Statistical analysis of combined sewer overflow receiving water data, 1989-1995

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Statistical Analysis of Combined Sewer Overflow Receiving Water Data, 1989-1995

for

MWRA Harbor and Outfall Monitoring Project

submitted to

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1.0 INTRODUCTION

1.1 Background

Since 1989, the Massachusetts Water Resources Authority (MWRA) has performed water quality measurements in areas of Boston Harbor and the Mystic, Charles, and Neponset Rivers which are likely to be affected by combined sewer overflows (CSOs). Under this ongoing monitoring program, samples are collected and analyzed for densities of two sewage indicator bacteria, fecal coliform and *Enterococcus*, as well as for temperature, salinity, and dissolved oxygen. Sewage indicator bacteria in the CSO receiving water system (i.e., Boston Harbor and its tributary rivers) originate primarily from raw sewage that is released from CSO discharges during rainfall events, or from storm drains that have been contaminated with sewage.

This report investigates the issue of whether or not a statistically significant decrease in sewage indicator bacteria counts has occurred within the CSO receiving water system since the inception of the monitoring program. During this time period, a number of modifications and improvements to the MWRA sewer system have been implemented, intended to decrease the amount of raw sewage entering Boston Harbor. For example, two screening and chlorination plants have been constructed, an effort has been made to locate and remove illegal sewage connections to storm drains, and CSO tidegates are being inspected and maintained in good working order. Such improvements should lead to a systematic decrease in receiving water bacteria counts, i.e., some sort of statistically significant temporal trend should be discernable, which is correlated to known CSO system improvements.

1.2 Characteristics of the Data

This report utilizes CSO receiving water data that were collected between 1989 and 1995, and analyzed for counts of fecal coliform and *Enterococcus*. A total of 7496 fecal coliform and 7096 *Enterococcus* sample counts are available for this study, comprised of surface samples throughout the receiving water system and bottom samples for stations in the tributary rivers only. The recorded tidal condition and sampling date for each sample were also used, and daily rainfall data at Logan Airport over this time period were obtained from the National Weather Service. A comprehensive description of the monitoring program is provided in the MWRA CSO Receiving Water Monitoring report (Rex, 1991).

A total of 130 sampling stations were utilized in this study. Station locations are shown in Figure 1-1. Due to the broad spatial coverage of the stations, samples could not be collected synoptically at all stations over a given time period. Also, the most intensive sampling occurred during warm weather periods; during colder weather, sampling was limited to those unfrozen waters easily accessible from shore. Few stations have data over the entire 1989-1995 period, and those that were sampled each year were not necessarily sampled in the same month each year. What results is a highly unevenly distributed data set, both spatially and temporally.

In addition to the irregular sampling intervals, the samples comprising the data set were collected under highly variable environmental conditions, which may influence sewage indicator bacteria counts. Examples of physical parameters which influence receiving water bacteria counts include rainfall, tidal state, geographic location, and temperature. In particular, bacteria counts are expected to be strongly related to rainfall, since raw sewage discharges occur primarily when stormwater runoff causes the capacity of the combined sewer/stormwater drainage and treatment system to be exceeded.

1.3 Previous Work

As part of their CSO Receiving Water Monitoring program, MWRA has produced annual reports summarizing the water quality within the receiving water system with respect to sewage indicator bacteria (Rex, 1991, 1993). These reports incorporate anthropogenic and environmental factors to help assess relationships between the variables that influence water quality, in particular the relationship between rainfall and bacteria counts. However, these reports focus on existing conditions in specific geographic areas within the receiving water system, and how they compare with water quality standards. Solow (1993) conducted a preliminary study on long term changes in the rainfall-bacteria count relationship at individual sampling stations. This report represents a more comprehensive attempt to assess interannual variability in bacteria counts, and to correlate the changes to improvements in the CSO drainage and discharge system.

1.4 Study Objectives

Both the irregular nature of the sampling program and the various physical parameters involved in the complex CSO receiving water system present a challenge to analyzing the impact of improvements to the CSO drainage and treatment system on sewage indicator bacteria counts. Statistical techniques are developed in this study to account for limited and highly variable data, and to isolate the effect of systemwide improvements implemented during the period from 1989-1995. The objective is to select and apply statistical methods suitable for answering the question: has CSO receiving water quality improved despite natural variations in rainfall and other environmental factors, and if so at what level of statistical significance?

1.5 Organization of this Report

Following this introduction (Section 1), Section 2 of this report describes the basic analytical approach that was followed to develop an appropriate statistical analysis given the characteristics and constraints of the available data. The selected statistical methodology, a Factorial Analysis of Variance using Randomized Blocks, is described in Section 3. Section 4 contains a brief summary of the procedure used to carry out the analysis. The results of the statistical analysis for both fecal coliform and *Enterococcus* are presented in Section 5. Finally, conclusions are presented in Section 6.

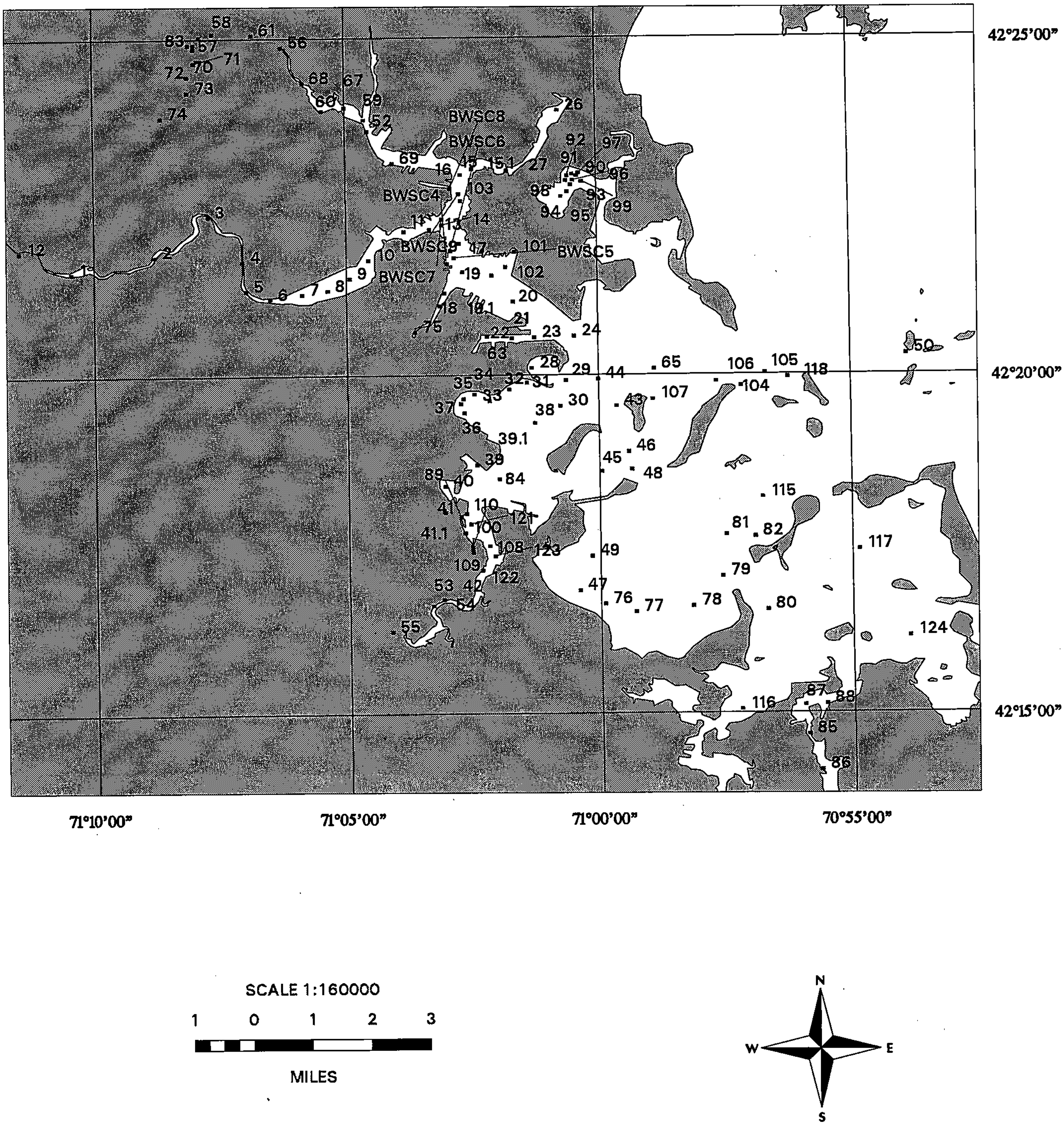

Figure 1-1

CSO Receiving Water Stations

2.0 ANALYTICAL APPROACH

Previous analyses of CSO receiving water quality have focused primarily on the relationship between sewage indicator bacteria counts and rainfall at individual stations, using basic statistical techniques such as linear regression (Rex, 1993). Linear regression is a simple and straightforward technique; it can easily be extended to assess changes in water quality over time by comparing the regressed bacteria count-rainfall relationship obtained for different years. Unfortunately, the irregular nature of the available data set and the need to account for competing environmental factors make it difficult to reliably define a rainfall-bacteria relationship at an individual station, much less to detect statistically significant changes in the regression relationship from year to year. Although rainfall is likely to have the greatest influence on bacteria counts, other variables such as tides, geography and seasonality also exert considerable influence.

The analytical approach chosen for the present study concentrates instead on testing the basic hypothesis that sewage indicator bacteria counts have decreased during the period from 1989-1995, when the effects of all known environmental variables have been accounted for. Assuming that some unknown environmental factor is not responsible, this hypothesis then implies that improvements to the CSO drainage and treatment system is responsible for any observed decrease. Since this approach does not attempt to identify functional relationships between bacterial counts and rainfall at individual stations, all samples can be devoted to testing this basic hypothesis. Consideration of this fundamental question alone increases the potential for obtaining a statistically significant result. Two important facets of this analytical approach are the consideration of the entire CSO receiving water system within the scope of the analysis, and the identification of key variables which affect receiving water bacteria counts.

2.1 Consideration of the Entire CSO Receiving Water System

This analysis seeks to detect statistically significant decreases in bacteria counts at all CSO receiving water stations considered as a whole, instead of focusing on individual stations or local groups of stations. Consideration of the entire CSO receiving water system utilizes all available data, which allows for a more powerful statistical analysis than one which only uses the fewer data available for individual stations. The tradeoff of this approach is that detailed hypotheses about specific portions of the vast Boston Harbor/tributary rivers system cannot be tested.

Previous analyses of CSO receiving water data have shown that more data need to be collected over a longer period of time to detect statistically significant changes at individual stations (Rex, 1991, 1993; Solow, 1993). By stepping back to a regional scale that looks at all stations considered together, the ability of an analysis to provide statistically significant results improves, since more data are utilized. Although detailed questions such as whether bacteria counts immediately downstream of a newly expanded treatment plant have decreased cannot be answered by such an approach, the simpler question of whether bacteria counts within the entire CSO receiving water system have decreased can be answered with greater reliability.

2.2 Identification of Key Variables Affecting Sewage Indicator Bacteria Counts

In a system as complex as Boston Harbor and its tributary rivers, a multitude of variables can potentially impact sewage indicator bacteria counts. Examples range from human-induced system improvements, to weather conditions (e.g., rainfall, temperature, and sunlight), to hydrodynamic flow and transport patterns. To include all possible factors would be virtually impossible without incorporating sophisticated mathematical and physical modeling techniques. Therefore, this statistical analysis focuses only on certain key variables. Key variables are defined as those which are expected to account for most of the variability in sewage indicator bacteria counts, and for which reliable sample data are available. Five key variables identified for this study are listed and briefly described below.

- Sampling Year. This is the fundamental variable of interest for this study, since the objective is to determine statistically significant interannual decreases in bacteria counts over the seven year period of study, from 1989 to 1995. Samples collected during the later years of this period should have lower bacteria counts than samples collected in early years, once competing environmental variables have been accounted for.

- Rainfall. Increased bacteria counts are expected to be strongly correlated to rainfall events, since CSO discharges principally occur when the addition of stormwater runoff exceeds existing treatment capacities. A lag time may exist between the incidence of a rain event over the sewer system and the responding bacteria count increase in the receiving water rivers, and in particular Boston Harbor. Counts should be lowest during dry periods, and increase in response to rainfall events of increasing intensity. Daily rainfall data at Logan Airport were obtained from the National Weather Service.

- Geographic Location. Different regions within the CSO receiving water system may exhibit different bacteria count characteristics, due to a variety of physical reasons. Certain water bodies may receive a greater CSO discharge volume than others. The condition of the sewerage network and the existence of treatment facilities is not consistent throughout the system. Differences between river, estuarine, and oceanic mixing patterns are also likely to affect regional bacteria counts. Precise station location information is available for each sampling station.

- Tidal Condition. Sample bacteria counts are likely to vary with the tidal condition at the time of sampling. Flood tides introduce a substantial amount of oceanic mixing and dilution, increase the salinity of the receiving water, induce transport of bacteria, and may potentially inhibit CSO discharges by keeping tide gates shut. In addition, only sampling stations located in or near Boston Harbor will be influenced by tides, while stations located in tributary rivers upstream of dams will not be subject to any tidal effects. Tidal condition information was recorded for every sample collected.

- Seasonality. Intra-annual seasonality effects can influence water bacteria counts in a number of ways. Temperature and salinity within the receiving waters can vary considerably throughout the course of the year. Factors such as spring snowmelt runoff may affect the amount of freshwater input and dilution. Precipitation patterns and intensities vary throughout the year, which affects the likelihood of CSO discharges. For this study, the month in which the sample was collected is used as the variable to account for overall seasonal variations in bacteria counts.

Of these five key variables affecting CSO receiving water bacteria counts, the sampling year and rainfall parameters are considered the primary variables of interest for this study. The sampling year is the variable which will be used to assess interannual decreases in bacteria counts, and rainfall is expected to be the single most influential variable in the CSO system.

Following this approach, an appropriate statistical methodology is developed in Section 3 that considers the entire CSO receiving water system as a whole, and focuses on sampling year and rainfall while systematically accounting for variations in bacteria counts due to geographic location, tidal condition and seasonality.

3.0 STATISTICAL METHODOLOGY

3.1 Factorial Analysis of Variance using Randomized Blocks

In accordance with the analytical approach described in Section 2, a statistical methodology has been developed to detect statistically significant reductions in sewage indicator bacteria counts within CSO receiving waters, over interannual time scales. The methodology is derived from classical analysis of variance (ANOVA) and experimental design techniques. It consists of two components, a factorial ANOVA and a partitioning of the data set using randomized blocks.

Factorial ANOVA

A factorial ANOVA is based on the concept of *experimental factors*, variables which potentially have an effect on the measured dependent variable of the analysis. For this study, the five key variables listed in Section 2.2 are considered as the relevant experimental factors. The dependent variables are calculated as

$$\ln(FC+1); \qquad \ln(EN+1)$$

where FC and EN are the sample fecal coliform and *Enterococcus* counts, respectively, in units of counts per 100 ml. The analysis is similar to a standard ANOVA, except that more than one experimental factor can be incorporated into the analysis, whereas a standard ANOVA only allows for one factor. To facilitate the analysis, each experimental factor is partitioned into a small number of discrete categories, or levels (e.g., no rainfall, light rainfall, and heavy rainfall). The number and definition of these levels for an experimental factor can vary based on the nature of the data and the goals of the analysis. The factor levels assigned to each of the five variables in this study will be discussed in Sections 3.2 and 3.3.

Although all five factors are likely to impact bacteria counts, the performance of an ANOVA generally decreases as the number of factors and factor levels is increased. Maintaining a small number of well defined categories simplifies the tested hypothesis, and thus increases the power and robustness of the analysis. For this reason, there is merit to including only the most essential factors, and maintaining broad factor levels, in the ANOVA. In Section 2, the primary variables of interest were identified as sampling year and rainfall. Therefore only these two experimental factors are retained in the ANOVA. The total number of factor level combinations obtained from the sampling year and rainfall variables determines the number of *treatments* contained in the factorial ANOVA. The various treatments are then compared using classical ANOVA techniques, which test hypotheses involving statistically significant differences between treatment means.

Data Partitioning using Randomized Blocks

The effects of the experimental factors not contained in the ANOVA treatments can be accounted for by partitioning the data into groups called *randomized blocks* prior to performing the factorial ANOVA. Each block should contain data that are as similar as possible with respect to the environmental factors and levels not accounted for in the ANOVA treatments. In this study, three secondary experimental factors have been identified that are not distinguished by the ANOVA treatments: geographic location, tidal condition, and seasonality. Each randomized block should therefore contain all data from a single factor level combination of these three secondary variables. The total number of possible factor level combinations determines the number of randomized blocks.

With the data partitioned in such a manner, most of the variability in the dependent variable (i.e., natural logarithm of bacteria counts) within a block is due to the treatments being analyzed in the ANOVA. Variability associated with the secondary environmental variables is thus reduced to differences between each block, which can be accounted for in the factorial ANOVA.

Within a block, data falling under each ANOVA treatment category are averaged together, and the averaged values are treated as a single replicate by the factorial ANOVA. Thus the ANOVA analysis does not compare means calculated directly from all data points for a treatment, as is done in a standard ANOVA. Rather, the means are calculated from individual values representing each randomized block, which themselves are averaged together from all appropriate data points within the block. Each of the randomized blocks is therefore given equal weight in the ANOVA, regardless of how many data points fall into that block.

For an ideal randomized blocks design the ANOVA treatments should be randomly distributed over all values within a block, so that there are no systematic biases with respect to the factors that have been omitted from the analysis. Usually, this is accomplished by experimental design. For this study, sample data have already been collected, and data are assigned to blocks after the fact. However, a considerable amount of freedom exists regarding the partitioning of the data, so that a random distribution can be approximated. The general idea is to distribute all available data among the various blocks and treatments as evenly as possible.

Clearly the success of this analysis is dependent upon the ability of the randomized blocking scheme to account for all variability in the bacteria count data due to factors other than sampling year and rainfall. By carefully grouping the available data using well defined blocking categories, the chances of detecting statistically significant interannual changes in bacteria counts can be maximized. Nevertheless, complications can arise during the blocking process, such as blocks with no data points for a particular treatment, or blocks with highly variable numbers of data points for different treatments. Estimation procedures have been developed to account for these issues, as described in Section 4.

The factorial ANOVA using randomized blocks technique is designed to investigate the subtle effects of a number of interacting variables (Scheffe, 1959; Kendall and Stuart, 1976). The methodology still falls within the realm of classical statistics, however, and has the benefit of being thoroughly tested in numerous applications. (Snedecor and Cochran, 1989).

3.2 Selection of Treatments

The sampling year and rainfall variables are considered as the two experimental factors for this factorial ANOVA analysis. Sampling year was divided into two levels and rainfall was divided into three levels, resulting in a total of six treatments. The selected levels are summarized in Table 3-1, and they are briefly described below.

Sampling Year

Seven years of sampling data were utilized in this study, from June 1989 through September 1995. The sampling year variable was divided into two levels, 1989-1991 which represents conditions prior to most system improvements, and 1992-1995 which represents conditions after some system improvements were implemented. Examples of system improvements include general operational improvements such as more reliable pumping at the Deer Island treatment plant, cessation of sludge discharge into the harbor, improved disinfection at both Deer and Nut Island treatment plants, reduction in treatment plant "bypasses," and community work to eliminate illegal sewer connections into storm drains. More specific CSO-related improvements included elimination of "dry weather overflows," improved inspection and maintenance of tidegates, and construction and operation of two SCO treatment facilities.

Rainfall

It was mentioned previously that bacteria counts are strongly related to rainfall, but that antecedent conditions before the event affect the bacteria response in receiving waters. Therefore three days of rainfall were associated with each sample, consisting of the sampling date plus the two previous days. Furthermore, the actual rainfall parameter used for the study was the root-mean-square (RMS) of the three days of rainfall values, which is calculated as:

$$RMS=\sqrt{(R_1)^2+(R_2)^2+(R_3)^2}$$

where RMS = Root-mean-square of three days of rainfall [in]
R_1 = Daily rainfall during sampling date [in]
R_2 = Daily rainfall one day prior sampling date [in]
R_3 = Daily rainfall two days prior to sampling date [in]

This parameter places greater weight on high intensity events, which are more likely to result in CSO discharges. In other words, by using the RMS a given amount of rainfall distributed evenly over three days is given less weight than the same amount of rainfall concentrated in one of the three days.

This RMS rainfall variable was divided into three levels: dry conditions, light rain, and heavy rain. RMS values of 0 inches (i.e., no rain over the past three days) were considered dry. RMS values between 0 and 0.25 inches were placed in the light rain level. RMS values greater than 0.25 inches were considered as heavy rain. Note that the RMS rainfall parameter yields values that are always smaller than the straight sum of rainfall over the three day period. The selected RMS rainfall levels were chosen to realistically represent different rainfall conditions while distributing the available data as evenly as possible over all three levels.

3.3 Selection of Randomized Blocks

The geographic location, tidal condition and seasonality variables are used to divide the sample data into randomized blocks. A total of eight geographic locations were identified, and the tidal condition and seasonality factors were each split into three levels. The selected levels are summarized in Table 3-1, and they are briefly described below.

Geographic Location

Geographic locations were selected by grouping together sampling stations that resided in the same regional water body within the CSO receiving waters. The various rivers and estuaries within the receiving water system can have noticeably different physical characteristics and CSO discharge loads. A sufficient amount of data had to be available for each location, which restricted the delineation of the water bodies to fairly broad regions. The location of dams along tributary rivers also affected the selection of geographic locations, since there is no tidal influence upstream of dams.

The eight geographic locations are presented in Figure 3-1. Note that the Charles River was split into upper and lower portions, since the lower Charles River Basin is much wider than the narrow upper portion, and there are ample sample data for the entire river. Both Charles River regions, as well as the Mystic River and Neponset Headwaters regions consist of sampling stations which recorded no tidal influence.

Tidal Condition

For each collected CSO receiving water sample, one of the following tidal condition categories was recorded:

1 High Slack Tide
2 High Ebb Tide
3 Low Ebb Tide
4 Low Slack Tide
5 Low Flood Tide
6 High Flood Tide

9 Freshwater Above Tidal Influence

For this analysis three tidal condition levels were distinguished, high tide, low tide and freshwater. Samples assigned values 1, 2, or 6 were grouped together as the high tide level. Samples with 3, 4, or 5 were assigned to the low tide level. Samples with a 9 were placed in the freshwater level.

Seasonality

The sample data were split into three temporal seasonality levels. The fall/winter season consists of samples collected from September through April, the spring season consists of May and June samples, and the summer season consists of July and August samples. These seasonality levels were developed to capture natural seasonal differences, and also to distribute the available data evenly among the three levels. Since most sampling occurred during warm weather months, the spring and summer seasonality levels are of shorter duration than the fall/winter level.

The two sampling year levels and three rainfall levels discussed in Section 3.2 yield a total of 2 x 3 = 6 ANOVA treatments. All possible combinations of the eight geographic location, three tidal condition and three seasonality variables yield the total number of randomized blocks, which are listed in Table 3-2. Note that a total of 36 blocks are obtained, which is considerably less than the total number of 8 x 3 x 3 = 72 block level combinations. This is because only one or two of the three tidal conditions can exist at any one geographic location. Regions which are tidally influenced fall under high tide or low tide, but do not have any stations with no tidal influence. Conversely, regions located upstream of dams fall only under the no tidal influence category.

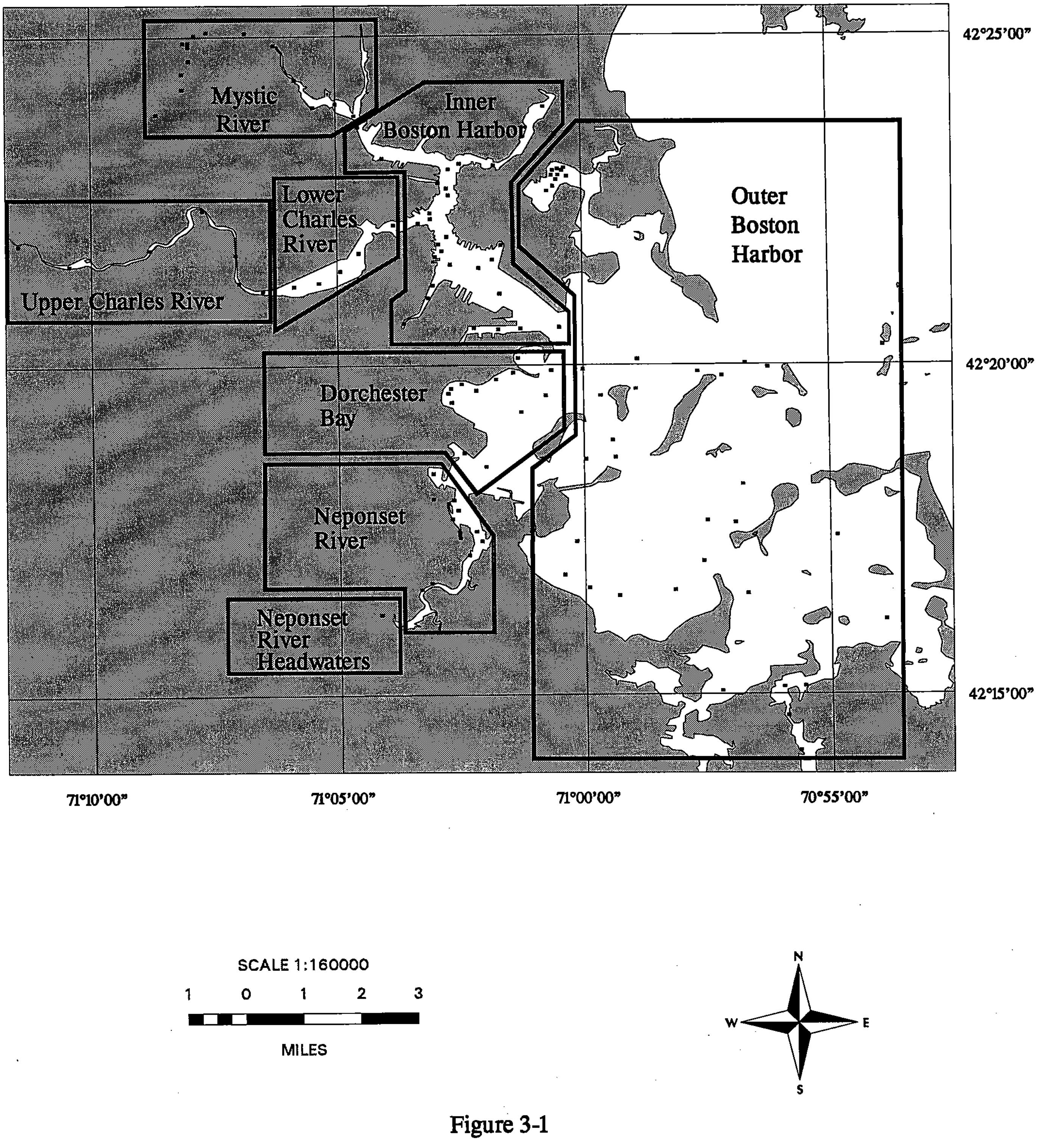

Figure 3-1

Geographic Locations for Randomized Blocks Partitioning

Table 3-1
Experimental Factor and Randomized Block Variable Levels for Factorial ANOVA

Variable	Number of Factor Levels	Factor Level Descriptions
Experimental Factors		
Sampling Year	2	1989-1991 (Before CSO system improvements)
		1992-1995 (After CSO system improvements)
Root-mean-square of 3 day rainfall (RMS)	3	RMS = 0 in
		RMS between 0 and 0.25 in
		RMS greater than 0.25 in
Randomized Blocks		
Geographic Location	8	Upper Charles River
		Lower Charles River
		Mystic River
		Neponset River Headwaters
		Neponset River
		Dorchester Bay
		Inner Boston Harbor
		Outer Boston Harbor
Tidal Condition	3	High Tide (above mean water level)
		Low Tide (above mean water level)
		Freshwater above Tidal Influence
Season	3	Fall/Winter (September-April)
		Spring (May-June)
		Summer (July-August)

Table 3-2
Randomized Blocks for Factorial ANOVA

Block Number	Environmental Variables		
	Geographic Region	Tidal Condition	Season
1	Upper Charles River	Freshwater	Fall/Winter
2	Upper Charles River	Freshwater	Spring
3	Upper Charles River	Freshwater	Summer
4	Lower Charles River	Freshwater	Fall/Winter
5	Lower Charles River	Freshwater	Spring
6	Lower Charles River	Freshwater	Summer
7	Mystic River	Freshwater	Fall/Winter
8	Mystic River	Freshwater	Spring
9	Mystic River	Freshwater	Summer
10	Neponset River Headwaters	Freshwater	Fall/Winter
11	Neponset River Headwaters	Freshwater	Spring
12	Neponset River Headwaters	Freshwater	Summer
13	Neponset River	High Tide	Fall/Winter
14	Neponset River	High Tide	Spring
15	Neponset River	High Tide	Summer
16	Neponset River	Low Tide	Fall/Winter
17	Neponset River	Low Tide	Spring
18	Neponset River	Low Tide	Summer
19	Dorchester Bay	High Tide	Fall/Winter
20	Dorchester Bay	High Tide	Spring
21	Dorchester Bay	High Tide	Summer
22	Dorchester Bay	Low Tide	Fall/Winter
23	Dorchester Bay	Low Tide	Spring
24	Dorchester Bay	Low Tide	Summer
25	Inner Boston Harbor	High Tide	Fall/Winter
26	Inner Boston Harbor	High Tide	Spring
27	Inner Boston Harbor	High Tide	Summer
28	Inner Boston Harbor	Low Tide	Fall/Winter
29	Inner Boston Harbor	Low Tide	Spring
30	Inner Boston Harbor	Low Tide	Summer
31	Outer Boston Harbor	High Tide	Fall/Winter
32	Outer Boston Harbor	High Tide	Spring
33	Outer Boston Harbor	High Tide	Summer
34	Outer Boston Harbor	Low Tide	Fall/Winter
35	Outer Boston Harbor	Low Tide	Spring
36	Outer Boston Harbor	Low Tide	Summer

4.0 SUMMARY OF ANALYTICAL PROCEDURE

This section provides a brief summary of the procedure that was followed to perform the factorial ANOVA using randomized blocks. In addition to highlighting the various steps executed during the analysis, a number of issues raised during the course of the analysis are discussed.

- Partition data among all blocks and treatments. Partition all data into the 36 randomized blocks developed in Section 3.3. Within each block, partition the data into the six treatments developed in Section 3.2. Each block/treatment combination is called a cell. Table 4-1 presents the distribution of all 7496 fecal coliform data points into the resulting 36 x 6 = 216 cells. Table 4-2 presents the distribution of all 7096 *Enterococcus* data points into the same 216 cells.

- Remove blocks with minimal data. In Table 4-1, 23 out of the 216 fecal coliform cells do not have any data points. In Table 4-2, 26 out of the 216 *Enterococcus* cells do not have any data points. For both bacteria, some blocks contain relatively few data points, and contain multiple cells with zero data points. Based on this information, blocks with fewer than 100 data points and more than one zero cell are removed from the analysis. Blocks which are removed are indicated in Tables 4-1 and 4-2.

  This procedure reduces the number of zero data cells that subsequently need to be estimated, without sacrificing a large amount of data. Also, by removing entire blocks the quality of the blocking scheme is not compromised. For fecal coliform, 5 blocks containing 15 out of the 23 zero cells (65%) and 231 out of the 7496 data points (3.1%) are removed. For *Enterococcus*, 5 blocks containing 15 out of the 26 zero cells (58%) and 229 out of the 7096 data points (3.2%) are removed.

- Average data points within a cell. All data points within a cell are averaged together to obtain a single value for each cell.

- Estimate values for cells with no data points. For cells with no data points, a value is estimated from the cells that have data following an iterative procedure described in Steel and Torrie (1960). This procedure estimates zero cells using averages of values along the row (block) and column (treatment) of the zero cell, and also a grand average of all values. Estimated values are incorporated into each subsequent estimation until all zero cells are estimated. This procedure is then iteratively repeated until successive rounds yield the same value for all estimated cells. Resulting fecal coliform values for the 31 x 6 = 186 cells are compiled in Table

4-3 for fecal coliform and in Table 4-4 for *Enterococcus*. Estimated values are highlighted in the table.

- Perform the factorial ANOVA. Perform the factorial ANOVA on the average cell values, following Snedecor and Cochran (1989). The analysis is similar to a standard ANOVA (i.e., compilation of sum of squares, mean squares and degrees of freedom), except for a few variations to allow for comparisons and interactions between the various treatments, and the inclusion of the randomized blocks as a source of variation instead of simply a set of replicates. Like a standard ANOVA, the result of the factorial ANOVA is a calculated F value for each treatment comparison, which can be compared to the tabulated F distribution at various significance levels. Calculated F values which exceed the tabulated value indicate a statistically significant change in that treatment comparison.

- Correct for unequal cell variances. As seen in Tables 4-1 and 4-2, the available data are not evenly distributed among all cells. In addition to the zero cells that were either removed or estimated, some cells contain only a few data points, while others contain over 100 data points. This results in an inequality of variance among the cell values presented in Table 4-3 and 4-4, which are used to perform the factorial ANOVA.

  An approximate correction procedure described in Scheffe (1959) is utilized to account for this inequality in sample variance. It consists of calculating the ANOVA sum of squares term using the squares of all data points in each cell. Also, the ANOVA error mean-square term is adjusted by a factor comprised of the average over all cells of the reciprocal of the number of data points in each cell. These adjustments are applied to the factorial ANOVA analysis to yield the final calculated F factors used to assess statistically significant differences.

A strong randomized blocking scheme has been identified as a key component of a successful factorial ANOVA for detecting statistically significant interannual changes in sewage indicator bacteria counts. Therefore, in addition to the original blocking scheme developed in Section 3.3 (scheme A), two slight variations were also developed, in hopes of improving the analysis further. One variation (scheme B) treated the entire Charles River as one geographic location, without distinguishing an upper and lower portion. The other variation (scheme C) maintained two Charles River regions, but divided the summer season into individual July and August levels. The analytical procedure summarized above was repeated for each of these two alternative blocking schemes. The results for all three blocking schemes are presented for both fecal coliform and *Enterococcus* in Section 5.

Table 4-1
Distribution of Fecal Coliform Samples over Treatments and Blocks

RANDOMIZED BLOCKS			TREATMENTS						Total # samples in block	
Geographic Region	Tidal Condition	Season	RMS = 0 in		0 in < RMS > .25 in		RMS > .25 in			
			89-91	92-95	89-91	92-95	89-91	92-95		
Upper Charles	freshwater	fall/winter	89	0	19	0	72	0	180	
Upper Charles	freshwater	spring	23	45	31	55	14	20	188	
Upper Charles	freshwater	summer	39	31	36	43	69	51	269	
Lower Charles	freshwater	fall/winter	110	6	32	5	83	4	240	
Lower Charles	freshwater	spring	60	58	60	65	32	23	298	
Lower Charles	freshwater	summer	58	36	38	52	80	47	311	
Mystic R.	freshwater	fall/winter	46	68	19	62	8	51	254	
Mystic R.	freshwater	spring	22	0	9	0	0	0	31	X
Mystic R.	freshwater	summer	77	135	37	38	102	46	435	
Nepon. Head.	freshwater	fall/winter	10	0	14	0	8	0	32	X
Nepon. Head.	freshwater	spring	0	8	2	3	0	6	19	X
Nepon. Head.	freshwater	summer	6	18	8	23	10	17	82	
Neponset R.	high	fall/winter	15	37	40	56	32	17	197	
Neponset R.	high	spring	0	44	15	38	2	43	142	
Neponset R.	high	summer	19	62	26	83	55	30	275	
Neponset R.	low	fall/winter	15	24	31	14	14	19	117	
Neponset R.	low	spring	1	34	0	25	5	34	99	
Neponset R.	low	summer	20	53	16	55	15	65	224	
Dorch. Bay	high	fall/winter	16	0	32	0	46	0	94	X
Dorch. Bay	high	spring	5	41	35	2	12	17	112	
Dorch. Bay	high	summer	25	46	28	78	80	24	281	
Dorch. Bay	low	fall/winter	15	0	28	0	12	0	55	X
Dorch. Bay	low	spring	18	6	15	19	19	24	101	
Dorch. Bay	low	summer	27	58	35	48	52	58	278	
Inner Harbor	high	fall/winter	52	36	52	44	64	22	270	
Inner Harbor	high	spring	46	39	66	53	15	27	246	
Inner Harbor	high	summer	97	93	43	58	152	51	494	
Inner Harbor	low	fall/winter	24	43	28	31	42	31	199	
Inner Harbor	low	spring	39	44	20	41	24	22	190	
Inner Harbor	low	summer	93	93	62	65	78	59	450	
Outer Harbor	high	fall/winter	29	10	32	5	21	0	97	
Outer Harbor	high	spring	1	26	36	10	0	11	84	
Outer Harbor	high	summer	53	97	46	103	71	156	526	
Outer Harbor	low	fall/winter	64	0	4	5	18	5	96	
Outer Harbor	low	spring	4	16	2	22	2	13	59	
Outer Harbor	low	summer	49	170	14	99	63	76	471	

Total number of fecal coliform samples: 7496

X denotes block that is removed due to insufficient data (more than 1 zero cell and fewer than 100 data points)

Table 4-2
Distribution of *Enterococcus* Samples over Treatments and Blocks

RANDOMIZED BLOCKS			TREATMENTS						Total # samples in block	
Geographic Region	Tidal Condition	Season	RMS = 0 in		0 in < RMS > .25 in		RMS > .25 in			
			89-91	92-95	89-91	92-95	89-91	92-95		
Upper Charles	freshwater	fall/winter	89	0	19	0	72	0	180	
Upper Charles	freshwater	spring	0	47	0	56	0	20	123	
Upper Charles	freshwater	summer	39	31	36	43	68	51	268	
Lower Charles	freshwater	fall/winter	108	6	32	5	83	4	238	
Lower Charles	freshwater	spring	16	57	12	65	2	23	175	
Lower Charles	freshwater	summer	58	37	38	50	79	47	309	
Mystic R.	freshwater	fall/winter	46	68	19	61	8	51	253	
Mystic R.	freshwater	spring	22	0	7	0	0	0	29	X
Mystic R.	freshwater	summer	77	133	37	38	102	46	433	
Nepon. Head.	freshwater	fall/winter	10	0	14	0	8	0	32	X
Nepon. Head.	freshwater	spring	0	8	2	3	0	6	19	X
Nepon. Head.	freshwater	summer	6	18	8	23	10	17	82	
Neponset R.	high	fall/winter	15	6	40	29	32	9	131	
Neponset R.	high	spring	0	38	15	8	2	33	96	
Neponset R.	high	summer	19	60	26	81	55	30	271	
Neponset R.	low	fall/winter	15	7	31	7	14	19	93	
Neponset R.	low	spring	1	7	0	19	5	32	64	
Neponset R.	low	summer	20	53	16	55	15	65	224	
Dorch. Bay	high	fall/winter	16	0	32	0	46	0	94	X
Dorch. Bay	high	spring	5	41	35	2	11	17	111	
Dorch. Bay	high	summer	25	43	28	79	80	23	278	
Dorch. Bay	low	fall/winter	15	0	28	0	12	0	55	X
Dorch. Bay	low	spring	18	6	15	19	19	24	101	
Dorch. Bay	low	summer	27	58	35	48	52	58	278	
Inner Harbor	high	fall/winter	52	36	52	44	64	22	270	
Inner Harbor	high	spring	46	38	66	50	15	27	242	
Inner Harbor	high	summer	97	90	43	58	152	50	490	
Inner Harbor	low	fall/winter	24	43	28	31	44	31	201	
Inner Harbor	low	spring	39	42	20	42	24	24	191	
Inner Harbor	low	summer	93	92	62	65	78	59	449	
Outer Harbor	high	fall/winter	29	10	32	4	21	0	96	
Outer Harbor	high	spring	1	26	36	10	0	11	84	
Outer Harbor	high	summer	53	96	46	102	71	156	524	
Outer Harbor	low	fall/winter	62	0	4	5	18	5	94	
Outer Harbor	low	spring	4	11	2	22	2	13	54	
Outer Harbor	low	summer	49	165	14	98	63	75	464	

Total number of *Enterococcus* samples: 7096

X denotes block that is removed due to insufficient data (more than 1 zero cell and fewer than 100 data points)

Table 4-3
Cell Average Fecal Coliform Values: ln(FC+1)

RANDOMIZED BLOCKS			TREATMENTS					
Geographic Region	Tidal Condition	Season	RMS = 0 in		0 in < RMS > .25 in		RMS > .25 in	
			89-91	92-95	89-91	92-95	89-91	92-95
Upper Charles	freshwater	fall/winter	6.48	**6.04**	7.06	**6.27**	7.29	**6.98**
Upper Charles	freshwater	spring	7.85	6.29	6.96	6.34	7.24	6.37
Upper Charles	freshwater	summer	6.60	5.76	6.10	6.49	7.41	6.63
Lower Charles	freshwater	fall/winter	5.81	7.06	6.14	6.76	6.69	6.40
Lower Charles	freshwater	spring	5.98	4.76	5.60	4.53	6.44	5.40
Lower Charles	freshwater	summer	5.43	4.35	5.13	4.85	6.52	5.62
Mystic R.	freshwater	fall/winter	5.48	5.83	6.25	6.43	8.12	6.67
Mystic R.	freshwater	summer	4.69	4.88	4.86	4.25	6.21	6.39
Nepon. Head.	freshwater	summer	7.29	6.73	7.77	6.92	8.07	7.97
Neponset R.	high	fall/winter	5.11	2.09	4.47	3.95	5.46	3.48
Neponset R.	high	spring	**4.63**	4.27	6.27	4.04	5.61	4.94
Neponset R.	high	summer	3.55	3.88	5.19	4.45	6.37	5.40
Neponset R.	low	fall/winter	4.60	5.10	5.73	5.76	7.53	5.76
Neponset R.	low	spring	3.78	4.95	**5.66**	4.93	8.16	5.72
Neponset R.	low	summer	5.59	5.15	5.75	4.90	6.18	6.50
Dorch. Bay	high	spring	1.10	2.33	2.60	2.40	3.23	2.64
Dorch. Bay	high	summer	2.43	2.00	2.51	2.37	3.91	3.23
Dorch. Bay	low	spring	1.49	2.04	1.59	2.10	3.73	2.90
Dorch. Bay	low	summer	2.43	2.15	2.96	2.56	2.97	4.12
Inner Harbor	high	fall/winter	4.50	4.39	4.15	4.90	5.89	4.63
Inner Harbor	high	spring	3.54	3.24	4.62	3.76	4.45	4.75
Inner Harbor	high	summer	4.37	3.73	5.62	3.49	5.82	5.31
Inner Harbor	low	fall/winter	5.65	4.17	4.47	3.77	6.78	4.84
Inner Harbor	low	spring	3.59	2.97	4.04	3.79	3.78	4.63
Inner Harbor	low	summer	3.86	4.23	4.68	3.32	5.70	4.91
Outer Harbor	high	fall/winter	3.45	1.33	2.85	1.76	3.53	**2.94**
Outer Harbor	high	spring	1.39	1.85	2.09	2.90	**3.59**	3.93
Outer Harbor	high	summer	1.58	2.25	2.83	1.48	2.52	2.51
Outer Harbor	low	fall/winter	2.18	**1.95**	2.86	2.88	3.66	2.07
Outer Harbor	low	spring	2.60	1.47	2.86	1.87	3.09	2.20
Outer Harbor	low	summer	1.93	1.78	3.44	1.99	3.04	2.45

Highlighted cells denote estimated values

Table 4-4
Cell Average *Enterococcus* Values: ln(EN+1)

RANDOMIZED BLOCKS			TREATMENTS					
Geographic Region	**Tidal Condition**	**Season**	**RMS = 0 in**		**0 in < RMS > .25 in**		**RMS > .25 in**	
			89-91	**92-95**	**89-91**	**92-95**	**89-91**	**92-95**
Upper Charles	freshwater	fall/winter	5.63	**5.71**	6.14	**5.95**	7.16	**6.62**
Upper Charles	freshwater	spring	**4.59**	4.62	**4.88**	4.93	**6.09**	5.37
Upper Charles	freshwater	summer	4.58	3.80	4.07	4.69	6.53	5.09
Lower Charles	freshwater	fall/winter	4.62	6.94	4.84	5.87	6.11	6.67
Lower Charles	freshwater	spring	2.26	3.14	2.29	3.28	3.69	4.20
Lower Charles	freshwater	summer	3.02	2.84	3.10	3.49	4.60	3.99
Mystic R.	freshwater	fall/winter	3.86	3.50	5.82	4.14	8.00	4.38
Mystic R.	freshwater	summer	3.81	3.84	3.69	3.49	4.73	5.27
Nepon. Head.	freshwater	summer	6.66	5.33	6.16	5.58	8.34	6.99
Neponset R.	high	fall/winter	3.45	2.60	3.03	3.47	4.22	3.22
Neponset R.	high	spring	**3.59**	2.79	4.16	4.90	4.30	4.72
Neponset R.	high	summer	2.77	2.81	3.20	3.06	5.19	3.86
Neponset R.	low	fall/winter	3.59	6.25	4.91	6.42	7.29	5.60
Neponset R.	low	spring	2.40	3.78	**4.27**	4.02	7.35	5.01
Neponset R.	low	summer	3.97	3.84	4.59	3.84	5.36	5.30
Dorch. Bay	high	spring	0.92	1.52	1.70	1.79	2.43	1.98
Dorch. Bay	high	summer	2.23	1.78	1.69	2.02	2.62	2.53
Dorch. Bay	low	spring	1.07	1.48	1.01	1.48	2.16	2.19
Dorch. Bay	low	summer	1.77	1.73	1.85	2.00	1.75	3.32
Inner Harbor	high	fall/winter	3.52	2.24	3.59	2.85	5.21	2.76
Inner Harbor	high	spring	1.94	2.41	2.46	2.50	2.87	3.53
Inner Harbor	high	summer	3.02	2.17	2.12	2.29	3.42	3.20
Inner Harbor	low	fall/winter	3.42	3.07	4.59	3.01	6.36	3.36
Inner Harbor	low	spring	2.28	2.76	2.10	3.21	3.06	4.39
Inner Harbor	low	summer	2.43	2.39	3.36	2.42	3.65	3.43
Outer Harbor	high	fall/winter	3.66	1.33	2.65	0.92	3.74	**2.96**
Outer Harbor	high	spring	0.92	1.58	1.60	2.44	**3.25**	3.67
Outer Harbor	high	summer	1.51	1.71	1.57	1.49	1.63	2.01
Outer Harbor	low	fall/winter	2.32	**1.87**	2.78	1.46	4.65	1.09
Outer Harbor	low	spring	1.67	1.64	1.89	1.62	1.35	2.45
Outer Harbor	low	summer	1.69	1.60	1.91	1.84	2.38	2.06

Highlighted cells denote estimated values

5.0 RESULTS

This section presents the results of the factorial analysis of variance (ANOVA) using randomized blocks methodology for assessing statistically significant interannual reductions in sewage indicator bacteria counts within the CSO receiving water system. The analysis is performed for both fecal coliform and *Enterococcus*, and for each indicator bacteria three slightly different randomized blocking schemes (schemes A, B and C; see Section 4) were considered, resulting in a total of six factorial ANOVA analyses. Summary tables are presented in this section, describing for each case the amount of decrease in bacteria counts between time periods, and also the degree of statistical significance of the observed reduction. Complete ANOVA results tables for each case are provided in the appendix, which includes the number of data points and average cell values for each ANOVA analysis.

Amount of Bacteria Count Reduction

Natural logarithm-transformed average bacteria counts for each of the six treatments making up the ANOVA analysis (i.e., combinations of two sampling years and three rainfall levels) are compiled in Table 5-1, for both fecal coliform and *Enterococcus* and for all three blocking schemes. Average bacteria counts are calculated using cell values corresponding to each block retained in the analysis. For example, the average values presented in Table 5-1 for fecal coliform, scheme A, are obtained from the cell values for the 31 blocks presented in Figure 4-3. The appendix lists cell values and averages for all six cases.

In Table 5-1, the 1989-1991 and 1992-1995 sampling year levels are compared for each of the three rainfall levels, expressed as a percent reduction. Overall temporal reduction is also presented, which consists of the average over the three rainfall levels. Note that the average values and percent reductions are of the ln(FC+1) and ln(EN+1) parameters, not the actual bacteria counts per 100 ml, FC and EN. Percent reductions for the actual bacteria counts would be higher than those presented for the natural logarithm transforms.

As indicated in Table 5-1, overall fecal coliform is reduced by 9.5%-10.8% between the periods 1989-1991 and 1992-1995, depending on the blocking scheme. The reduction is more pronounced during the low rain and high rain levels (about 10.6%-12.6%) than during dry conditions (about 5.1%-7.7%). This is consistent with the biggest improvements occurring during wet weather, when CSO discharges are most likely. Wet weather sewerage system improvements include more reliable pumping at the Deer Island plant, and construction and operation of two CSO treatment facilities. The somewhat smaller reduction in dry weather bacteria counts could be attributed to factors like the cessation of sludge discharges, elimination of dry weather overflows from combined sewer outfalls, and improved disinfection at the treatment plants. The reduction of illegal sewer connections to storm drains would improve water quality during both dry and wet weather.

Enterococcus exhibits a much smaller degree of temporal reduction than fecal coliform. For the three blocking schemes, overall *Enterococcus* is reduced by 4.6%-6.0% between 1989-1991 and 1992-1995. Dry weather conditions indicate a negligible change in bacteria count, and light rain conditions exhibit a maximum decrease of 1.9%. Heavy rain conditions, however, indicate a greater decrease of 11.5%-13.1%. As is the case for fecal coliform, the greatest temporal reduction in *Enterococcus* counts occurs during heavy rainfall conditions, when CSO discharges are more likely and bacteria counts are higher. However, *Enterococcus* exhibits substantially less temporal reduction during light rain and no rain conditions than does fecal coliform.

This difference between fecal coliform and *Enterococcus* reductions may be attributable to differences in receiving water mixing and bacteria attenuation characteristics, sources and characteristics of bacteria release other than CSO discharges during rainfall events, or the relative difference in bacteria quantity under different conditions. Note in table 5-1 that for all blocking schemes and rainfall conditions, higher values during 1989-1991 generally are followed by a greater percent reduction during 1992-1995. Cases with a ten percent reduction or higher usually start out with a natural logarithm of bacteria count value well over 4, regardless of the rainfall condition.

Degree of Statistical Significance

The factorial ANOVA using randomized blocks tests for statistically significant changes among its treatments by comparing a calculated F factor at its calculated degrees of freedom to tabulated F distribution values for varying significance levels. Factorial ANOVA results are summarized for fecal coliform and *Enterococcus* and all three blocking schemes in Table 5-2. The table lists the various sources of variation, or effects, that are accounted for by the factorial ANOVA analysis. Full ANOVA results tables are presented in the appendix. For each source of variation, the number of degrees of freedom (DoF) and the calculated F value are presented. Selected values from the tabulated F distribution are provided in Table 5-3 for comparison with the calculated values in Table 5-2. For a selected significance level and the corresponding effect and error DoF, a calculated F value greater than the tabulated value indicates a statistically significant change in the source of variation.

The different sources of variation considered by the factorial ANOVA are a block effect, an overall treatments effect, and individual treatment effects. Significant block effects indicate that the blocking scheme was successful in accounting for the competing environmental variables. The time treatments compare the overall 1989-1991 period to the 1992-1995 period. The rainfall treatments compare the overall effect of changes in rainfall, and since three rainfall levels are considered, statistical comparisons can also be made between individual rainfall levels.

The time treatment comparison is of primary interest in this factorial ANOVA study, since the objective of this investigation is to detect statistically significant changes in bacteria counts over time, after accounting for other environmental variables that also affect bacteria counts.

As indicated in Table 5-2, calculated fecal coliform F factors for the time treatment comparison range from 20.57 to 30.41. These calculated values are conservatively compared to tabulated values in Table 5-3 at the DoF closest to but lower than the calculated DoF. The degrees of freedom associated with the time treatment comparison (effect DoF;error DoF) ranges from 1;130 to 1;179. The calculated fecal coliform F factors far exceed the tabulated values in Table 5-3 for 1;120 DoF at the 0.5% significance level. Thus the reductions in fecal coliform count between 1989-1991 and 1992-1995, shown in Table 5-1, are determined by the factorial ANOVA to be statistically significant with 99.5% confidence.

The smaller temporal reduction in *Enterococcus* shown in Table 5-1, is found by the factorial ANOVA analysis to be less strongly significant. Time treatment comparison F factors range from 2.69-4.43, with degrees of freedom between 1;130 and 1;174. For blocking schemes A and B, the calculated F factors for the time treatment comparison are significant at 5.0%, but not at 2.5%. For scheme C, the time treatment comparison is significant only at 25%, and not at 10%. Thus the relatively small reductions in *Enterococcus* between 1989-1991 and 1992-1995 exhibit only borderline statistical significance in the factorial ANOVA. Nevertheless, the strongest result is for scheme A, which does indicate a statistically significant reduction with 95% confidence.

For both bacteria, the blocks effect is strongly significant, which indicates that the randomized blocking procedure was successful in accounting for the competing sources of variability in bacteria counts. Had the data been assigned to the various blocks in a random manner instead of being careful partitioning into groups with similar characteristics, the calculated blocks effect would be much smaller and would likely be not statistically significant. The various rainfall effects are all also strongly significant, as is expected since rainfall is directly related to CSO discharges and resulting bacteria counts.

Note that for most comparisons, very little difference exists between the three blocking schemes, compared to the large degree of statistical significance exhibited. For the most part the selected blocking scheme has little bearing on the results. The only exception is the time treatment comparison for *Enterococcus*, where the low F factors result in schemes A and B having a noticeably greater significance than scheme C. Thus the particulars of the blocking procedure become more important when dealing with more subtle reductions in bacteria count.

Blocking scheme A produces the most significant results for the time treatment comparison, so it is considered as the optimal scheme out of the three that were analyzed. Using this scheme, natural logarithm fecal coliform counts between 1989-1991 and 1992-1995 are reduced by 10.8%, which is statistically significant at the 0.5% level of significance. Natural logarithm *Enterococcus* counts using scheme A are reduced by 6.0%, which is significant at the 5.0% level of significance. Thus the factorial ANOVA using randomized blocks methodology has successfully demonstrated a statistically significant decrease in sewage indicator bacteria within CSO receiving waters between the period from 1989 to 1995.

Table 5-1
Average Bacteria Count Values over all Blocks with Temporal Percent Reductions

	Randomized Blocking Scheme	TREATMENTS						OVERALL	
		RMS = 0 in		0 in < RMS > .25 in		RMS > .25 in			
		89-91	92-95	89-91	92-95	89-91	92-95	89-91	92-95
Fecal Coliform; ln(FC+1)									
Mean	A	4.16	3.84	4.62	4.07	5.45	4.78	4.74	4.23
% Reduction		7.7%		11.8%		12.2%		10.8%	
Mean	B	3.90	3.65	4.44	3.88	5.29	4.62	4.54	4.05
% Reduction		6.4%		12.6%		12.6%		10.8%	
Mean	C	4.00	3.79	4.51	3.96	5.50	4.92	4.67	4.22
% Reduction		5.1%		12.2%		10.6%		9.5%	
***Enterococcus*; ln(EN+1)**									
Mean	A	3.01	3.00	3.29	3.24	4.50	3.91	3.60	3.38
% Reduction		0.1%		1.5%		13.1%		6.0%	
Mean	B	2.84	2.86	3.14	3.08	4.32	3.76	3.43	3.23
% Reduction		-0.8%		1.9%		13.1%		5.8%	
Mean	C	2.92	2.96	3.15	3.15	4.52	4.00	3.53	3.37
% Reduction		-1.3%		0.1%		11.5%		4.6%	

Table 5-2
Factorial ANOVA Results

FECAL COLIFORM

	Scheme A		Scheme B		Scheme C	
Source of Variation	DoF	F	DoF	F	DoF	F
Blocks	30	39.12	27	39.01	38	29.78
Overall Treatments	5	26.91	5	27.59	5	30.49
Time Treatments	**1**	**30.41**	**1**	**27.04**	**1**	**20.57**
Rainfall Treatments	2	50.86	2	53.70	2	64.40
Rain/no rain	1	55.28	1	60.49	1	62.94
high/low rain	1	46.43	1	46.91	1	65.87
Error	**142**		**130**		**179**	
Total	177		162		222	

ENTEROCOCCUS

	Scheme A		Scheme B		Scheme C	
Source of Variation	DoF	F	DoF	F	DoF	F
Blocks	30	28.54	27	29.48	38	24.64
Overall Treatments	5	25.52	5	25.52	5	29.78
Time Treatments	**1**	**4.96**	**1**	**4.43**	**1**	**2.69**
Rainfall Treatments	2	57.49	2	57.86	2	69.75
Rain/no rain	1	51.43	1	51.80	1	54.50
high/low rain	1	63.55	1	63.93	1	85.00
Error	**139**		**130**		**174**	
Total	174		162		217	

Table 5-3
Selected F-Distribution Values*

Level of Significance	Degrees of Freedom						
	1;60	1;100	1;120	1;125	1;150	1;200	infinity
25%	1.35	N/A	1.34	N/A	N/A	N/A	1.32
10%	2.79	N/A	2.75	N/A	N/A	N/A	2.71
5.0%	N/A	3.94	N/A	3.92	3.91	3.89	N/A
2.5%	5.29	N/A	5.15	N/A	N/A	N/A	5.02
1.0%	N/A	6.9	N/A	6.84	6.81	6.76	N/A
0.5%	8.49	N/A	8.18	N/A	N/A	N/A	7.88

* Source: Snedecor and Cochran (1989)

N/A Not available in cited source

6.0 CONCLUSIONS

The objective of this study was to test the hypothesis that sewage indicator bacteria counts in the CSO receiving water system have experienced statistically significant decreases over the period from 1989 to 1995, in response to systemwide improvements to the CSO drainage and treatment network during this period. Such an investigation is complicated by the high natural variability in bacteria counts due to varying environmental conditions, and the uneven temporal and spatial distribution of the available data set. A factorial analysis of variance (ANOVA) technique was developed to perform the statistical analysis, adding a randomized blocks procedure to account for competing environmental variability. This methodology utilizes advanced statistical techniques yet still falls under the realm of classical statistics, and has been successfully implemented in a variety of applications.

The analysis follows an approach which fully utilizes all available data by considering the entire receiving water system as a whole, and systematically accounts for naturally occurring bacteria count variability by addressing five key variables which affect bacteria counts: sampling year, rainfall, geographic location, tidal condition, and season. By following this approach, the statistical analysis is allowed to focus on isolating the temporal effect of CSO system improvements that have taken place between 1989 and 1995. This temporal effect is evaluated by comparing two time periods; 1989-1991 which represents conditions prior to implementation of the CSO system improvements, and 1992-1995 which represents conditions after improvements have taken effect.

The factorial ANOVA was successfully able to detect statistically significant temporal reductions in both fecal coliform and *Enterococcus*. The reduction is greatest under heavy rain conditions and smallest under dry conditions, which is consistent with the nature of improvements to the CSO system. Fecal coliform counts in the receiving water system are generally higher than *Enterococcus* counts; they exhibit a greater amount of temporal reduction and have a higher degree of statistical significance. Thus the quantity of bacteria present appears have an impact on the magnitude and statistical significance of temporal reductions attributed to CSO system improvements.

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APPENDIX

Fecal Coliform
Scheme A
Distribution of Samples over Treatments and Blocks

RANDOMIZED BLOCKS			TREATMENTS						Total # samples in block
Geographic Region	Tidal Condition	Season	RMS = 0 in		0 in < RMS > .25 in		RMS > .25 in		
			89-91	92-95	89-91	92-95	89-91	92-95	
Upper Charles	freshwater	fall/winter	89	0	19	0	72	0	180
Upper Charles	freshwater	spring	23	45	31	55	14	20	188
Upper Charles	freshwater	summer	39	31	36	43	69	51	269
Lower Charles	freshwater	fall/winter	110	6	32	5	83	4	240
Lower Charles	freshwater	spring	60	58	60	65	32	23	298
Lower Charles	freshwater	summer	58	36	38	52	80	47	311
Mystic R.	freshwater	fall/winter	46	68	19	62	8	51	254
Mystic R.	freshwater	spring	22	0	9	0	0	0	31
Mystic R.	freshwater	summer	77	135	37	38	102	46	435
Nepon. Head.	freshwater	fall/winter	10	0	14	0	8	0	32
Nepon. Head.	freshwater	spring	0	8	2	3	0	6	19
Nepon. Head.	freshwater	summer	6	18	8	23	10	17	82
Neponset R.	high	fall/winter	15	37	40	56	32	17	197
Neponset R.	high	spring	0	44	15	38	2	43	142
Neponset R.	high	summer	19	62	26	83	55	30	275
Neponset R.	low	fall/winter	15	24	31	14	14	19	117
Neponset R.	low	spring	1	34	0	25	5	34	99
Neponset R.	low	summer	20	53	16	55	15	65	224
Dorch. Bay	high	fall/winter	16	0	32	0	46	0	94
Dorch. Bay	high	spring	5	41	35	2	12	17	112
Dorch. Bay	high	summer	25	46	28	78	80	24	281
Dorch. Bay	low	fall/winter	15	0	28	0	12	0	55
Dorch. Bay	low	spring	18	6	15	19	19	24	101
Dorch. Bay	low	summer	27	58	35	48	52	58	278
Inner Harbor	high	fall/winter	52	36	52	44	64	22	270
Inner Harbor	high	spring	46	39	66	53	15	27	246
Inner Harbor	high	summer	97	93	43	58	152	51	494
Inner Harbor	low	fall/winter	24	43	28	31	42	31	199
Inner Harbor	low	spring	39	44	20	41	24	22	190
Inner Harbor	low	summer	93	93	62	65	78	59	450
Outer Harbor	high	fall/winter	29	10	32	5	21	0	97
Outer Harbor	high	spring	1	26	36	10	0	11	84
Outer Harbor	high	summer	53	97	46	103	71	156	526
Outer Harbor	low	fall/winter	64	0	4	5	18	5	96
Outer Harbor	low	spring	4	16	2	22	2	13	59
Outer Harbor	low	summer	49	170	14	99	63	76	471

Total number of fecal coliform samples: 7496

Fecal Coliform
Scheme A
Cell Average Values (Blocks with Insufficient Data Removed)

RANDOMIZED BLOCKS			TREATMENTS					
Geographic Region	Tidal Condition	Season	RMS = 0 in		0 in < RMS > .25 in		RMS > .25 in	
			89-91	92-95	89-91	92-95	89-91	92-95
Upper Charles	freshwater	fall/winter	6.48	**6.04**	7.06	**6.27**	7.29	**6.98**
Upper Charles	freshwater	spring	7.85	6.29	6.96	6.34	7.24	6.37
Upper Charles	freshwater	summer	6.60	5.76	6.10	6.49	7.41	6.63
Lower Charles	freshwater	fall/winter	5.81	7.06	6.14	6.76	6.69	6.40
Lower Charles	freshwater	spring	5.98	4.76	5.60	4.53	6.44	5.40
Lower Charles	freshwater	summer	5.43	4.35	5.13	4.85	6.52	5.62
Mystic R.	freshwater	fall/winter	5.48	5.83	6.25	6.43	8.12	6.67
Mystic R.	freshwater	summer	4.69	4.88	4.86	4.25	6.21	6.39
Nepon. Head.	freshwater	summer	7.29	6.73	7.77	6.92	8.07	7.97
Neponset R.	high	fall/winter	5.11	2.09	4.47	3.95	5.46	3.48
Neponset R.	high	spring	**4.63**	4.27	6.27	4.04	5.61	4.94
Neponset R.	high	summer	3.55	3.88	5.19	4.45	6.37	5.40
Neponset R.	low	fall/winter	4.60	5.10	5.73	5.76	7.53	5.76
Neponset R.	low	spring	3.78	4.95	**5.66**	4.93	8.16	5.72
Neponset R.	low	summer	5.59	5.15	5.75	4.90	6.18	6.50
Dorch. Bay	high	spring	1.10	2.33	2.60	2.40	3.23	2.64
Dorch. Bay	high	summer	2.43	2.00	2.51	2.37	3.91	3.23
Dorch. Bay	low	spring	1.49	2.04	1.59	2.10	3.73	2.90
Dorch. Bay	low	summer	2.43	2.15	2.96	2.56	2.97	4.12
Inner Harbor	high	fall/winter	4.50	4.39	4.15	4.90	5.89	4.63
Inner Harbor	high	spring	3.54	3.24	4.62	3.76	4.45	4.75
Inner Harbor	high	summer	4.37	3.73	5.62	3.49	5.82	5.31
Inner Harbor	low	fall/winter	5.65	4.17	4.47	3.77	6.78	4.84
Inner Harbor	low	spring	3.59	2.97	4.04	3.79	3.78	4.63
Inner Harbor	low	summer	3.86	4.23	4.68	3.32	5.70	4.91
Outer Harbor	high	fall/winter	3.45	1.33	2.85	1.76	3.53	**2.94**
Outer Harbor	high	spring	1.39	1.85	2.09	2.90	**3.59**	3.93
Outer Harbor	high	summer	1.58	2.25	2.83	1.48	2.52	2.51
Outer Harbor	low	fall/winter	2.18	**1.95**	2.86	2.88	3.66	2.07
Outer Harbor	low	spring	2.60	1.47	2.86	1.87	3.09	2.20
Outer Harbor	low	summer	1.93	1.78	3.44	1.99	3.04	2.45
		sum	128.96	119.02	143.11	126.21	168.99	148.29
		mean	**4.16**	**3.84**	**4.62**	**4.07**	**5.45**	**4.78**
		% reduction	**7.7%**		**11.8%**		**12.2%**	
		overall mean	**4.74**	**4.23**				
		overall % reduction	**10.8%**					

Highlighted cells denote estimated values

Fecal Coliform
Scheme A
ANOVA Analysis

	ANOVA Multipliers										
	RMS = 0 in		0 in < RMS > .25 in		RMS > .25 in		Factorial	Treatment	time	rain	interaction
	89-91	92-94	89-91	92-94	89-91	92-94	Effect Total	SS	SS	SS	SS
time	-1	1	-1	1	-1	1	-47.54	12.15082	12.1508		
rain/no rain	-2	-2	1	1	1	1	90.64	22.08497		22.085	
interaction	2	-2	-1	1	-1	1	-17.72	0.844082			0.8440817
high rain/low rain	0	0	-1	-1	1	1	47.96	18.54969		18.5497	
interaction	0	0	1	-1	-1	1	-3.80	0.116452			0.1164516
								53.74601	12.1508	40.6347	0.9605333

Correction: C = 3744.75
Total SS = 1055.92
Blocks SS = 468.833
Error SS = 533.34

	Squares of ANOVA Multipliers						sum	divisor for SS
time	1	1	1	1	1	1	6	186
rain/no rain	4	4	1	1	1	1	12	372
interaction	4	4	1	1	1	1	12	372
high rain/low rain	0	0	1	1	1	1	4	124
interaction	0	0	1	1	1	1	4	124

#treat= 6
#blocks= 31
#cells= 186
#zeros= 8
avg of recip= 0.1064

ANOVA Results

Source of Variation	DoF	SS	MS	F
Blocks	30	468.83	15.63	39.12
Treatments	5	53.75	10.75	26.91
Time	1	12.15	12.15	**30.41**
Rainfall	2	40.63	20.32	50.86
Rain/no rain	*1*	*22.08*	*22.08*	*55.28*
high/low rain	*1*	*18.55*	*18.55*	*46.43*
Error	142	533.34	0.40	
Total	177	1055.92		

Fecal Coliform
Scheme B
Distribution of Samples over Treatments and Blocks

RANDOMIZED BLOCKS			TREATMENTS						Total # samples in block
Geographic Region	Tidal Condition	Season	RMS = 0 in		0 in < RMS > .25 in		RMS > .25 in		
			89-91	92-95	89-91	92-95	89-91	92-95	
Charles R.	freshwater	fall/winter	199	6	51	5	155	4	420
Charles R.	freshwater	spring	83	103	91	120	46	43	486
Charles R.	freshwater	summer	97	67	74	95	149	98	580
Mystic R.	freshwater	fall/winter	46	68	19	62	8	51	254
Mystic R.	freshwater	spring	22	0	9	0	0	0	31
Mystic R.	freshwater	summer	77	135	37	38	102	46	435
Nepon. Head.	freshwater	fall/winter	10	0	14	0	8	0	32
Nepon. Head.	freshwater	spring	0	8	2	3	0	6	19
Nepon. Head.	freshwater	summer	6	18	8	23	10	17	82
Neponset R.	high	fall/winter	15	37	40	56	32	17	197
Neponset R.	high	spring	0	44	15	38	2	43	142
Neponset R.	high	summer	19	62	26	83	55	30	275
Neponset R.	low	fall/winter	15	24	31	14	14	19	117
Neponset R.	low	spring	1	34	0	25	5	34	99
Neponset R.	low	summer	20	53	16	55	15	65	224
Dorch. Bay	high	fall/winter	16	0	32	0	46	0	94
Dorch. Bay	high	spring	5	41	35	2	12	17	112
Dorch. Bay	high	summer	25	46	28	78	80	24	281
Dorch. Bay	low	fall/winter	15	0	28	0	12	0	55
Dorch. Bay	low	spring	18	6	15	19	19	24	101
Dorch. Bay	low	summer	27	58	35	48	52	58	278
Inner Harbor	high	fall/winter	52	36	52	44	64	22	270
Inner Harbor	high	spring	46	39	66	53	15	27	246
Inner Harbor	high	summer	97	93	43	58	152	51	494
Inner Harbor	low	fall/winter	24	43	28	31	42	31	199
Inner Harbor	low	spring	39	44	20	41	24	22	190
Inner Harbor	low	summer	93	93	62	65	78	59	450
Outer Harbor	high	fall/winter	29	10	32	5	21	0	97
Outer Harbor	high	spring	1	26	36	10	0	11	84
Outer Harbor	high	summer	53	97	46	103	71	156	526
Outer Harbor	low	fall/winter	64	0	4	5	18	5	96
Outer Harbor	low	spring	4	16	2	22	2	13	59
Outer Harbor	low	summer	49	170	14	99	63	76	471

Total number of fecal coliform samples: 7496

Fecal Coliform
Scheme B
Cell Average Values (Blocks with Insufficient Data Removed)

RANDOMIZED BLOCKS			TREATMENTS					
			RMS = 0 in		0 in < RMS > .25 in		RMS > .25 in	
Geographic Region	Tidal Condition	Season	89-91	92-95	89-91	92-95	89-91	92-95
Charles R.	freshwater	fall/winter	6.11	7.06	6.48	6.76	6.97	6.40
Charles R.	freshwater	spring	6.50	5.43	6.06	5.36	6.68	5.85
Charles R.	freshwater	summer	5.90	5.01	5.60	5.59	6.93	6.15
Mystic R.	freshwater	fall/winter	5.48	5.83	6.25	6.43	8.12	6.67
Mystic R.	freshwater	summer	4.69	4.88	4.86	4.25	6.21	6.39
Nepon. Head.	freshwater	summer	7.29	6.73	7.77	6.92	8.07	7.97
Neponset R.	high	fall/winter	5.11	2.09	4.47	3.95	5.46	3.48
Neponset R.	high	spring	**4.55**	4.27	6.27	4.04	5.61	4.94
Neponset R.	high	summer	3.55	3.88	5.19	4.45	6.37	5.40
Neponset R.	low	fall/winter	4.60	5.10	5.73	5.76	7.53	5.76
Neponset R.	low	spring	3.78	4.95	**5.68**	4.93	8.16	5.72
Neponset R.	low	summer	5.59	5.15	5.75	4.90	6.18	6.50
Dorch. Bay	high	spring	1.10	2.33	2.60	2.40	3.23	2.64
Dorch. Bay	high	summer	2.43	2.00	2.51	2.37	3.91	3.23
Dorch. Bay	low	spring	1.49	2.04	1.59	2.10	3.73	2.90
Dorch. Bay	low	summer	2.43	2.15	2.96	2.56	2.97	4.12
Inner Harbor	high	fall/winter	4.50	4.39	4.15	4.90	5.89	4.63
Inner Harbor	high	spring	3.54	3.24	4.62	3.76	4.45	4.75
Inner Harbor	high	summer	4.37	3.73	5.62	3.49	5.82	5.31
Inner Harbor	low	fall/winter	5.65	4.17	4.47	3.77	6.78	4.84
Inner Harbor	low	spring	3.59	2.97	4.04	3.79	3.78	4.63
Inner Harbor	low	summer	3.86	4.23	4.68	3.32	5.70	4.91
Outer Harbor	high	fall/winter	3.45	1.33	2.85	1.76	3.53	**2.97**
Outer Harbor	high	spring	1.39	1.85	2.09	2.90	**3.62**	3.93
Outer Harbor	high	summer	1.58	2.25	2.83	1.48	2.52	2.51
Outer Harbor	low	fall/winter	2.18	**1.96**	2.86	2.88	3.66	2.07
Outer Harbor	low	spring	2.60	1.47	2.86	1.87	3.09	2.20
Outer Harbor	low	summer	1.93	1.78	3.44	1.99	3.04	2.45
		sum	109.24	102.27	124.28	108.68	148.01	129.32
		mean	**3.90**	**3.65**	**4.44**	**3.88**	**5.29**	**4.62**
		% reduction	**6.4%**		**12.6%**		**12.6%**	
		overall mean	**4.54**	**4.05**				
		overall % reduction	**10.8%**					

Highlighted cells denote estimated values

Fecal Coliform
Scheme B
ANOVA Analysis

ANOVA Multipliers

	RMS = 0 in		0 in < RMS > .25 in		RMS > .25 in		Factorial	Treatment	time	rain	interaction
	89-91	92-94	89-91	92-94	89-91	92-94	Effect Total	SS	SS	SS	SS
time	-1	1	-1	1	-1	1	-41.26	10.13326	10.1333		
rain/no rain	-2	-2	1	1	1	1	87.27	22.66682		22.6668	
interaction	2	-2	-1	1	-1	1	-20.35	1.232507			1.2325074
high rain/low rain	0	0	-1	-1	1	1	44.37	17.57765		17.5777	
interaction	0	0	1	-1	-1	1	-3.09	0.085251			0.0852509
								51.69549	10.1333	40.2445	1.3177583

Correction: C = 3101.16
Total SS = 951.84
Blocks SS = 394.697
Error SS = 505.45

Squares of ANOVA Multipliers

							sum	divisor for SS
time	1	1	1	1	1	1	6	168
rain/no rain	4	4	1	1	1	1	12	336
interaction	4	4	1	1	1	1	12	336
high rain/low rain	0	0	1	1	1	1	4	112
interaction	0	0	1	1	1	1	4	112

#treat= 6
#blocks= 28
#cells= 168
#zeros= 5
avg of recip= 0.0964

ANOVA Results

Source of Variation	DoF	SS	MS	F
Blocks	27	394.70	14.62	39.01
Treatments	5	51.70	10.34	27.59
Time	1	10.13	10.13	**27.04**
Rainfall	2	40.24	20.12	53.70
Rain/no rain	*1*	*22.67*	*22.67*	*60.49*
high/low rain	*1*	*17.58*	*17.58*	*46.91*
Error	130	505.45	0.37	
Total	162	951.84		

Fecal Coliform
Scheme C
Distribution of Samples over Treatments and Blocks

RANDOMIZED BLOCKS			TREATMENTS						Total # samples in block
Geographic Region	Tidal Condition	Season	RMS = 0 in		0 in < RMS > .25 in		RMS > .25 in		
			89-91	92-95	89-91	92-95	89-91	92-95	
Upper Charles	freshwater	fall/winter	89	0	19	0	72	0	180
Upper Charles	freshwater	spring	23	45	31	55	14	20	188
Upper Charles	freshwater	jul	39	31	35	43	69	51	268
Upper Charles	freshwater	aug	0	0	1	0	0	0	1
Lower Charles	freshwater	fall/winter	110	6	32	5	83	4	240
Lower Charles	freshwater	spring	60	58	60	65	32	23	298
Lower Charles	freshwater	jul	51	36	34	52	74	47	294
Lower Charles	freshwater	aug	7	0	4	0	6	0	17
Mystic R.	freshwater	fall/winter	46	68	19	62	8	51	254
Mystic R.	freshwater	spring	22	0	9	0	0	0	31
Mystic R.	freshwater	jul	21	0	21	0	16	0	58
Mystic R.	freshwater	aug	56	135	16	38	86	46	377
Nepon. Head.	freshwater	fall/winter	10	0	14	0	8	0	32
Nepon. Head.	freshwater	spring	0	8	2	3	0	6	19
Nepon. Head.	freshwater	jul	2	15	4	21	8	16	66
Nepon. Head.	freshwater	aug	4	3	4	2	2	1	16
Neponset R.	high	fall/winter	15	37	40	56	32	17	197
Neponset R.	high	spring	0	44	15	38	2	43	142
Neponset R.	high	jul	7	61	21	76	46	28	239
Neponset R.	high	aug	12	1	5	7	9	2	36
Neponset R.	low	fall/winter	15	24	31	14	14	19	117
Neponset R.	low	spring	1	34	0	25	5	34	99
Neponset R.	low	jul	8	34	0	49	15	65	171
Neponset R.	low	aug	12	19	16	6	0	0	53
Dorch. Bay	high	fall/winter	16	0	32	0	46	0	94
Dorch. Bay	high	spring	5	41	35	2	12	17	112
Dorch. Bay	hugh	jul	12	43	23	70	70	22	240
Dorch. Bay	high	aug	13	3	5	8	10	2	41
Dorch. Bay	low	fall/winter	15	0	28	0	12	0	55
Dorch. Bay	low	spring	18	6	15	19	19	24	101
Dorch. Bay	low	jul	13	41	16	45	47	58	220
Dorch. Bay	low	aug	14	17	19	3	5	0	58
Inner Harbor	high	fall/winter	52	36	52	44	64	22	270
Inner Harbor	high	spring	46	39	66	53	15	27	246
Inner Harbor	high	jul	20	45	22	48	27	35	197
Inner Harbor	high	aug	77	48	21	10	125	16	297
Inner Harbor	low	fall/winter	24	43	28	31	42	31	199
Inner Harbor	low	spring	39	44	20	41	24	22	190
Inner Harbor	low	jul	50	27	15	43	13	43	191
Inner Harbor	low	aug	43	66	47	22	65	16	259
Outer Harbor	high	fall/winter	29	10	32	5	21	0	97
Outer Harbor	high	spring	1	26	36	10	0	11	84
Outer Harbor	high	jul	1	19	3	36	11	25	95
Outer Harbor	high	aug	52	78	43	67	60	131	431
Outer Harbor	low	fall/winter	64	0	4	5	18	5	96
Outer Harbor	low	spring	4	16	2	22	2	13	59
Outer Harbor	low	jul	28	64	2	29	0	29	152
Outer Harbor	low	aug	21	106	12	70	63	47	319

Total number of fecal coliform samples: 7496

Fecal Coliform
Scheme C
Cell Average Values (Blocks with Insufficient Data Removed)

RANDOMIZED BLOCKS			TREATMENTS					
Geographic Region	Tidal Condition	Season	RMS = 0 in		0 in < RMS > .25 in		RMS > .25 in	
			89-91	92-95	89-91	92-95	89-91	92-95
Upper Charles	freshwater	fall/winter	6.48	**6.07**	7.06	**6.23**	7.29	**7.19**
Upper Charles	freshwater	spring	7.85	6.29	6.96	6.34	7.24	6.37
Upper Charles	freshwater	jul	6.6	5.76	6.11	6.49	7.41	6.63
Lower Charles	freshwater	fall/winter	5.81	7.06	6.14	6.76	6.69	6.4
Lower Charles	freshwater	spring	5.98	4.76	5.6	4.53	6.44	5.4
Lower Charles	freshwater	jul	5.51	4.35	5.13	4.85	6.49	5.62
Mystic R.	freshwater	fall/winter	5.48	5.83	6.25	6.43	8.12	6.67
Mystic R.	freshwater	aug	4.88	4.88	5.29	4.25	6.45	6.39
Nepon. Head.	freshwater	jul	7.37	6.83	7.05	6.86	7.69	7.88
Nepon. Head.	freshwater	aug	7.25	6.22	8.49	7.6	9.59	9.43
Neponset R.	high	fall/winter	5.11	2.09	4.47	3.95	5.46	3.48
Neponset R.	high	spring	**4.49**	4.27	6.27	4.04	5.61	4.94
Neponset R.	high	jul	3.77	3.86	5.37	4.36	6.09	5.16
Neponset R.	high	aug	3.42	5.14	4.42	5.43	7.78	8.75
Neponset R.	low	fall/winter	4.6	5.1	5.73	5.76	7.53	5.76
Neponset R.	low	spring	3.78	4.95	**5.58**	4.93	8.16	5.72
Neponset R.	low	jul	5.36	5	**5.69**	5.04	6.18	6.5
Dorch. Bay	high	spring	1.1	2.33	2.6	2.4	3.23	2.64
Dorch. Bay	hugh	jul	2.41	1.94	2.37	2.28	3.53	3.03
Dorch. Bay	high	aug	2.44	2.87	3.12	3.15	6.63	5.52
Dorch. Bay	low	spring	1.49	2.04	1.59	2.1	3.73	2.9
Dorch. Bay	low	jul	1.72	1.9	2.05	2.59	2.67	4.12
Dorch. Bay	low	aug	3.1	2.76	3.73	2.12	5.78	**4.07**
Inner Harbor	high	fall/winter	4.5	4.39	4.15	4.9	5.89	4.63
Inner Harbor	high	spring	3.54	3.24	4.62	3.76	4.45	4.75
Inner Harbor	high	jul	3.82	3.22	3.88	3.69	4.66	4.96
Inner Harbor	high	aug	4.51	4.22	7.44	2.51	6.07	6.06
Inner Harbor	low	fall/winter	5.65	4.17	4.47	3.77	6.78	4.84
Inner Harbor	low	spring	3.59	2.97	4.04	3.79	3.78	4.63
Inner Harbor	low	jul	3.86	3.43	5.69	3.33	6.21	4.61
Inner Harbor	low	aug	3.86	4.56	4.35	3.31	5.6	5.71
Outer Harbor	high	fall/winter	3.45	1.33	2.85	1.76	3.53	**3.15**
Outer Harbor	high	spring	1.39	1.85	2.09	2.9	**3.7**	3.93
Outer Harbor	high	jul	1.39	2.98	0.92	1.56	2.17	2.27
Outer Harbor	high	aug	1.58	2.08	2.97	1.44	2.59	2.56
Outer Harbor	low	fall/winter	2.18	**1.95**	2.86	2.88	3.66	2.07
Outer Harbor	low	spring	2.6	1.47	2.86	1.87	3.09	2.2
Outer Harbor	low	jul	1.58	2.43	1.93	2.72	**3.49**	2.48
Outer Harbor	low	aug	2.4	1.39	3.69	1.69	3.04	2.43
		sum	155.90	147.98	175.88	154.37	214.50	191.85
		mean	**4.00**	**3.79**	**4.51**	**3.96**	**5.50**	**4.92**
		% reduction	**5.1%**		**12.2%**		**10.6%**	
		overall mean	**4.67**	**4.22**				
		overall % reduction	**9.5%**					

Highlighted cells denote estimated values

Fecal Coliform
Scheme C
ANOVA Analysis

ANOVA Multipliers	RMS = 0 in		0 in < RMS > .25 in		RMS > .25 in		Factorial	Treatment	time	rain	interaction
	89-91	92-94	89-91	92-94	89-91	92-94	Effect Total	SS	SS	SS	SS
time	-1	1	-1	1	-1	1	-52.08	11.59114	11.5911		
rain/no rain	-2	-2	1	1	1	1	128.84	35.46954		35.4695	
interaction	2	-2	-1	1	-1	1	-28.32	1.713723			1.7137231
high rain/low rain	0	0	-1	-1	1	1	76.10	37.12314		37.1231	
interaction	0	0	1	-1	-1	1	-1.14	0.008331			0.0083308
								85.90588	11.5911	72.5927	1.7220538

Correction: C = 4626.49
Total SS = 1428.68
Blocks SS = 637.75
Error SS = 705.02

Squares of ANOVA Multipliers							sum	divisor for SS
time	1	1	1	1	1	1	6	234
rain/no rain	4	4	1	1	1	1	12	468
interaction	4	4	1	1	1	1	12	468
high rain/low rain	0	0	1	1	1	1	4	156
interaction	0	0	1	1	1	1	4	156

#treat= 6
#blocks= 39
#cells= 234
#zeros= 11
avg of recip= 0.1431

ANOVA Results

Source of Variation	DoF	SS	MS	F
Blocks	38	637.75	16.78	29.78
Treatments	5	85.91	17.18	30.49
Time	1	11.59	11.59	**20.57**
Rainfall	2	72.59	36.30	64.40
Rain/no rain	*1*	*35.47*	*35.47*	*62.94*
high/low rain	*1*	*37.12*	*37.12*	*65.87*
Error	179	705.02	0.56	
Total	222	1428.68		

Enterococcus
Scheme A
Distribution of Samples over Treatments and Blocks

RANDOMIZED BLOCKS			TREATMENTS						Total # samples in block
Geographic Region	Tidal Condition	Season	RMS = 0 in		0 in < RMS > .25 in		RMS > .25 in		
			89-91	92-95	89-91	92-95	89-91	92-95	
Upper Charles	freshwater	fall/winter	89	0	19	0	72	0	180
Upper Charles	freshwater	spring	0	47	0	56	0	20	123
Upper Charles	freshwater	summer	39	31	36	43	68	51	268
Lower Charles	freshwater	fall/winter	108	6	32	5	83	4	238
Lower Charles	freshwater	spring	16	57	12	65	2	23	175
Lower Charles	freshwater	summer	58	37	38	50	79	47	309
Mystic R.	freshwater	fall/winter	46	68	19	61	8	51	253
Mystic R.	freshwater	spring	22	0	7	0	0	0	29
Mystic R.	freshwater	summer	77	133	37	38	102	46	433
Nepon. Head.	freshwater	fall/winter	10	0	14	0	8	0	32
Nepon. Head.	freshwater	spring	0	8	2	3	0	6	19
Nepon. Head.	freshwater	summer	6	18	8	23	10	17	82
Neponset R.	high	fall/winter	15	6	40	29	32	9	131
Neponset R.	high	spring	0	38	15	8	2	33	96
Neponset R.	high	summer	19	60	26	81	55	30	271
Neponset R.	low	fall/winter	15	7	31	7	14	19	93
Neponset R.	low	spring	1	7	0	19	5	32	64
Neponset R.	low	summer	20	53	16	55	15	65	224
Dorch. Bay	high	fall/winter	16	0	32	0	46	0	94
Dorch. Bay	high	spring	5	41	35	2	11	17	111
Dorch. Bay	high	summer	25	43	28	79	80	23	278
Dorch. Bay	low	fall/winter	15	0	28	0	12	0	55
Dorch. Bay	low	spring	18	6	15	19	19	24	101
Dorch. Bay	low	summer	27	58	35	48	52	58	278
Inner Harbor	high	fall/winter	52	36	52	44	64	22	270
Inner Harbor	high	spring	46	38	66	50	15	27	242
Inner Harbor	high	summer	97	90	43	58	152	50	490
Inner Harbor	low	fall/winter	24	43	28	31	44	31	201
Inner Harbor	low	spring	39	42	20	42	24	24	191
Inner Harbor	low	summer	93	92	62	65	78	59	449
Outer Harbor	high	fall/winter	29	10	32	4	21	0	96
Outer Harbor	high	spring	1	26	36	10	0	11	84
Outer Harbor	high	summer	53	96	46	102	71	156	524
Outer Harbor	low	fall/winter	62	0	4	5	18	5	94
Outer Harbor	low	spring	4	11	2	22	2	13	54
Outer Harbor	low	summer	49	165	14	98	63	75	464

Total number of *Enterococcus* samples: 7096

Enterococcus
Scheme A
Cell Average Values (Blocks with Insufficient Data Removed)

RANDOMIZED BLOCKS			TREATMENTS					
Geographic Region	Tidal Condition	Season	RMS = 0 in		0 in < RMS > .25 in		RMS > .25 in	
			89-91	92-95	89-91	92-95	89-91	92-95
Upper Charles	freshwater	fall/winter	5.63	**5.71**	6.14	**5.95**	7.16	**6.62**
Upper Charles	freshwater	spring	**4.59**	4.62	**4.88**	4.93	**6.09**	5.37
Upper Charles	freshwater	summer	4.58	3.80	4.07	4.69	6.53	5.09
Lower Charles	freshwater	fall/winter	4.62	6.94	4.84	5.87	6.11	6.67
Lower Charles	freshwater	spring	2.26	3.14	2.29	3.28	3.69	4.20
Lower Charles	freshwater	summer	3.02	2.84	3.10	3.49	4.60	3.99
Mystic R.	freshwater	fall/winter	3.86	3.50	5.82	4.14	8.00	4.38
Mystic R.	freshwater	summer	3.81	3.84	3.69	3.49	4.73	5.27
Nepon. Head.	freshwater	summer	6.66	5.33	6.16	5.58	8.34	6.99
Neponset R.	high	fall/winter	3.45	2.60	3.03	3.47	4.22	3.22
Neponset R.	high	spring	**3.59**	2.79	4.16	4.90	4.30	4.72
Neponset R.	high	summer	2.77	2.81	3.20	3.06	5.19	3.86
Neponset R.	low	fall/winter	3.59	6.25	4.91	6.42	7.29	5.60
Neponset R.	low	spring	2.40	3.78	**4.27**	4.02	7.35	5.01
Neponset R.	low	summer	3.97	3.84	4.59	3.84	5.36	5.30
Dorch. Bay	high	spring	0.92	1.52	1.70	1.79	2.43	1.98
Dorch. Bay	high	summer	2.23	1.78	1.69	2.02	2.62	2.53
Dorch. Bay	low	spring	1.07	1.48	1.01	1.48	2.16	2.19
Dorch. Bay	low	summer	1.77	1.73	1.85	2.00	1.75	3.32
Inner Harbor	high	fall/winter	3.52	2.24	3.59	2.85	5.21	2.76
Inner Harbor	high	spring	1.94	2.41	2.46	2.50	2.87	3.53
Inner Harbor	high	summer	3.02	2.17	2.12	2.29	3.42	3.20
Inner Harbor	low	fall/winter	3.42	3.07	4.59	3.01	6.36	3.36
Inner Harbor	low	spring	2.28	2.76	2.10	3.21	3.06	4.39
Inner Harbor	low	summer	2.43	2.39	3.36	2.42	3.65	3.43
Outer Harbor	high	fall/winter	3.66	1.33	2.65	0.92	3.74	**2.96**
Outer Harbor	high	spring	0.92	1.58	1.60	2.44	**3.25**	3.67
Outer Harbor	high	summer	1.51	1.71	1.57	1.49	1.63	2.01
Outer Harbor	low	fall/winter	2.32	**1.87**	2.78	1.46	4.65	1.09
Outer Harbor	low	spring	1.67	1.64	1.89	1.62	1.35	2.45
Outer Harbor	low	summer	1.69	1.60	1.91	1.84	2.38	2.06
		sum	93.17	93.07	102.02	100.47	139.49	121.22
		mean	**3.01**	**3.00**	**3.29**	**3.24**	**4.50**	**3.91**
		% reduction	**0.1%**		**1.5%**		**13.1%**	
		overall mean	**3.60**	**3.38**				
		overall % reduction	**6.0%**					

Highlighted cells denote estimated values

Enteroccccus
Scheme A
ANOVA Analysis

	ANOVA Multipliers										
	RMS = 0 in		0 in < RMS > .25 in		RMS > .25 in		Factorial	Treatment	time	rain	interaction
	89-91	92-94	89-91	92-94	89-91	92-94	Effect Total	SS	SS	SS	SS
time	-1	1	-1	1	-1	1	-19.92	2.133368	2.13337		
rain/no rain	-2	-2	1	1	1	1	90.72	22.12397		22.124	
interaction	2	-2	-1	1	-1	1	-19.62	1.034797			1.0347968
high rain/low rain	0	0	-1	-1	1	1	58.22	27.33523		27.3352	
interaction	0	0	1	-1	-1	1	-16.72	2.254503			2.2545032
								54.88187	2.13337	49.4592	3.2893

Correction: C = 2267.59
Total SS = 888.02
Blocks SS = 368.343
Error SS = 464.80

	Squares of ANOVA Multipliers						sum	divisor for SS
time	1	1	1	1	1	1	6	186
rain/no rain	4	4	1	1	1	1	12	372
interaction	4	4	1	1	1	1	12	372
high rain/low rain	0	0	1	1	1	1	4	124
interaction	0	0	1	1	1	1	4	124

#treat= 6
#blocks= 31
#cells= 186
#zeros= 11
avg of recip= 0.1286

ANOVA Results

Source of Variation	DoF	SS	MS	F
Blocks	30	368.34	12.28	28.54
Treatments	5	54.88	10.98	25.52
Time	1	2.13	2.13	**4.96**
Rainfall	2	49.46	24.73	57.49
Rain/no rain	*1*	*22.12*	*22.12*	*51.43*
high/low rain	*1*	*27.34*	*27.34*	*63.55*
Error	139	464.80	0.43	
Total	174	888.02		

Enterococcus
Scheme B
Distribution of Samples over Treatments and Blocks

RANDOMIZED BLOCKS			TREATMENTS						Total # samples in block
Geographic Region	Tidal Condition	Season	RMS = 0 in		0 in < RMS > .25 in		RMS > .25 in		
			89-91	92-95	89-91	92-95	89-91	92-95	
Charles R.	freshwater	fall/winter	197	6	51	5	155	4	418
Charles R.	freshwater	spring	16	104	12	121	2	43	298
Charles R.	freshwater	summer	97	68	74	93	147	98	577
Mystic R.	freshwater	fall/winter	46	68	19	61	8	51	253
Mystic R.	freshwater	spring	22	0	7	0	0	0	29
Mystic R.	freshwater	summer	77	133	37	38	102	46	433
Nepon. Head.	freshwater	fall/winter	10	0	14	0	8	0	32
Nepon. Head.	freshwater	spring	0	8	2	3	0	6	19
Nepon. Head.	freshwater	summer	6	18	8	23	10	17	82
Neponset R.	high	fall/winter	15	6	40	29	32	9	131
Neponset R.	high	spring	0	38	15	8	2	33	96
Neponset R.	high	summer	19	60	26	81	55	30	271
Neponset R.	low	fall/winter	15	7	31	7	14	19	93
Neponset R.	low	spring	1	7	0	19	5	32	64
Neponset R.	low	summer	20	53	16	55	15	65	224
Dorch. Bay	high	fall/winter	16	0	32	0	46	0	94
Dorch. Bay	high	spring	5	41	35	2	11	17	111
Dorch. Bay	high	summer	25	43	28	79	80	23	278
Dorch. Bay	low	fall/winter	15	0	28	0	12	0	55
Dorch. Bay	low	spring	18	6	15	19	19	24	101
Dorch. Bay	low	summer	27	58	35	48	52	58	278
Inner Harbor	high	fall/winter	52	36	52	44	64	22	270
Inner Harbor	high	spring	46	38	66	50	15	27	242
Inner Harbor	high	summer	97	90	43	58	152	50	490
Inner Harbor	low	fall/winter	24	43	28	31	44	31	201
Inner Harbor	low	spring	39	42	20	42	24	24	191
Inner Harbor	low	summer	93	92	62	65	78	59	449
Outer Harbor	high	fall/winter	29	10	32	4	21	0	96
Outer Harbor	high	spring	1	26	36	10	0	11	84
Outer Harbor	high	summer	53	96	46	102	71	156	524
Outer Harbor	low	fall/winter	62	0	4	5	18	5	94
Outer Harbor	low	spring	4	11	2	22	2	13	54
Outer Harbor	low	summer	49	165	14	98	63	75	464

Total number of *Enterococcus* samples: 7096

Enterococcus
Scheme B
Cell Average Values (Blocks with Insufficient Data Removed)

RANDOMIZED BLOCKS			TREATMENTS					
Geographic Region	Tidal Condition	Season	RMS = 0 in		0 in < RMS > .25 in		RMS > .25 in	
			89-91	92-95	89-91	92-95	89-91	92-95
Charles R.	freshwater	fall/winter	5.08	6.94	5.32	5.87	6.60	6.67
Charles R.	freshwater	spring	2.26	3.81	2.29	4.04	3.69	4.75
Charles R.	freshwater	summer	3.64	3.28	3.57	4.05	5.49	4.56
Mystic R.	freshwater	fall/winter	3.86	3.50	5.82	4.14	8.00	4.38
Mystic R.	freshwater	summer	3.81	3.84	3.69	3.49	4.73	5.27
Nepon. Head.	freshwater	summer	6.66	5.33	6.16	5.58	8.34	6.99
Neponset R.	high	fall/winter	3.45	2.60	3.03	3.47	4.22	3.22
Neponset R.	high	spring	**3.58**	2.79	4.16	4.90	4.30	4.72
Neponset R.	high	summer	2.77	2.81	3.20	3.06	5.19	3.86
Neponset R.	low	fall/winter	3.59	6.25	4.91	6.42	7.29	5.60
Neponset R.	low	spring	2.40	3.78	**4.28**	4.02	7.35	5.01
Neponset R.	low	summer	3.97	3.84	4.59	3.84	5.36	5.30
Dorch. Bay	high	spring	0.92	1.52	1.70	1.79	2.43	1.98
Dorch. Bay	high	summer	2.23	1.78	1.69	2.02	2.62	2.53
Dorch. Bay	low	spring	1.07	1.48	1.01	1.48	2.16	2.19
Dorch. Bay	low	summer	1.77	1.73	1.85	2.00	1.75	3.32
Inner Harbor	high	fall/winter	3.52	2.24	3.59	2.85	5.21	2.76
Inner Harbor	high	spring	1.94	2.41	2.46	2.50	2.87	3.53
Inner Harbor	high	summer	3.02	2.17	2.12	2.29	3.42	3.20
Inner Harbor	low	fall/winter	3.42	3.07	4.59	3.01	6.36	3.36
Inner Harbor	low	spring	2.28	2.76	2.10	3.21	3.06	4.39
Inner Harbor	low	summer	2.43	2.39	3.36	2.42	3.65	3.43
Outer Harbor	high	fall/winter	3.66	1.33	2.65	0.92	3.74	**2.97**
Outer Harbor	high	spring	0.92	1.58	1.60	2.44	**3.23**	3.67
Outer Harbor	high	summer	1.51	1.71	1.57	1.49	1.63	2.01
Outer Harbor	low	fall/winter	2.32	**1.89**	2.78	1.46	4.65	1.09
Outer Harbor	low	spring	1.67	1.64	1.89	1.62	1.35	2.45
Outer Harbor	low	summer	1.69	1.60	1.91	1.84	2.38	2.06
		sum	79.44	80.07	87.89	86.22	121.07	105.27
		mean	**2.84**	**2.86**	**3.14**	**3.08**	**4.32**	**3.76**
		% reduction	**-0.8%**		**1.9%**		**13.1%**	
		overall mean	**3.43**	**3.23**				
		overall % reduction	**5.8%**					

Highlighted cells denote estimated values

Enterococcus
Scheme B
ANOVA Analysis

ANOVA Multipliers											
	RMS = 0 in		0 in < RMS > .25 in		RMS > .25 in		Factorial	Treatment	time	rain	interaction
	89-91	92-94	89-91	92-94	89-91	92-94	Effect Total	SS	SS	SS	SS
time	-1	1	-1	1	-1	1	-16.84	1.68801	1.68801		
rain/no rain	-2	-2	1	1	1	1	81.43	19.73466		19.7347	
interaction	2	-2	-1	1	-1	1	-18.73	1.044086			1.044086
high rain/low rain	0	0	-1	-1	1	1	52.23	24.3569		24.3569	
interaction	0	0	1	-1	-1	1	-14.13	1.782651			1.7826509
								48.6063	1.68801	44.0916	2.8267369

	Squares of ANOVA Multipliers						sum	divisor for SS
time	1	1	1	1	1	1	6	168
rain/no rain	4	4	1	1	1	1	12	336
interaction	4	4	1	1	1	1	12	336
high rain/low rain	0	0	1	1	1	1	4	112
interaction	0	0	1	1	1	1	4	112

Correction: C = 1866.4
Total SS = 827.33
Blocks SS = 303.288
Error SS = 475.44

#treat= 6
#blocks= 28
#cells= 168
#zeros= 5
avg of recip= 0.1042

ANOVA Results

Source of Variation	DoF	SS	MS	F
Blocks	27	303.29	11.23	29.48
Treatments	5	48.61	9.72	25.52
Time	1	1.69	1.69	**4.43**
Rainfall	2	44.09	22.05	57.86
Rain/no rain	*1*	*19.73*	*19.73*	*51.80*
high/low rain	*1*	*24.36*	*24.36*	*63.93*
Error	130	475.44	0.38	
Total	162	827.33		

Enterococcus
Scheme C
Distribution of Samples over Treatments and Blocks

RANDOMIZED BLOCKS			TREATMENTS						Total # samples in block
Geographic Region	Tidal Condition	Season	RMS = 0 in		0 in < RMS > .25 in		RMS > .25 in		
			89-91	92-95	89-91	92-95	89-91	92-95	
Upper Charles	freshwater	fall/winter	89	0	19	0	72	0	180
Upper Charles	freshwater	spring	0	47	0	56	0	20	123
Upper Charles	freshwater	jul	39	31	35	43	68	51	267
Upper Charles	freshwater	aug	0	0	1	0	0	0	1
Lower Charles	freshwater	fall/winter	108	6	32	5	83	4	238
Lower Charles	freshwater	spring	16	57	12	65	2	23	175
Lower Charles	freshwater	jul	51	37	34	50	73	47	292
Lower Charles	freshwater	aug	7	0	4	0	6	0	17
Mystic R.	freshwater	fall/winter	46	68	19	61	8	51	253
Mystic R.	freshwater	spring	22	0	7	0	0	0	29
Mystic R.	freshwater	jul	21	0	21	0	16	0	58
Mystic R.	freshwater	aug	56	133	16	38	86	46	375
Nepon. Head.	freshwater	fall/winter	10	0	14	0	8	0	32
Nepon. Head.	freshwater	spring	0	8	2	3	0	6	19
Nepon. Head.	freshwater	jul	2	15	4	21	8	16	66
Nepon. Head.	freshwater	aug	4	3	4	2	2	1	16
Neponset R.	high	fall/winter	15	6	40	29	32	9	131
Neponset R.	high	spring	0	38	15	8	2	33	96
Neponset R.	high	jul	7	60	21	74	46	28	236
Neponset R.	high	aug	12	0	5	7	9	2	35
Neponset R.	low	fall/winter	15	7	31	7	14	19	93
Neponset R.	low	spring	1	7	0	19	5	32	64
Neponset R.	low	jul	8	34	0	49	15	65	171
Neponset R.	low	aug	12	19	16	6	0	0	53
Dorch. Bay	high	fall/winter	16	0	32	0	46	0	94
Dorch. Bay	high	spring	5	41	35	2	11	17	111
Dorch. Bay	hugh	jul	12	43	23	71	70	21	240
Dorch. Bay	high	aug	13	0	5	8	10	2	38
Dorch. Bay	low	fall/winter	15	0	28	0	12	0	55
Dorch. Bay	low	spring	18	6	15	19	19	24	101
Dorch. Bay	low	jul	13	41	16	45	47	58	220
Dorch. Bay	low	aug	14	17	19	3	5	0	58
Inner Harbor	high	fall/winter	52	36	52	44	64	22	270
Inner Harbor	high	spring	46	38	66	50	15	27	242
Inner Harbor	high	jul	20	45	22	48	27	35	197
Inner Harbor	high	aug	77	45	21	10	125	15	293
Inner Harbor	low	fall/winter	24	43	28	31	44	31	201
Inner Harbor	low	spring	39	42	20	42	24	24	191
Inner Harbor	low	jul	50	27	15	43	13	43	191
Inner Harbor	low	aug	43	65	47	22	65	16	258
Outer Harbor	high	fall/winter	29	10	32	4	21	0	96
Outer Harbor	high	spring	1	26	36	10	0	11	84
Outer Harbor	high	jul	1	19	3	36	11	25	95
Outer Harbor	high	aug	52	77	43	66	60	131	429
Outer Harbor	low	fall/winter	62	0	4	5	18	5	94
Outer Harbor	low	spring	4	11	2	22	2	13	54
Outer Harbor	low	jul	28	63	2	29	0	28	150
Outer Harbor	low	aug	21	102	12	69	63	47	314

Total number of *Enterococcus* samples: 7096

Enterococcus
Scheme C
Cell Average Values (Blocks with Insufficient Data Removed)

RANDOMIZED BLOCKS			TREATMENTS					
Geographic Region	Tidal Condition	Season	RMS = 0 in		0 in < RMS > .25 in		RMS > .25 in	
			89-91	92-95	89-91	92-95	89-91	92-95
Upper Charles	freshwater	fall/winter	5.63	**5.74**	6.14	**5.93**	7.16	**6.78**
Upper Charles	freshwater	spring	**4.52**	4.62	**4.76**	4.93	**6.12**	5.37
Upper Charles	freshwater	jul	4.58	3.8	4.03	4.69	6.53	5.09
Lower Charles	freshwater	fall/winter	4.62	6.94	4.84	5.87	6.11	6.67
Lower Charles	freshwater	spring	2.26	3.14	2.29	3.28	3.69	4.2
Lower Charles	freshwater	jul	2.97	2.84	3.15	3.49	4.56	3.99
Mystic R.	freshwater	fall/winter	3.86	3.5	5.82	4.14	8	4.38
Mystic R.	freshwater	aug	3.84	3.84	3.53	3.49	4.81	5.27
Nepon. Head.	freshwater	jul	6.98	5.33	5.85	5.5	7.87	6.83
Nepon. Head.	freshwater	aug	6.5	5.36	6.48	6.46	10.23	9.43
Neponset R.	high	fall/winter	3.45	2.6	3.03	3.47	4.22	3.22
Neponset R.	high	spring	**3.54**	2.79	4.16	4.9	4.3	4.72
Neponset R.	high	jul	2.05	2.81	3.14	2.94	4.66	3.67
Neponset R.	high	aug	3.2	**4.49**	3.44	4.25	7.9	6.64
Neponset R.	low	fall/winter	3.59	6.25	4.91	6.42	7.29	5.6
Neponset R.	low	spring	2.4	3.78	**4.16**	4.02	7.35	5.01
Neponset R.	low	jul	4.29	3.79	**4.19**	3.98	5.36	5.3
Dorch. Bay	high	spring	0.92	1.52	1.7	1.79	2.43	1.98
Dorch. Bay	hugh	jul	1.79	1.78	1.61	1.99	2.28	2.36
Dorch. Bay	high	aug	2.64	**2.66**	2.04	2.26	5	4.3
Dorch. Bay	low	spring	1.07	1.48	1.01	1.48	2.16	2.19
Dorch. Bay	low	jul	1.41	1.59	1.31	2.02	1.51	3.32
Dorch. Bay	low	aug	2.1	2.07	2.3	1.79	3.97	**3.11**
Inner Harbor	high	fall/winter	3.52	2.24	3.59	2.85	5.21	2.76
Inner Harbor	high	spring	1.94	2.41	2.46	2.5	2.87	3.53
Inner Harbor	high	jul	1.54	1.97	1.82	2.37	2.22	2.99
Inner Harbor	high	aug	3.4	2.37	2.43	1.89	3.68	3.7
Inner Harbor	low	fall/winter	3.42	3.07	4.59	3.01	6.36	3.36
Inner Harbor	low	spring	2.28	2.76	2.1	3.21	3.06	4.39
Inner Harbor	low	jul	1.88	1.72	3.51	2.52	4.25	3.28
Inner Harbor	low	aug	3.07	2.67	3.32	2.23	3.53	3.84
Outer Harbor	high	fall/winter	3.66	1.33	2.65	0.92	3.74	**3.12**
Outer Harbor	high	spring	0.92	1.58	1.6	2.44	**3.33**	3.67
Outer Harbor	high	jul	0.92	2.21	1.23	1.56	1.5	2.31
Outer Harbor	high	aug	1.52	1.58	1.59	1.45	1.66	1.95
Outer Harbor	low	fall/winter	2.32	**1.87**	2.78	1.46	4.65	1.09
Outer Harbor	low	spring	1.67	1.64	1.89	1.62	1.35	2.45
Outer Harbor	low	jul	1.22	1.59	1.56	1.97	**2.97**	2.11
Outer Harbor	low	aug	2.31	1.6	1.97	1.78	2.38	2.04
		sum	113.80	115.33	122.98	122.87	176.27	156.02
		mean	**2.92**	**2.96**	**3.15**	**3.15**	**4.52**	**4.00**
		% reduction	**-1.3%**		**0.1%**		**11.5%**	
		overall mean	**3.53**	**3.37**				
		overall % reduction	**4.6%**					

Highlighted cells denote estimated values

Enterococcus
Scheme C
ANOVA Analysis

	ANOVA Multipliers										
	RMS = 0 in		0 in < RMS > .25 in		RMS > .25 in		Factorial	Treatment	time	rain	interaction
	89-91	92-94	89-91	92-94	89-91	92-94	Effect Total	SS	SS	SS	SS
time	-1	1	-1	1	-1	1	-18.83	1.515252	1.51525		
rain/no rain	-2	-2	1	1	1	1	119.88	30.70772		30.7077	
interaction	2	-2	-1	1	-1	1	-23.42	1.172001			1.1720009
high rain/low rain	0	0	-1	-1	1	1	86.44	47.89663		47.8966	
interaction	0	0	1	-1	-1	1	-20.14	2.600126			2.6001256
								83.89173	1.51525	78.6043	3.7721265

Correction: C = 2784.98
Total SS = 1210.56
Blocks SS = 527.592
Error SS = 599.08

	Squares of ANOVA Multipliers						sum	divisor for SS
time	1	1	1	1	1	1	6	234
rain/no rain	4	4	1	1	1	1	12	468
interaction	4	4	1	1	1	1	12	468
high rain/low rain	0	0	1	1	1	1	4	156
interaction	0	0	1	1	1	1	4	156

#treat= 6
#blocks= 39
#cells= 234
#zeros= 16
avg of recip= 0.1637

ANOVA Results

Source of Variation	DoF	SS	MS	F
Blocks	38	527.59	13.88	24.64
Treatments	5	83.89	16.78	29.78
Time	1	1.52	1.52	**2.69**
Rainfall	2	78.60	39.30	69.75
Rain/no rain	*1*	*30.71*	*30.71*	*54.50*
high/low rain	*1*	*47.90*	*47.90*	*85.00*
Error	174	599.08	0.56	
Total	217	1210.56		

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