett Chi-Square Statistic: 304.838 DF = 1 Prob = .000

Regression Analysis

Analysis of Variance Table

Source	Sum-of-Squares	DF	Mean-Square	F-Ratio	P
Regression	797.678	1	797.678	396.936	0.000
Residual	1213.792	604	2.010		

Variable	Coefficient	T	P(2 Tail)
Constant	1.578	18.582	0.000
LOGTURB	1.208	19.923	0.000

Dep Var: LOGFC N: 606 Multiple R: 0.630 Squared Multiple R: 0.397
Adjusted Squared Multiple R: .396 Standard Error of Estimate: 1.418