Water quality at three Boston beaches: results of intensive monitoring, 1996

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WATER QUALITY AT THREE BOSTON HARBOR BEACHES: RESULTS OF INTENSIVE MONITORING, 1996

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The Harbor Quality Task Force
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WATER QUALITY AT THREE BOSTON HARBOR BEACHES: RESULTS OF INTENSIVE MONITORING, 1996

SUMMARY

This study was an effort to develop a predictive measure, using rainfall, of bathing beach water quality at three Boston Harbor beaches: Constitution Beach in East Boston on Winthrop Bay, Carson Beach in South Boston on Northern Dorchester Bay, and Wollaston Beach in Quincy on Quincy Bay. Water samples were collected daily during the swimming season (July-August 1996) and analyzed for counts of two sewage indicator bacteria: fecal coliform and *Enterococcus.* Daily rainfall measurements were made at nearby rain gauges. The severity and frequency of bacterial pollution differed dramatically among the three beaches, and among different locations within each beach. Dry weather pollution was a significant problem at some locations, and high bacteria counts were associated with light to moderate rain at other locations. Elevated bacteria counts associated with rainstorms generally returned to acceptable levels after one day. The high variability in conditions associated with bacterial contamination of beaches makes it difficult to derive a simple "rule of thumb" for weather conditions which should trigger all beach postings. Recommendations are made for continued monitoring and guidelines are suggested for "precautionary postings" after rain events.

INTRODUCTION

As the water quality of Boston Harbor has improved, there is renewed public interest in using the Harbor's beaches. The state of Massachusetts is investing $30 million dollars to physically improve the beaches. Beach closings are fewer, but still remain a problem, often after rainstorms. The Metropolitan District Commission (MDC) has been monitoring beach water quality since 1973 by weekly sampling and the agency now routinely collects samples on Wednesdays and Thursdays for fecal coliform and *Enterococcus.* If a sample violates the water quality standard the beach is posted with a swimming advisory until subsequent samples are within the standard.

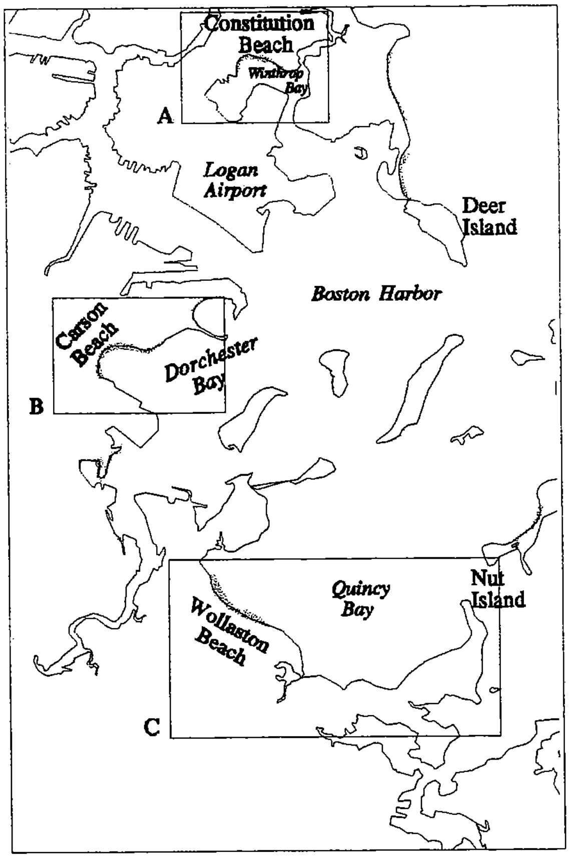
Solely using microbiological culture results for posting beaches is problematic because the data are not available at the earliest until 24 hours after the sample was collected. By the time results are available, water quality will have changed due to weather conditions and tidal flushing. A predictive measure of water quality is desirable. Rain, which can cause sewer overflows and storm runoff, is thought to be the most important environmental factor affecting beach contamination. If the relationship between rain and beach contamination were understood locally in more detail, it should be possible to develop a way to use rainfall data to predict when a beach should be posted (American Public Health Association 1995).

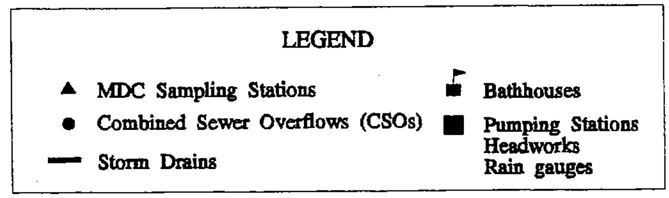
The purpose of the study described here was to examine the relationship between rainfall, daily bacterial water quality measurements, and beach postings at MDC Boston Harbor beaches. Three beaches were selected which are affected by different pollution sources, and where previous data suggest that the beaches respond differently to rainfall.

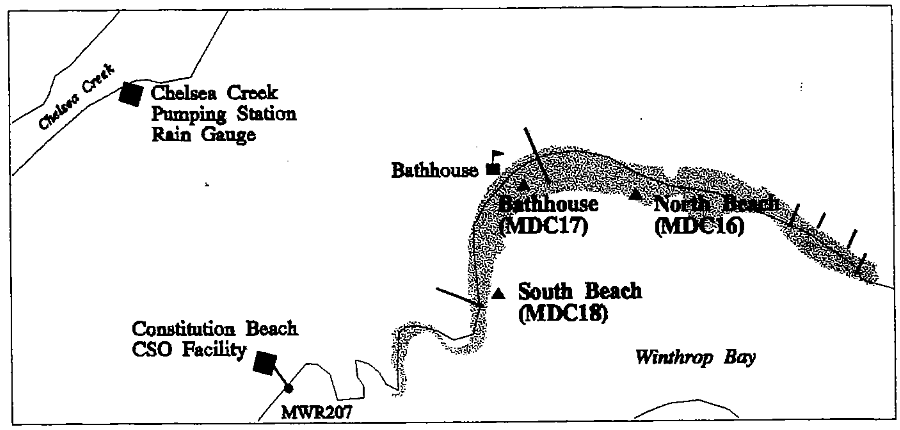
METHODS

Sampling Locations

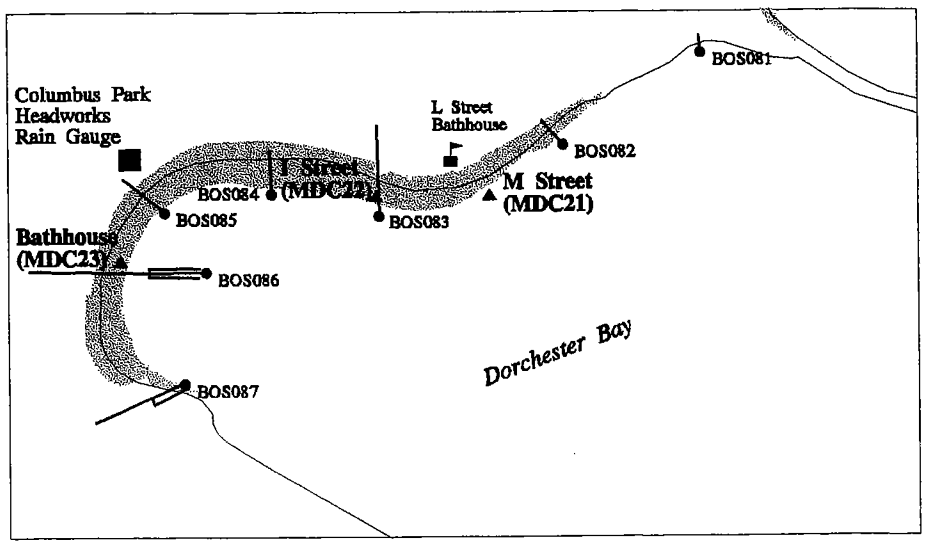
Ten sites were sampled at three Boston Harbor beaches. Figure 1A-C shows the sampling locations: Constitution Beach in East Boston (three sites), Carson Beach in South Boston (three sites), and Wollaston Beach in Quincy (four sites).



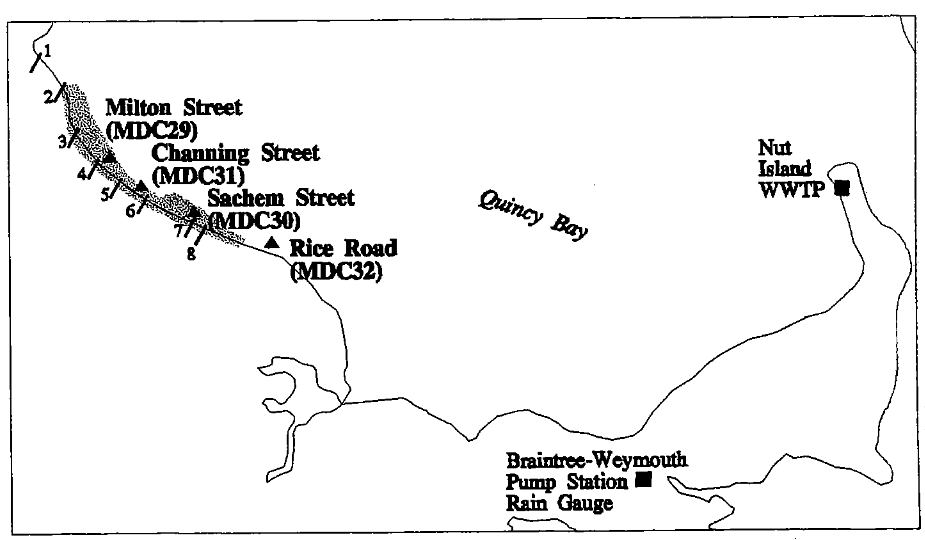




A. Constitution Beach



B. Carson Beach



C. Wollaston Beach

Figure 1 Map of sampling stations

Table 1. Sampling locations at Boston Harbor beaches.

MDC Beach and Location	MWRA Location Code
Constitution Beach North	MDC16
Constitution Bathhouse	MDC17
Constitution South	MDC18
Carson Beach at M Street	MDC21
Carson Beach at I Street	MDC22
Carson Beach Bathhouse	MDC23
Wollaston Beach at Milton Street	MDC29
Wollaston Beach at Channing Street	MDC31
Wollaston Beach at Sachem Street	MDC30
Wollaston Beach at Rice Road	MDC32

Pollution sources

Constitution Beach is located near MWRA's Constitution Beach CSO treatment facility, which discharges approximately 10 MG/year screened and chlorinated combined sewage. A contaminated storm drain on the beach was found to be connected to the waste pipe discharges of numerous houses; many illegal connections were corrected by Boston Water and Sewer Commission, but that storm drain or another may still be a pollution source. Carson Beach is affected by seven CSOs along the beach. The outfalls are subtidal. All of the CSO outfalls also discharge uncombined storm water from storm drains connected downstream of the regulators. Wollaston Beach is affected by discharges from eight storm drains located on the beach. These drains are all intertidal (exposed at low tide).

Sampling schedule

From July 8 to August 31, 1996, MDC personnel collected water samples daily at the locations historically monitored weekly by MDC. An attempt was made to collect samples at high tide, ± 3h,[1] but some samples were collected at lower stages of the tide. At several locations, the water is not deep enough to sample at low tide.

Parameters

Table 2 lists the variables measured. In addition to measured variables, tide stage information was recorded based on tide charts and sampling time.

[1] MDC collected samples and MWRA performed analyses on Fridays, Saturdays, Sundays, Mondays and Tuesdays. The MDC's consultant, Inchcape collected data on Wednesdays and Thursdays at the study beaches and weekly and at all other MDC beaches, as in past years.

Table 2. Variables measured.

Variable	Method
Water temperature	*in situ,* mercury thermometer
Fecal coliform	Standard Methods 9222D, membrane filtration
Enterococcus	Standard Methods 9230 C 2. *c.* membrane filtration
Salinity	S-C-T meter (Yellow Springs Instruments, model 33)
Rainfall	Rainfall reported by National Weather Service a Logan Airport, and MWRA gauges located at Columbus Park Headworks, Chelsea Creek Headworks, Braintree-Weymouth Pump Station

For enumeration of bacteria, MWRA Central Lab Standard Operating Procedures were followed. In brief, the procedure for fecal coliform is filtration of an aliquot of sample through a sterile membrane filter, then the filter is placed on mFC agar with rosolic acid and incubated at 44.5°C for 24h. After incubation, blue colonies are enumerated as fecal coliform. For enterococci, an aliquot of sample is filtered through a sterile membrane. The filter is placed on *m Enterococcus* agar and incubated at 35°C for 48h. Red colonies are counted as enterococci.

Sample collection

Water was collected in sterile sample bottles by wading out to a depth of two-three feet., with sampling person standing down-current of the sample collection point. Samples were collected 0.3m below the surface and stored immediately on icepaks in a cooler. Samples were processed within 6h of collection.

Data storage and analysis

Data are stored in the MWRA Laboratory Information Management System Database and the MWRA Environmental Quality Department Oracle® Database. Graphic and statistical analyses were performed using Microsoft® Excel and Statview® (Abacus Concepts, Inc. Berkeley CA).

RESULTS

Rainfall

Table 3 shows the rainfall pattern measured at three locations during the two-month study period: the MWRA Braintree-Weymouth pumping station, near Wollaston Beach; the MWRA Chelsea Creek pumping station, near Constitution Beach; and at the Columbus Park headworks, near Carson Beach. This was a fairly rainy summer, with precipitation 0.01 inches and over measured on 17 of 62 days. There was one major storm exceeding 3 inches on July 13. All other rain events were less than one inch. In this report, we define a significant rainfall as ≥ 0.2 inches. At Braintree-Weymouth, there were eight days where rainfall ≥ 0.2 inches; at Chelsea Creek, seven; and at Columbus Park, nine. There were substantial differences in rainfall among the gauging stations on six days: July 3, 4, and 9, and August 7, 9, and 13. On August 7, a very intense but brief "pocket thunderstorm" moved through South Boston depositing 0.29 inches in 15 minutes. The other rain gauges recorded no rain that day. Total rainfall amounts at each station during the sampling period were similar: 6.11 inches at Chelsea Creek, 6.59 inches at Braintree-Weymouth, and 6.76 inches at Columbus Park. Table 3. rainfall.

Table 3. MWRA Rain gauge data for July and August, 1996. Daily rainfall in inches.

July, 1996 rain gauge data (inches/day)				August, 1996 rain gauge data (inches/day)			
Date	Braintree-Weymouth	Chelsea Creek	Columbus Park	Date	Braintree-Weymouth	Chelsea Creek	Columbus Park
1-Jul-96	0.06	0.01	0.09	1-Aug-96	0.03	0.04	0.05
2-Jul-96	0	0	0	2-Aug-96	0	0	0
3-Jul-96	0.25	0.02	0.01	3-Aug-96	0	0	0
4-Jul-96	0.02	0.43	0.42	4-Aug-96	0	0	0
5-Jul-96	0	0	0	5-Aug-96	0	0	0
6-Jul-96	0	0	0	6-Aug-96	0	0	0
7-Jul-96	0	0	0	7-Aug-96	0	0	0.29
8-Jul-96	0	0	0	8-Aug-96	0	0	0
9-Jul-96	0.09	0.28	0.09	9-Aug-96	0.33	0.01	0.31
10-Jul-96	0	0	0	10-Aug-96	0.36	0.16	0.36
11-Jul-96	0	0	0	11-Aug-96	0	0	0
12-Jul-96	0	0	0	12-Aug-96	0	0	0
13-Jul-96	3.17	3.16	3.17	13-Aug-96	0.49	0.21	0.28
14-Jul-96	0	0	0	14-Aug-96	0	0.01	0
15-Jul-96	0	0	0	15-Aug-96	0	0	0
16-Jul-96	0	0	0	16-Aug-96	0	0	0
17-Jul-96	0	0	0	17-Aug-96	0	0	0
18-Jul-96	0	0	0	18-Aug-96	0	0	0
19-Jul-96	0.13	0.04	0.08	19-Aug-96	0	0	0
20-Jul-96	0	0	0	20-Aug-96	0	0	0
21-Jul-96	0	0	0	21-Aug-96	0	0	0
22-Jul-96	0	0	0	22-Aug-96	0	0	0
23-Jul-96	0.56	0.66	0.72	23-Aug-96	0.14	0.06	0.08
24-Jul-96	0	0	0	24-Aug-96	0.35	0.42	0.34
25-Jul-96	0	0	0	25-Aug-96	0	0	0
26-Jul-96	0.03	0.09	0.09	26-Aug-96	0	0	0
27-Jul-96	0	0	0	27-Aug-96	0	0	0
28-Jul-96	0	0	0	28-Aug-96	0.18	0.18	0.12
29-Jul-96	0	0	0	29-Aug-96	0	0	0
30-Jul-96	0	0	0	30-Aug-96	0	0	0
31-Jul-96	0.4	0.33	0.26	31-Aug-96	0	0	0

Combined sewer overflow events

The only CSO treatment facility affecting a study area, Constitution Beach (MWR207), discharged once during this time period, during the 3.16 inch rainstorm (Table 4). Although not metered, Carson Beach untreated CSOs (BOS081, BOS082, BOS083, BOS084, BOS085, BOS086, BOS087) may have discharged during that storm also. Other storms may have produced some overflows at these Carson Beach locations, the conditions producing overflows at these outfalls at low to moderate amounts of rain are strongly affected by a complex interaction of time of day, tide, rainfall intensity, and groundwater conditions. The brief, intense storm recorded at Columbus Park headworks on August 7 may have caused discharges from at least some of the CSOs along Carson Beach. The sewer system model does not generally show any overflows occurring unless at least about one-half of an inch of rain falls (Boston Water and Sewer Commission).

Table 4. Constitution Beach CSO discharges July-August 1996.

Day	Rain	Duration	Flow	Fecal coliform	Total chlorine residual
7/13/96	3.16 in	6.75 h	0.75MG	<10 col/100 ml	3.6 mg/l

Bacteria monitoring results

Two bacterial pollution indicators are monitored at MDC beaches: fecal coliform and *Enterococcus* (Table 5). Massachusetts state standards for bacterial bathing water quality are based on fecal coliform counts, while the USEPA recommends using *Enterococcus* in marine waters (USEPA 1986). Fecal coliform have a long history of use, are present in large numbers in human waste, and are reasonably good indicators of the risk to human health from bacterial diseases like typhoid fever and shigellosis. *Enterococcus* is also found in human waste, although in lower numbers than fecal coliform. *Enterococcus* is much slower to die off in salt water than fecal coliform, and in some epidemiological studies has been found to be more closely correlated with the risk of acquiring gastroenteritis after swimming (Cabelli 1981). Because *Enterococcus* is more persistent in salt water, it is thought to mimic the behavior of viruses, some of which can survive for long periods in the marine environment.

Table 5. Guidelines for posting Massachusetts State beaches. When the maximum criteria are exceeded, beaches are posted with warnings that swimming may be unsafe.

	Colonies/100 ml	
Indicator Organism	Maximum allowable level	Maximum geometric mean to meet swimming standard
Fecal coliform	200	200
Enterococcus	104	35

A total of 615 samples were analyzed for fecal coliform, and 535 for *Enterococcus*. Table 6 summarizes the percent of samples at each sampling location not meeting water quality standards. The numbers of samples that did not meet the state swimming standard during this period varied widely among beaches and among individual locations at beaches: while only 2% of samples for fecal coliform at the M Street location at Carson Beach failed to meet standards, 48% of samples analyzed for fecal coliform at Sachem Street on Wollaston Beach exceeded allowable standards. The "cleanest" water was at Carson Beach, followed by Constitution Beach. Wollaston Beach,with 27% of all samples exceeding fecal coliform standards had the poorest water quality. The *Enterococcus* violations were generally similar to fecal coliform at Constitution Beach and Carson Beach, but at Wollaston Beach *Enterococcus* violations were fewer than fecal coliform violations.

Table 6. Percent of samples collected during July and August, 1996 exceeding MDC bathing water standards. This includes samples collected during all weather conditions.

Location	% samples exceeding standard[1] (N/Total N)	
	Fecal coliform	*Enterococcus*
Constitution Beach		
All sites	12% (22/186)	14% (23/162)
North Beach	8% (5/62)	15% (8/54)
Bathhouse	13% (8/62)	11% (6/54)
South Beach	15% (9/62)	17% (9/54)
Carson Beach		
All sites	6% (10/179)	6% (10/155)
M Street	2% (1/60)	4% (2/52)
I Street	8% (5/59)	8% (4/51)
Bathhouse	7% (4/60)	7% (4/54)
Wollaston Beach		
All sites	27% (68/250)	15% (25/218)
Milton Street	16% (10/61)	13% (7/53)
Channing Street	24% (15/63)	11% (6/55)
Sachem Street	48% (30/63)	16% (9/55)
Rice Road	21% (13/63)	5% (3/55)

[1]Fecal coliform ≥ 200 col/100ml
Enterococcus ≥ 104 col/100 ml

Table 7 gives the geometric mean bacteria counts at each sampling location, for all samples and for samples collected in wet and dry weather. All sites at Constitution and Carson beaches met the baseline water quality standard easily, but the Sachem Street site at Wollaston Beach failed the state standard for fecal coliform.

Table 7. Geometric mean bacteria counts at three Boston Harbor beaches, July 1996-August 1996, for all samples and for samples collected during dry weather and wet weather.

	Geometric mean (colonies/100 ml)					
	Fecal coliform			*Enterococcus*		
Location	All	Dry weather[1]	Wet weather[2]	All	Dry weather	Wet weather
Constitution Beach						
All sites	32	21	91	20	12	59
North Beach	34	27	117	19	12	63
Bathhouse	30	18	104	20	10	68
South Beach	31	18	63	22	13	47
Carson Beach						
All sites	20	14	41	15	12	20
M Street	17	16	18	13	12	18
I Street	24	16	20	16	11	20
Bathhouse	18	11	22	16	12	22
Wollaston Beach						
All sites	80	64	124	26	19	54
Milton Street	36	35	56	24	18	40
Channing Street	98	105	112	33	19	84
Sachem Street	218	185	298	31	21	106
Rice Road	52	25	130	19	18	24

[1] Dry weather is defined as three consecutive days, including sampling day, of no rainfall.
[2] Wet weather is defined as two consecutive days, including sampling day, where total rain ≥ 0.2 inches. Although the 0.5 inches of rain are generally needed to activate CSOs on Carson Beach, storm drains discharge during smaller rain events.

Relationship between rainfall and bacteria counts

The average wet weather and dry weather bacteria data at the three beaches suggest differing responses to rainfall among the beaches. This section will explore in more detail how each sampling location was affected by rain events.

Constitution Beach. Daily bacteria levels at each sampling site together with daily rainfall measured at the Chelsea Creek Headworks are shown in Figure 2 (fecal coliform) and Figure 3 (*Enterococcus*). The major storm on July 13 of 3.16 inches was accompanied by high levels of both indicators, except at the North beach site. Bacteria levels were not greatly elevated, and dropped to acceptable levels the next. day. Paradoxically, the next rain event, only 0.04 inches, was followed by very high counts that were localized at the South beach site (fecal coliform were 7,400, *Enterococcus* 260). Again counts fell to well within swimming standards the next day. A medium-sized rainstorm on July 23 (0.66 in.) was followed by high *Enterococcus* counts that persisted for three days, but fecal coliform counts dropped to acceptable levels after one day. Periods of dry weather showed sporadic high bacteria counts, varying among locations. The most extreme violations were on August 24 (rainfall was a moderate 0.42 inches). All sites had very high bacteria counts, including the highest counts recorded at any beach during this study. Counts dropped sharply the next day to well within standards.

Carson Beach. Figures 4 and 5 show fecal coliform and *Enterococcus* counts, respectively, and rainfall. High bacteria counts followed the major storm on July 13, and fell to swimming standards the next day. At I Street, fecal coliform counts returned to high levels two days after the storm. I Street showed a "delayed" pattern again; fecal coliform and *Enterococcus* counts after a 0.72 inch storm on July 23 did not reach their peak until July 25. The most dramatic event was on August 7, when a "pocket thunderstorm" moved through the area late in the day, depositing 0.29 inches of rain in 15 minutes. Fortuitously, samples were collected twice that day. Samples collected in the morning had very low bacteria levels, but samples collected late afternoon after the storm showed fecal coliform levels at the Bathhouse and I Street greater than 4,000 col/ml (*Enterococcus* was not measured in the second set of samples). Two other days with moderate rainfall August 10 and 13, each had one sample with high fecal coliform. The only high bacteria counts recorded during dry weather were high *Enterococcus* counts at the Bathhouse and I Street on August 27.

Wollaston Beach. Figures 6 and 7 show rainfall and fecal coliform and *Enterococcus* counts, respectively, at four sites on Wollaston Beach. There is no consistent pattern with rainfall at any of the locations for fecal coliform. *Enterococcus* violations show a clearer pattern with rainfall than do fecal coliform. Dry weather violations were common, especially for fecal coliform. The largest rain event, on July 23, did not produce bacteria violations at all stations.

Regression analyses. One original objective of this study was to derive a simple model of bacteria counts on rain, which could be used to help predict when beaches should be posted after a given amount of rain. A common approach is to perform a linear regression analysis. In this case, the response variable is log-transformed bacteria counts, and the predictor variable is rainfall. Figures A1-A6 in the Appendix show the results of regression analyses. Briefly, log-transformed bacteria counts were regressed on the variable TWO DAY SUM (the total rain that fell on the day of sampling plus the previous day). All the data from all locations at each beach were used. All the regressions showed a statistically significant relationship, except for fecal coliform at Wollaston Beach. However, the R^2 values were ≤ 0.1 for all the equations; so the relationships between rain amount and bacteria counts were only weakly predictive. This weakness is partly caused by high bacteria counts often occurring in dry weather. Other environmental factors like rain intensity, tide, groundwater level, and wind, are likely to contribute to the variance. A more complex model, either a multiple regression or a sewer system model would take more variables into account, but it would be impractical to use a complex model in real time to decide whether or not to post a beach.

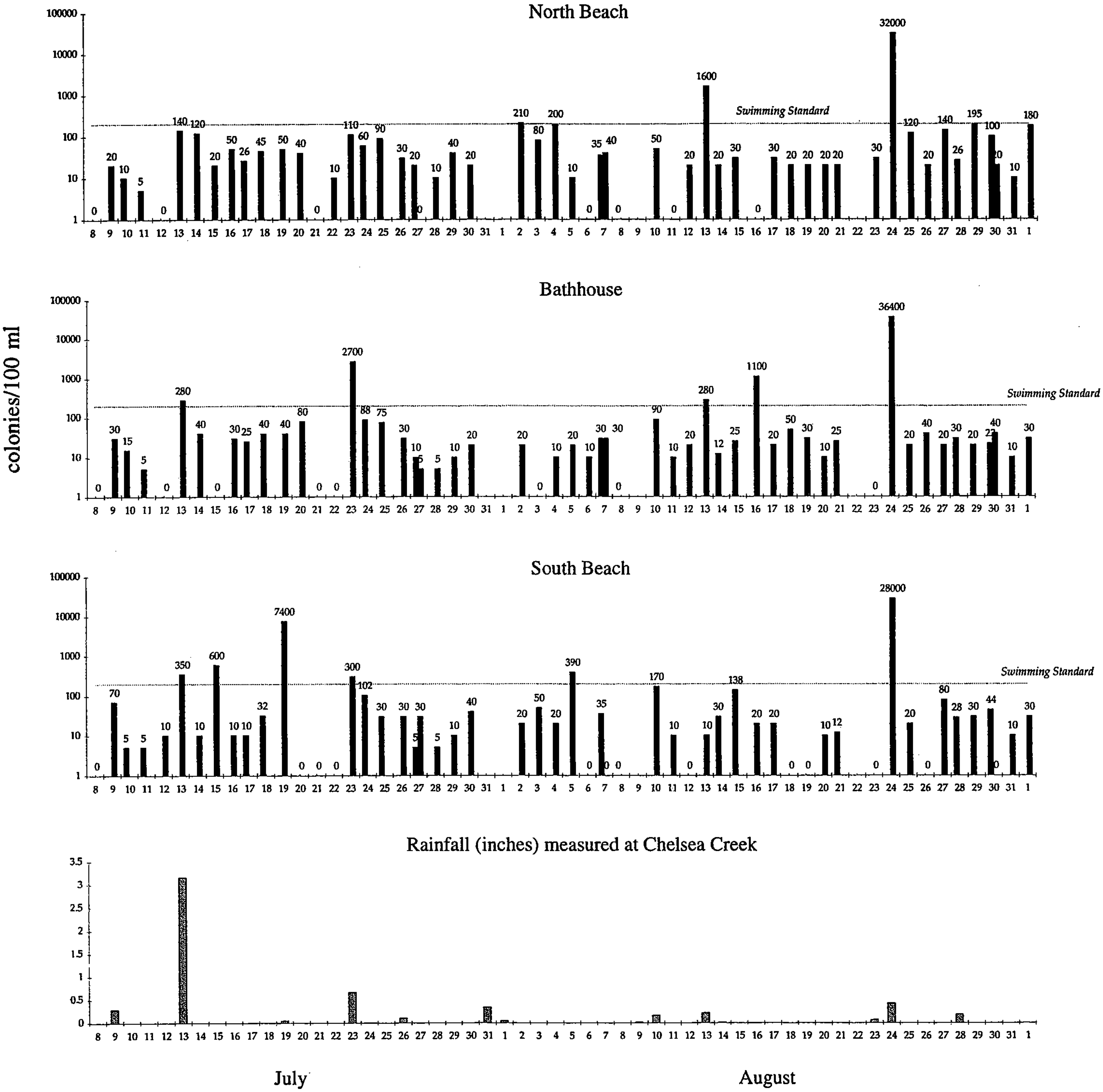


Figure 2: Fecal coliform counts from three locations at Constitution Beach and daily rainfall at the Chelsea Creek headworks facility, 1996.

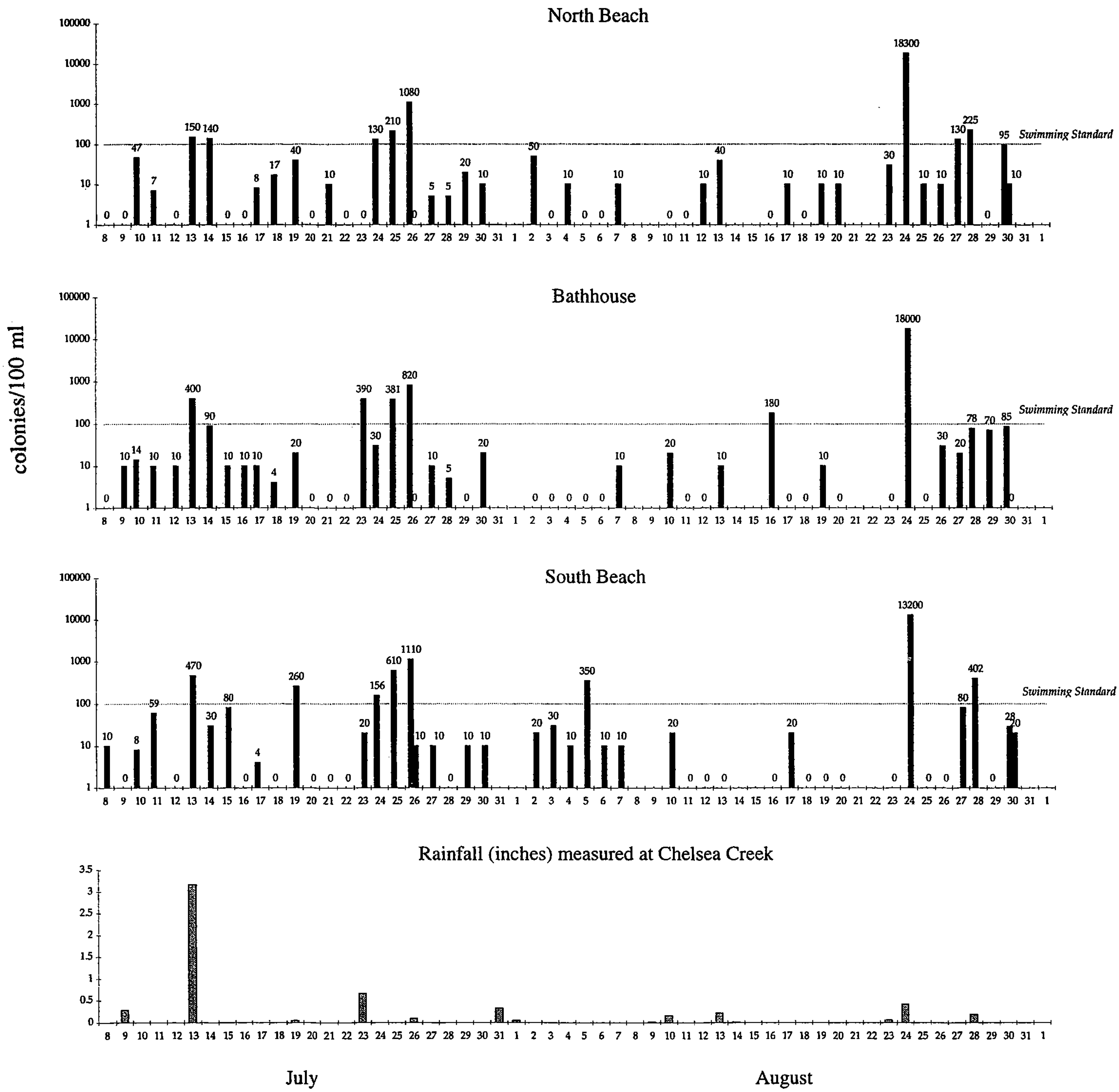


Figure 3: *Enterococcus* counts from three locations at Constitution Beach and daily rainfall at the Chelsea Creek headworks facility, 1996.

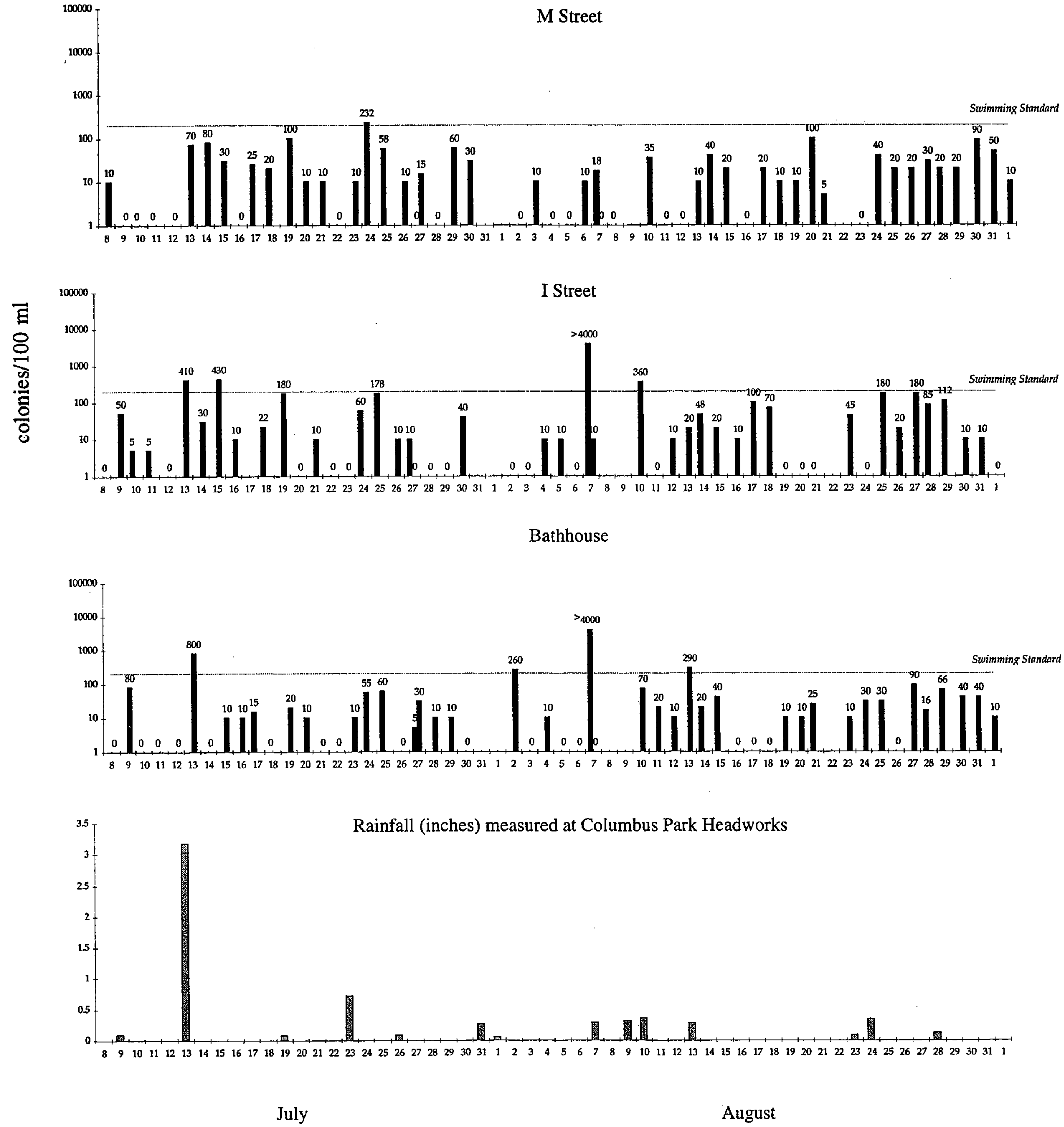


Figure 4: Fecal coliform counts from three locations at Carson Beach and daily rainfall at the Columbus Park headworks facility, 1996.

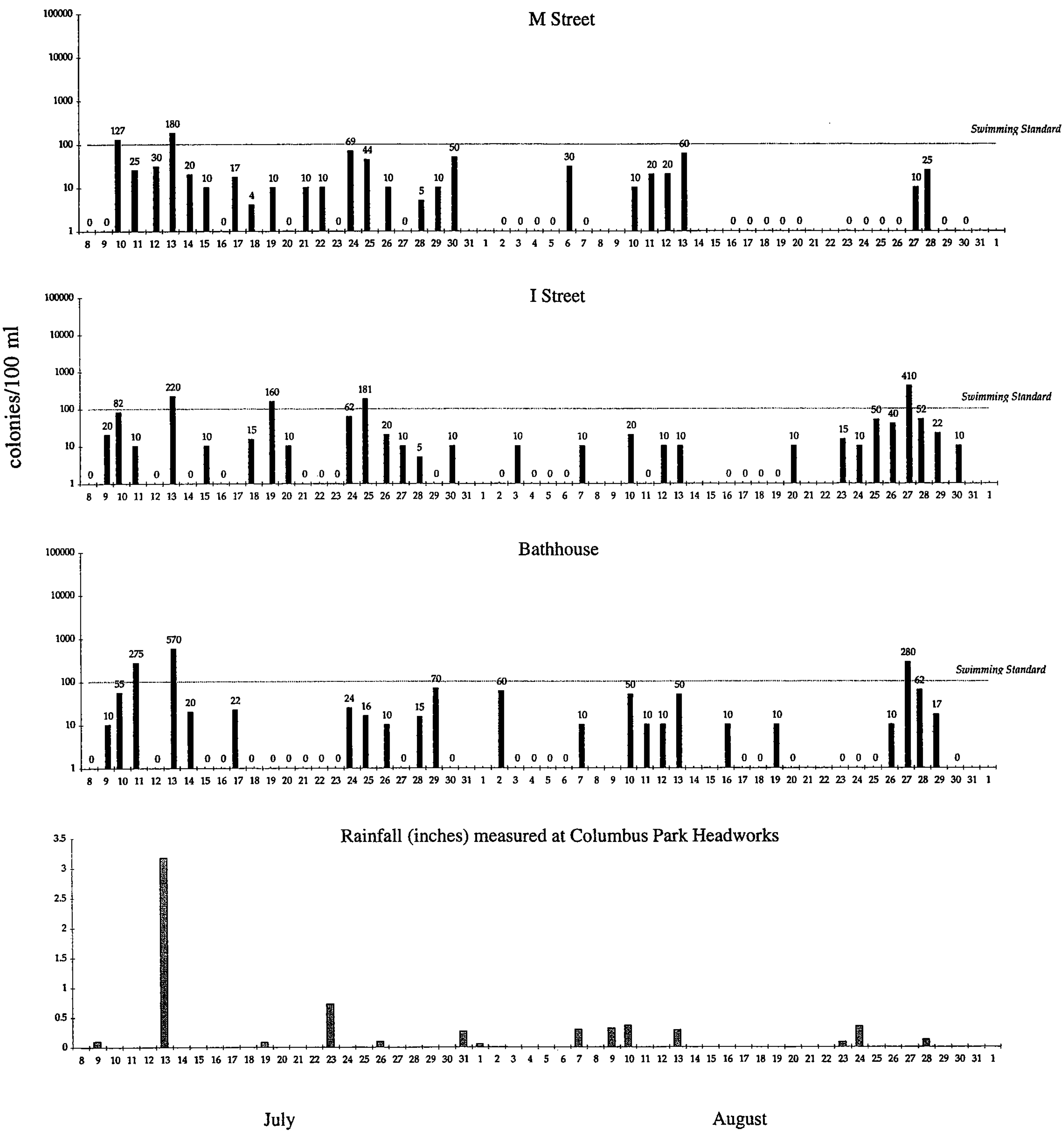


Figure 5: *Enterococcus* counts from three locations at Carson Beach and daily rainfall at the Columbus Park headworks facility, 1996.

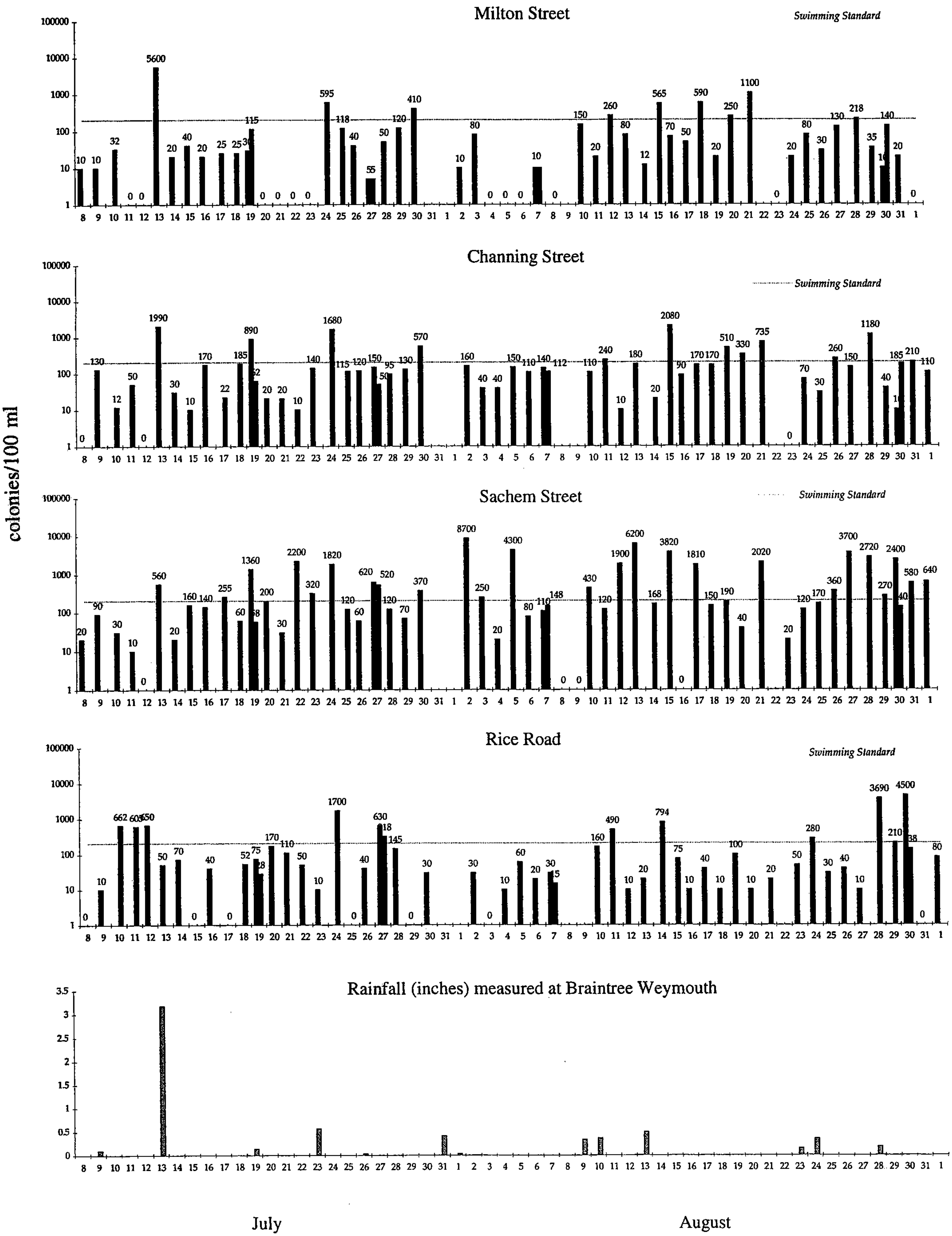


Figure 6: Fecal coliform counts from four locations at Wollaston Beach and daily rainfall at the Braintree Weymouth pumping facility, 1996.

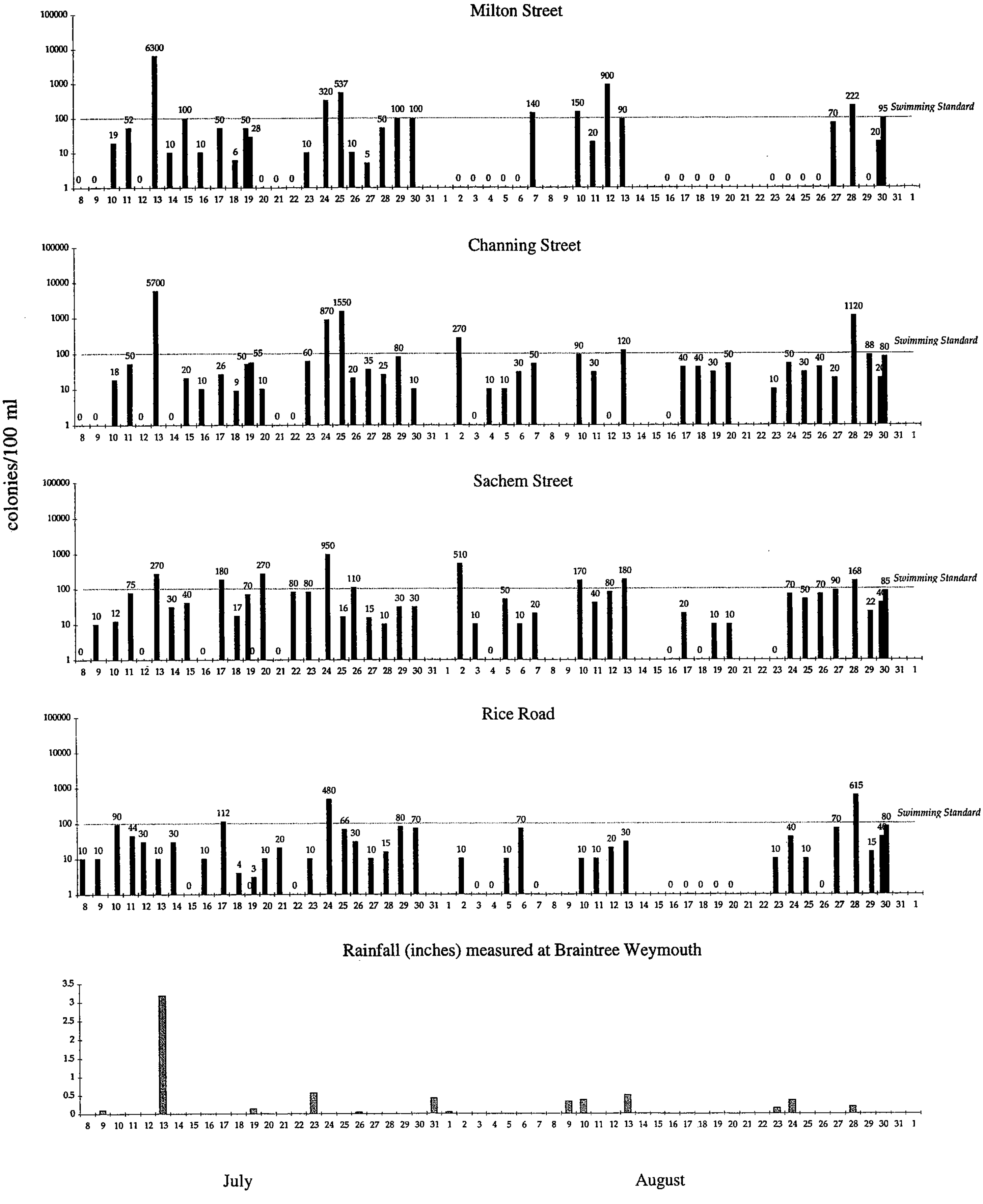


Figure 7: *Enterococcus* counts from four locations at Wollaston Beach and daily rainfall at the Braintree Weymouth pumping facility, 1996.

Contingency tables. The uniformly weak regression analyses and the high numbers of positive samples in dry weather led us to use contingency table analyses to explore whether bacteria violations were in fact related to wet weather. By casting the data into categories, "wet" vs. "dry" and "> standards" vs. "< standards," we can do chi-square tests to determine whether or not significantly more violations occurred in wet weather than would be expected by chance alone. In this study, more samples were collected in dry weather than wet, so it is possible that even if rain were a significant factor, there could be more violations in dry than wet.

Table 8 A-C gives the results of contingency table analyses of rain and bacteria data for the beaches. Not all data points were included in this analysis; only data which were collected on days defined as "dry" or "wet" were used. Constitution Beach was the only beach where there were greater numbers of violations in wet weather and fewer in dry weather for both indicators than would be expected by chance alone at high levels of statistical significance. At Carson Beach, fecal coliform violations were statistically significantly higher in wet weather than dry, but there were not enough (only five) high *Enterococcus* samples to yield meaningful results. At Wollaston Beach, high *Enterococcus* counts were found more frequently in wet weather (and low counts more frequently in dry weather) than expected by chance, but for fecal coliform the relationship of violations with weather was marginal, not strong enough to reject the null hypothesis of no weather effect.

Relationship between tide stage of sampling time and bacteria counts

In order to better understand if the stage of the tide existing when sampling occurred might bias the results, we performed chi-square analyses of the relationship between tide data, cast into two categories,"high" and "low" and bacteria data cast in two categories, "within standards" and "exceeds standards" for each indicator. Table 9 A-C shows the results of these analyses. Except at Constitution Beach for *Enterococcus* samples, there were no statistically significant relationships between bacteria violations and high and low tide. At Constitution Beach, violations of the *Enterococcus* standard were more frequent at low tide. The general lack of relationship to tide only applies to sampling time, not to when CSO or storm drain discharges actually occurred.

Table 8. Contingency table analysis of relationship between bacteria and rainfall at three Boston Harbor beaches.

A. Constitution Beach

Fecal coliform

	Wet	Dry	Totals
≥ 200	*(3.8)* 9	*(7.2)* 2	11
<200	*(29.2)* 24	*(55.8)* 61	85
Totals	33	63	96

Chi square = 12.4, $p = 0.005$

Enterococcus

	Wet	Dry	Totals
≥ 104	*(4.4)* 10	*(7.6)* 2	12
<104	*(25.6)* 20	*(43.4)* 49	69
Totals	30	51	81

Chi square =12.9, $p = 0.0003$

B. Carson Beach

Fecal coliform

	Wet	Dry	Totals
≥ 200	*(2.7)* 7	*(4.3)* 0	7
<200	*(36.3)* 32	*(57.7)* 62	94
Totals	39	62	101

Chi square = 12.0, $p = 0.005$

Enterococcus

	Wet	Dry	Totals
≥ 104	*(1.9)* 3	*(3.1)* 2	5
<104	*(31.1)* 30	*(49.9)* 51	81
Totals	33	53	86

Chi square =1.1, $p = 0.3$ (NS)

C. Wollaston Beach

Fecal coliform

	Wet	Dry	Totals
≥ 200	*(11.7)* 16	*(23.3)* 19	35
<200	*(32.3)* 28	*(64.7)* 69	97
Totals	44	88	132

Chi square = 3.3, $p = 0.07$

Enterococcus

	Wet	Dry	Totals
≥ 104	*(5)* 11	*(9)* 3	14
<104	*(35)* 29	*(63)* 69	98
Totals	40	72	112

Chi square =12.8, $p = 0.0003$

Wet = Two-day summed rain ≥ 0.2 inches, Dry = Three-day summed rain = 0 inches,
≥ 200= Sample had ≥200 fecal coliform/100 ml, <200= Sample had <200 fecal coliform/100 ml
≥ 104 = Sample had ≥ 104 *Enterococcus*/100 ml, <104 = Sample had <104 *Enterococcus*/100 ml
Expected values are in italics, df = 1 for all analyses

Table 9. Contingency table analysis of relationship between bacteria counts and tide.

A. Constitution Beach

Fecal coliform

	Low	High	Totals
≥ 200	*(9.2)* 13	*(12.8)* 9	224
<200	*(59.8)* 56	*(83.2)* 87	143
Totals	69	96	165

Chi square = 3.1, p = 0.08

Enterococcus

	Low	High	Totals
≥ 104	*(9.1)* 14	*(11.9)* 7	21
<104	*(56.9)* 52	*(75.1)* 80	132
Totals	66	87	153

Chi square = 5.5, p = 0.02

B. Carson Beach

Fecal coliform

	Low	High	Totals
≥ 200	*(3.6)* 2	*(6.4)* 8	10
<200	*(54.4)* 56	*(98.6)* 97	153
Totals	58	105	163

Chi square = 1.1, p = 0.28 (NS)

Enterococcus

	Low	High	Totals
≥ 104	*(3.5)* 2	*(6.5)* 8	10
<104	*(48.5)* 50	*(89.5)* 88	138
Totals	52	96	148

Chi square =1.1, p = 0.3 (NS)

C. Wollaston Beach

Fecal coliform

	Low	High	Totals
≥ 200	*(21.7)* 18	*(33.3)* 37	55
<200	*(67.3)* 71	*(103.7)* 100	171
Totals	89	137	226

Chi square = 1.3, p = 0.25 (NS)

Enterococcus

	Low	High	Totals
≥ 104	*(7.8)* 6	*(13.2)* 15	21
<104	*(69.2)* 71	*(115.8)* 114	185
Totals	77	129	206

Chi square = 0.8, p = 0.38 (NS)

≥ 200= Sample had ≥200 fecal coliform/100 ml, <200= Sample had <200 fecal coliform/100 ml
≥ 104 = Sample had ≥ 103 *Enterococcus*/100 ml, <104 = Sample had <104 *Enterococcus*/100 ml
Chi-square expected values are in italics, df = 1 for all analyses

DISCUSSION

The most striking result of this study is the great variability of bacterial water quality at these beaches. Although it has been commonly understood that the worst pollution problems occur after heavy rainstorms, which carry contaminants into the water from storm drains and CSOs, this study showed that dry weather contamination is also a serious issue. Contamination during dry weather was most severe at the two beaches where storm drains discharge onto the beach: Constitution and Wollaston. Dry weather contamination presents a difficult management problem because it is so unpredictable.

Variability in levels of contamination was great, even at locations within a single beach. Wollaston Beach provides the best examples of this: for example on August 2, we recorded a count of 8,700 fecal coliform at Sachem Street and a count of 30 fecal coliform at Rice Road, the adjacent sampling station. This implies the actual bacteria loadings from the source affecting Sachem Street are relatively small. Unfortunately, the source appears to be in the intertidal region, which is where people swim. Samples collected a few hundred yards further into Quincy Bay as part of MWRA's routine monitoring are generally among the cleanest in Boston Harbor (MWRA data 1989-1996).

Bacteria levels at Constitution and Carson beaches decreased rapidly after rainstorms, with elevated counts usually decreasing to swimming standards after one day. Unfortunately, some locations (I Street and Constitution Beach) occasionally showed a lag effect, with increasing bacteria levels up to two days after the storm. The causes for this delayed effect should be explored. It is possible that the physical configuration of the combined sewers at Carson Beach could allow an overflow at a regulator which could be retained in the pipe until washed out in a subsequent tide (pers. communication, P. Keohane BWSC).

Constitution Beach could be severely affected by relatively small rain events, and the rain threshold for posting should be lower than for Carson Beach. Rain intensity, as well as total amount falling should be considered—at Carson Beach a fifteeen minute storm caused extreme high bacteria counts.

Potential further studies:
Other ongoing studies may shed some light on the actual public health risk to swimmers. MWRA is currently collecting samples near Carson Beach and Wollaston Beach as part of a study of anthropogenic viruses in Boston Harbor (Cibik and Margolin 1995). Further analyses could address the correlation between the two bacteria indicators.

The significance of antecedant rain conditions could be explored. Is the quality of combined sewer overflows as important as the quantity? The overflows at Carson Beach during these two months could be modeled and the model results related to bacteria data.

Although rainfall is a major factor affecting contamination at these three beaches, dry weather contamination is a serious problem at two beaches affected by contaminated storm water. Beach monitoring and posting procedures should take into account the effect of rain, the probability of dry weather contamination, and the length of time it takes for the bathing area to return to safe bacteria levels after a rainstorm. Because of the lag time between sampling for bacteria and availability of results, it would be prudent to routinely post beaches after significant rain, rather than waiting for culture results.

RECOMMENDATIONS

General

Rain storms of 0.5 inches or greater should trigger "precautionary" postings at all beaches, except as noted below, for the day following the storm. At beaches without significant dry weather problems remove posting the next day unless the storm was unusually severe. Samples should be collected as soon after the rain as possible, and the following day to confirm the decision.

Constitution Beach

- Continue daily sampling to track effects of remediation
- "Precautionary posting" after even smallest rainstorms for one day

Rationale: A very small amount of rain can affect Constitution Beach, so a conservative approach would be to post the beach after any amount of rain. Daily sampling would enable MDC to "unpost" the beach the next day if the results so indicated. Daily sampling would also highlight the contaminated storm drain and dry weather pollution problems and track their resolution.

Carson Beach

- Formalize communication between Columbus Park Headworks staff and MDC. Columbus Park should notify MDC if choking, or if they note a CSO discharge, or when rain exceeds 0.5 inches in a day.
- "Precautionary" posting if >0.5 inches of rain.
- Continue weekly sampling and during and after rain events until levels within standard
- Explore cause of delayed effect at I Street

Rationale: Dry weather violations very rare, CSOs are the major source of contamination, and are linked to Columbus Park activities.

Wollaston Beach

- "Precautionary" posting if >0.5 inches of rain, but wait for culture results to remove posting.
- Continue daily monitoring to track effects of remediation.
- If early monitoring in 1997 shows continued problems at Sachem St., consider "precautionary" posting of Sachem Street area.

Rationale: Dry weather problems very common at Sachem Street, with fecal coliform violations almost half of days sampled.

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APPENDIX

CONSTITUTION BEACH REGRESSION ANALYSIS: FECAL COLIFORM

Regression Summary

Log Fecal Coliform vs. TWO_DAY_SUM

Count	186
Num. Missing	19
R	.217
R Squared	.047
Adjusted R Squared	.042
RMS Residual	.884

ANOVA Table

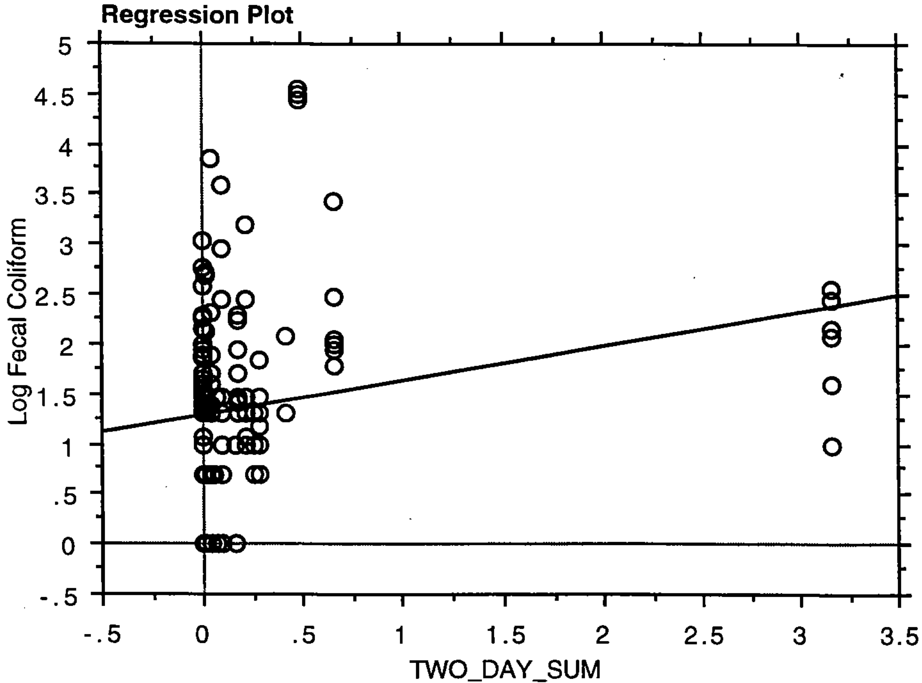
Log Fecal Coliform vs. TWO_DAY_SUM

	DF	Sum of Squares	Mean Square	F-Value	P-Value
Regression	1	7.132	7.132	9.121	.0029
Residual	184	143.883	.782		
Total	185	151.015			

Regression Coefficients

Log Fecal Coliform vs. TWO_DAY_SUM

	Coefficient	Std. Error	Std. Coeff.	t-Value	P-Value
Intercept	1.299	.068	1.299	19.076	<.0001
TWO_DAY_SUM	.347	.115	.217	3.020	.0029



Y = 1.299 + .347 * X; R^2 = .047

Figure A1

CONSTITUTION BEACH REGRESSION ANALYSIS: ENTEROCOCCUS

Regression Summary
Log Enterococcus vs. TWO_DAY_SUM

Count	162
Num. Missing	43
R	.316
R Squared	.100
Adjusted R Squared	.094
RMS Residual	.905

ANOVA Table
Log Enterococcus vs. TWO_DAY_SUM

	DF	Sum of Squares	Mean Square	F-Value	P-Value
Regression	1	14.506	14.506	17.726	<.0001
Residual	160	130.935	.818		
Total	161	145.440			

Regression Coefficients
Log Enterococcus vs. TWO_DAY_SUM

	Coefficient	Std. Error	Std. Coeff.	t-Value	P-Value
Intercept	.874	.075	.874	11.652	<.0001
TWO_DAY_SUM	.498	.118	.316	4.210	<.0001

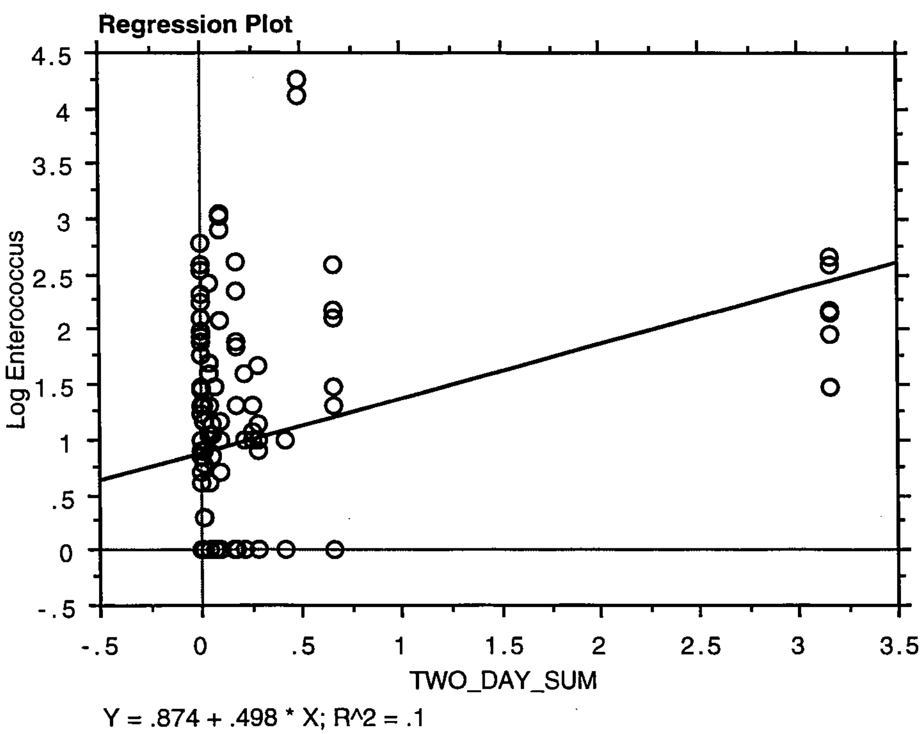


Figure A2

CARSON BEACH REGRESSION ANALYSIS: FECAL COLIFORM

Regression Summary
Log Fecal Coliform vs. TWO_DAY_SUM

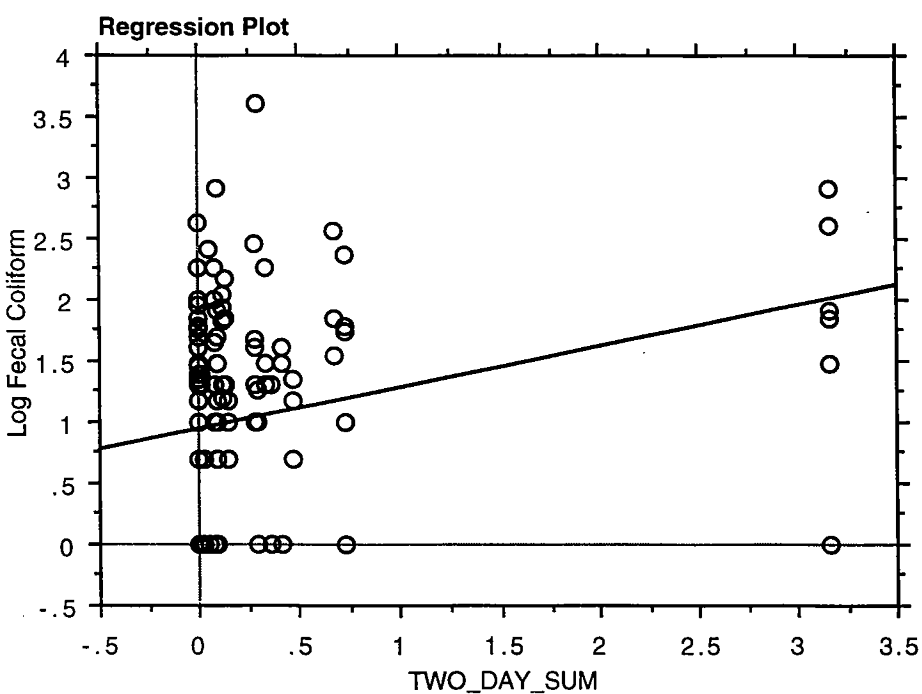
Count	179
Num. Missing	26
R	.238
R Squared	.057
Adjusted R Squared	.051
RMS Residual	.797

ANOVA Table
Log Fecal Coliform vs. TWO_DAY_SUM

	DF	Sum of Squares	Mean Square	F-Value	P-Value
Regression	1	6.747	6.747	10.619	.0013
Residual	177	112.459	.635		
Total	178	119.206			

Regression Coefficients
Log Fecal Coliform vs. TWO_DAY_SUM

	Coefficient	Std. Error	Std. Coeff.	t-Value	P-Value
Intercept	.953	.063	.953	15.034	<.0001
TWO_DAY_SUM	.335	.103	.238	3.259	.0013



Y = .953 + .335 * X; R^2 = .057

Figure A3

CARSON BEACH REGRESSION ANALYSIS: ENTEROCOCCUS

Regression Summary
Log Enterococcus vs. TWO_DAY_SUM

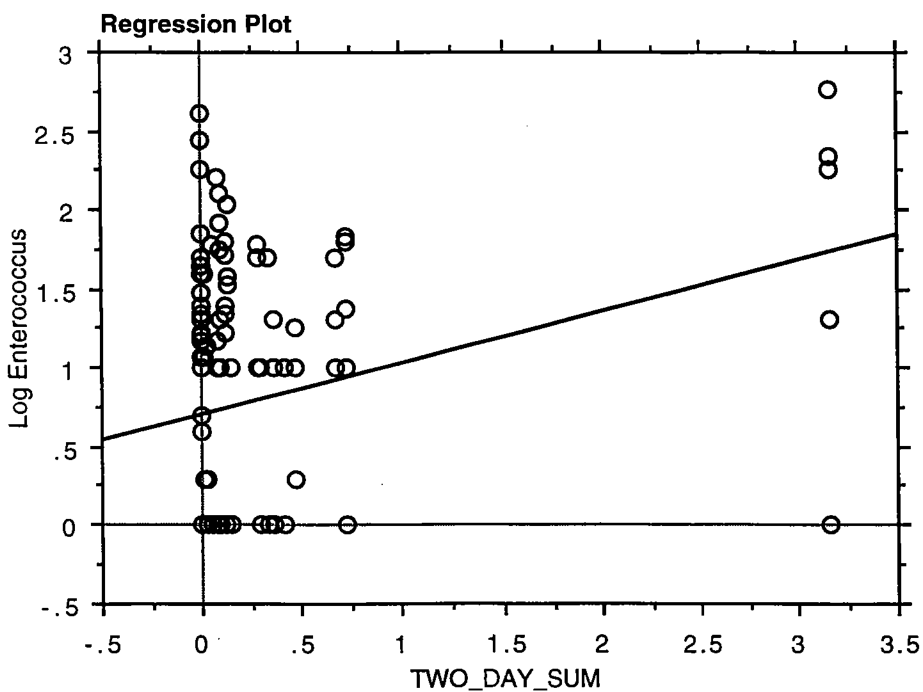
Count	155
Num. Missing	50
R	.267
R Squared	.071
Adjusted R Squared	.065
RMS Residual	.731

ANOVA Table
Log Enterococcus vs. TWO_DAY_SUM

	DF	Sum of Squares	Mean Square	F-Value	P-Value
Regression	1	6.259	6.259	11.729	.0008
Residual	153	81.649	.534		
Total	154	87.908			

Regression Coefficients
Log Enterococcus vs. TWO_DAY_SUM

	Coefficient	Std. Error	Std. Coeff.	t-Value	P-Value
Intercept	.708	.063	.708	11.316	<.0001
TWO_DAY_SUM	.325	.095	.267	3.425	.0008



Y = .708 + .325 * X; R^2 = .071

Figure A4

WOLLASTON BEACH REGRESSION ANALYSIS: FECAL COLIFORM

Regression Summary
Log Fecal Coliform vs. TWO_DAY_SUM

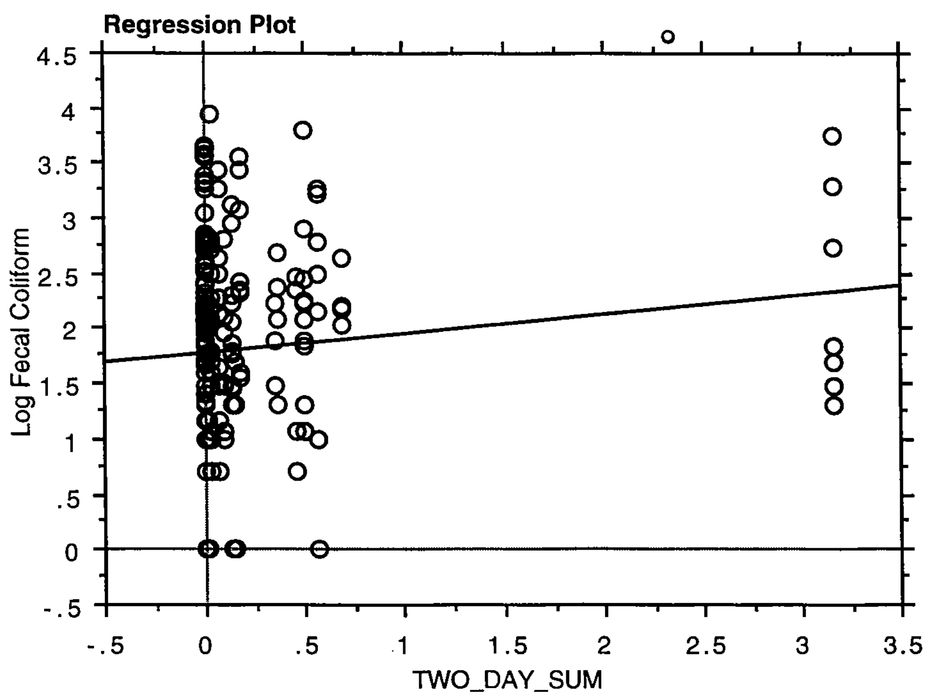
Count	250
Num. Missing	23
R	.112
R Squared	.012
Adjusted R Squared	8.450E-3
RMS Residual	.915

ANOVA Table
Log Fecal Coliform vs. TWO_DAY_SUM

	DF	Sum of Squares	Mean Square	F-Value	P-Value
Regression	1	2.617	2.617	3.122	.0785
Residual	248	207.846	.838		
Total	249	210.462			

Regression Coefficients
Log Fecal Coliform vs. TWO_DAY_SUM

	Coefficient	Std. Error	Std. Coeff.	t-Value	P-Value
Intercept	1.779	.061	1.779	29.055	<.0001
TWO_DAY_SUM	.180	.102	.112	1.767	.0785



Y = 1.779 + .18 * X; R^2 = .012

Figure A5

WOLLASTON BEACH REGRESSION ANALYSIS: ENTEROCOCCUS

Regression Summary
Log Enterococcus vs. TWO_DAY_SUM

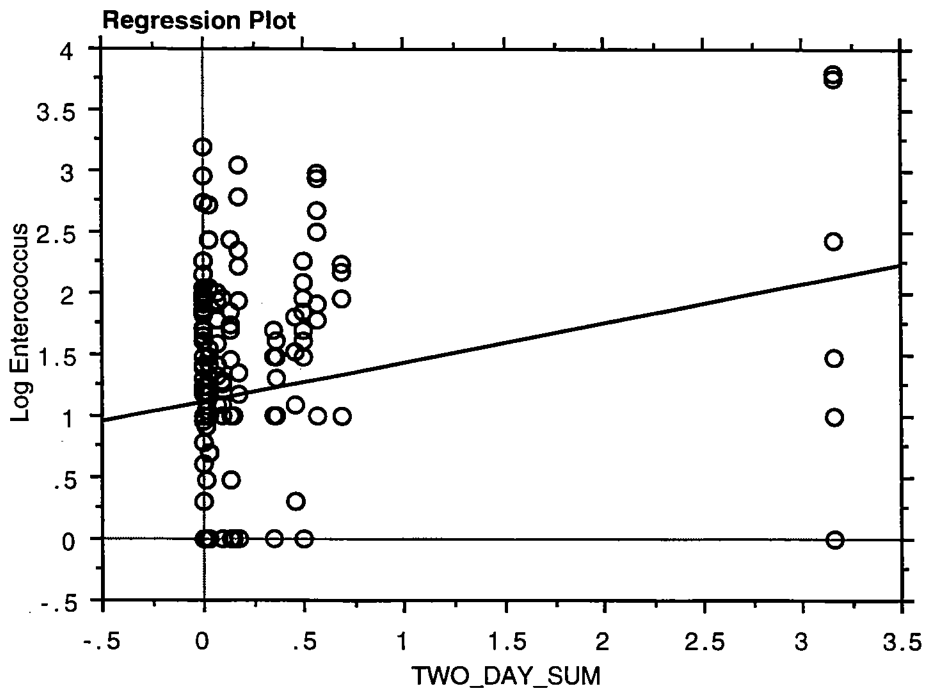
Count	218
Num. Missing	55
R	.227
R Squared	.051
Adjusted R Squared	.047
RMS Residual	.839

ANOVA Table
Log Enterococcus vs. TWO_DAY_SUM

	DF	Sum of Squares	Mean Square	F-Value	P-Value
Regression	1	8.225	8.225	11.691	.0008
Residual	216	151.968	.704		
Total	217	160.194			

Regression Coefficients
Log Enterococcus vs. TWO_DAY_SUM

	Coefficient	Std. Error	Std. Coeff.	t-Value	P-Value
Intercept	1.115	.060	1.115	18.510	<.0001
TWO_DAY_SUM	.322	.094	.227	3.419	.0008



Y = 1.115 + .322 * X; R^2 = .051

Figure A6

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