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A Spatial and Temporal Analysis of Boston Harbor Microbiological Data

Massachusetts Water Resources Authority

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A SPATIAL AND TEMPORAL ANALYSIS OF BOSTON HARBOR MICROBIOLOGICAL DATA

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EXECUTIVE SUMMARY

Coliform bacteria, found in sewage in large numbers, have been used for decades as indicators of both diminished water quality resulting from sewage input and increased risk to public health. Studies from as early as 1905 have relied upon bacteria counts to quantify the conditions of Boston Harbor waters. As a result, a large amount of historical information has accumulated.

The objective of this study was to enhance our understanding of spatial and temporal variability in Boston Harbor bacteria levels using this long-term data base. We sought to:

- determine if fecal coliform and *Enterococcus* bacteria counts showed harborwide differences.
- evaluate the relationship of fecal coliform counts with rainfall and wastewater treatment plant effluents.
- investigate whether water quality as measured by fecal coliform bacteria levels has improved over the decades.

Data accumulated during the past decade (1980's) showed that fecal coliform levels varied among different regions around Boston Harbor. The lowest levels of fecal coliform were offshore in Quincy and Dorchester Bays and off Nantasket. Areas typically showing high fecal coliform counts have been the Inner Harbor and the Neponset River. At beaches, those outside Boston Harbor, both to the north and to the south, have had lower fecal coliform counts and fewer closures than beaches within the harbor. Among Boston Harbor beaches, the most contaminated were Constitution, Tenean, and Wollaston.

Despite the great spatial differences in fecal coliform densities in the harbor area, and the methodological differences in measuring indicator bacteria used over the years, we found a definite trend in water quality: many areas of the harbor now (the 1980's) exhibit much lower counts in the Inner Harbor, near Deer Island, Governors Island, President Roads, Moon Head, Dorchester Bay and

Nantasket have decreased at least 10- to 100-fold over the past 50 years. In some cases the decrease is as much as 1000-fold. Dramatically lower coliform counts coincided with the opening of the Deer and Nut Island sewage treatment plants. The building of CSO treatment facilities and the elimination of the Moon Island CSO has decreased coliform loadings from CSOs, with concomitant improvements in water quality.

Several caveats to this general conclusion of improving water quality must be noted. Sporadic high counts, which have usually been associated with major rainfalls or failure of chlorination at the treatment plants, have continued to occur throughout the harbor. In addition, water quality remains poor (compared to swimming standards) in certain areas, especially in the Inner Harbor, the Neponset River, at Tenean Beach, and at Wollaston Beach. In much of the harbor, shellfishing, which is the water use most sensitive to sewage pollution, remains prohibited or restricted. It is likely that these areas and uses are, at least in part, compromised by "nonpoint sources" that may be difficult to abate.

1.0 INTRODUCTION

Coliform bacteria have been utilized as indicators of both diminished water quality resulting from sewage input and increased risk to public health for decades. Studies from as early as 1905 have relied upon bacteria counts to quantify the conditions of Boston Harbor waters. As a result, a large amount of historical information has accumulated. This report is an effort to discover if, in this wealth of data collected over decades, there is evidence of broad-scale trends in time and space in Boston Harbor. These data were collected by different agencies, with overlapping time scales, varied stations, and different analytic protocols, and have not previously been evaluated for common trends. Variations in sampling and methodology can make the examination of long-term changes in harbor waters difficult. This not withstanding, the objective of this study was to address the question:

> How can the historical data base enhance our understanding of spatial and temporal variability in harborwide coliform counts? Specifically:
>
> - are there spatial differences in fecal coliform levels?
> - do environmental parameters show a strong relationship to fecal coliform levels?
> - have fecal coliform counts changed over the past few decades?

To answer this question, we evaluated the available historical data in terms of its suitability for further investigation, selected key studies for further statistical analysis, and examined the results.

2.0 METHODS

Different agencies in the Commonwealth of Massachusetts use bacterial indicators to assess water quality and levels of pollution for different purposes, including monitoring shellfish growing areas, bathing beaches, and effects of known and unknown sources of sewage. The data collected for these various purposes are often not intercomparable, because of differing study designs, areas sampled, frequency of sampling, laboratory methods, type of bacteria measured, etc.

We examined a number of studies for their suitability for further analysis (Table 2-1). These included historical reports from the Federal Water Pollution Control Administration (FWPC) 1967; Division of Water Pollution Control (DWPC) 1969, 1970,1973; Metropolitan District Commission (MDC) 1985, 1986, 1987, 1988, 1989; Massachusetts Department of Environmental Protection (MDEP) 1990; Massachusetts Department of Environmental Quality Engineering (MDEQE) 1982, 1984, 1986a,b; Camp Dresser McKee (CDM) 1967; Mass. Senate 1930; House Report 2565, 1939; and Robinson, et al. (New England Aquarium) 1990. Additional data was acquired in machine readable form from Massachusetts Water Resources Authority (MWRA), Department of Environmental Protection (DEP, formerly DEQE), and Division of Marine Fisheries (DMF), and as data sheets from DMF. There were additional sources of data, but they were not as readily accessible and were not included as part of this project. The data were evaluated in terms of their utility for further analyses. Some studies were selected for use only in long-term comparisons. Station locations for the studies chosen for additional analysis (Table 2-2) are shown in Figures 2-1 through 2-6. Selected data (Table 2-2) were entered into a computer file, and verified, visually checked for accuracy, and screened for errors through the use of programmed error checks. Coliform counts were plotted by date; and the mean, median, range, and quartiles were computed and plotted for data screening purposes. The distribution of raw and log (x+1) transformed counts was evaluated using frequency plots.

TABLE 2-1. HISTORICAL MICROBIOLOGICAL STUDIES IN GREATER BOSTON AREA.

SOURCE OF DATA	PROGRAM TYPE	YEARS	SELECTED FOR FURTHER ANALYSIS	TOTAL COLIFORM	FECAL COLIFORM	ENTEROCOCCUS
MDC	Beach closure monitoring program	1982-1984		MF	MF	
		1985		MF	MF	
		1986			MF	MF
		1987	X		MF	MF
		1988	X		MF	MF
		1989	X		MF	MF
		1990	X		MF	MF
DMF	Shellfish bed monitoring	1986-1989	X(1987 only)	MPN	MPN	
MWRA	CSO monitoring	1989,1990	X		MF	MF
DMF/DEQE	Shellfish bed monitoring	1976-1986			MPN	
	Quincy Bay study	1979		MPN	MPN	
	Tidal study	1970		MPN	MPN	
MA Dept. Public Health	Dorchester Bay study	1970		MPN	MPN	
DEP(DEQE)	Boston Harbor water quality studies	1985-1989	X	MF	MF	MF(limi-ted)
Town of Hingham Dept. of Public Health	Beach monitoring program	1970-present		X*	X*	

TABLE 2-1. (Continued)

SOURCE OF DATA	PROGRAM TYPE	YEARS	SELECTED FOR FURTHER ANALYSIS	TOTAL COLIFORM	FECAL COLIFORM	ENTEROCOCCUS
MWRC, DWPC	Pollution Survey	1972	X	MPN	MPN	
DWPC CDM		1967 1966	X	MF,MPN X**	MF,MPN X**	
Mass Dept. of Public Health		1949 1935 1929-1930	1935 study used for comparative purposes	MPN	MPN, *B.coli*	
Senate Report 56		1929-1930		#/CC	% positive per CC	
New England Aquarium (Robinson et al. 1990)		1987-1989	used for comparative purposes		MF	

*Staff member did not know method employed.
**Method was not stated.

TABLE 2-2. DESCRIPTION OF DATA SELECTED FOR FURTHER ANALYSIS OF LONG-TERM TRENDS IN BOSTON HARBOR.

DECADE	DATA SOURCE & YEARS SELECTED	BEST USE	LIMITATIONS
1980-1990	MDC Beach Data 1987-1989	Large consistently collected data base; stations nr. CSO's. Spatial comparisons over time.	No measurement >4000; nearshore stations only; summer only
	DMF Car Station and shellfish monitoring 1987	Good spatial distribution of stations; already on diskette; good for comparison to historical DMF data; tide and rainfall info. avail.	Sporadic collections; computer file not complete.
	DEP (formerly DEQE) 1985-1988	Good harborwide spatial distribution; with supporting physicochemical data; good for spatial and historical comparisons; on diskette	Sporadic sampling; summer only.
	MWRA CSO 1989, 1990	Good spatial coverage, esp. near CSOs; intensive study; on diskette	3 week periods
1970-1980	DWPC 1972	Good spatial distribution. Historical comparison.	Summer only; MPN
	DPH 1970	Good historical comparison; good environmental info.	Dorchester only; MPN
1960's	DWPC 1967	Good for short-term temporal comparisons; MPN and MF methods used, allowing comparisons; tide and salinity data	Only 4 stations sampled consistently (6 sampling dates).

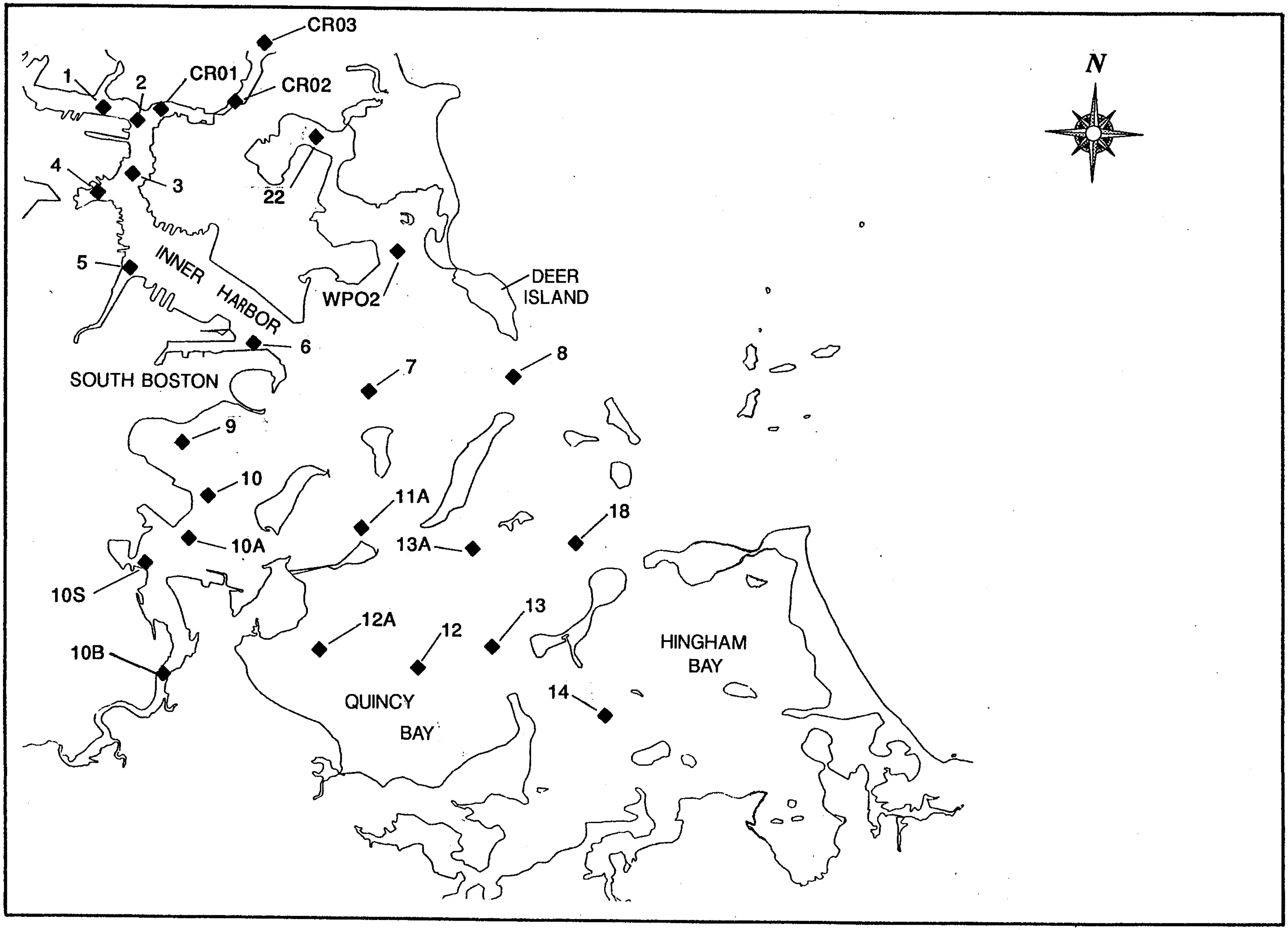


Figure 2-1. Stations sampled by MDEP as part of Boston Harbor Water Quality sampling program from 1985-1988.

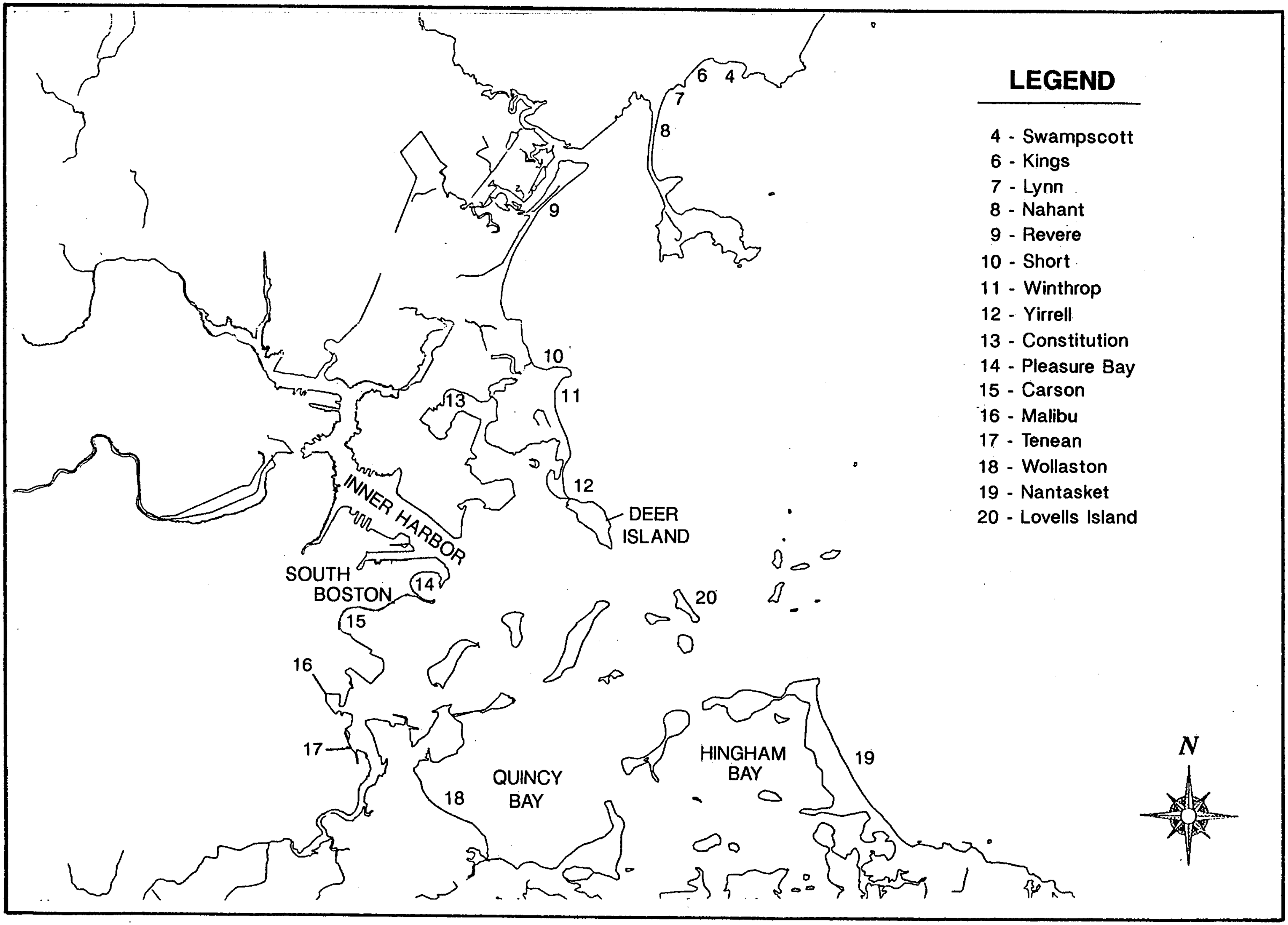


Figure 2-2. Locations of beaches sampled during MDC beach monitoring program from 1987-1989.

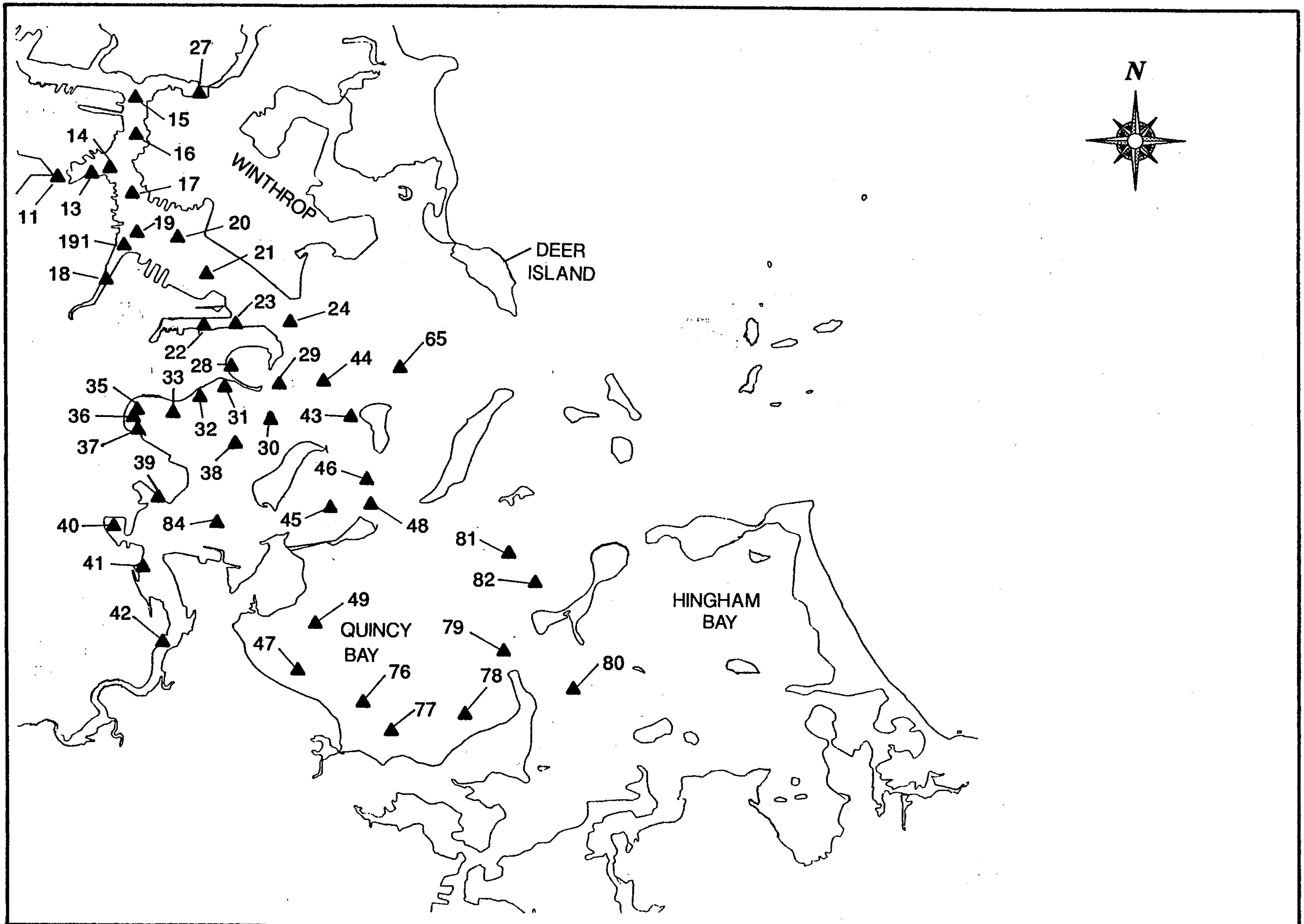


Figure 2-3. Stations sampled during MWRA's CSO Monitoring Program in 1989 and 1990.

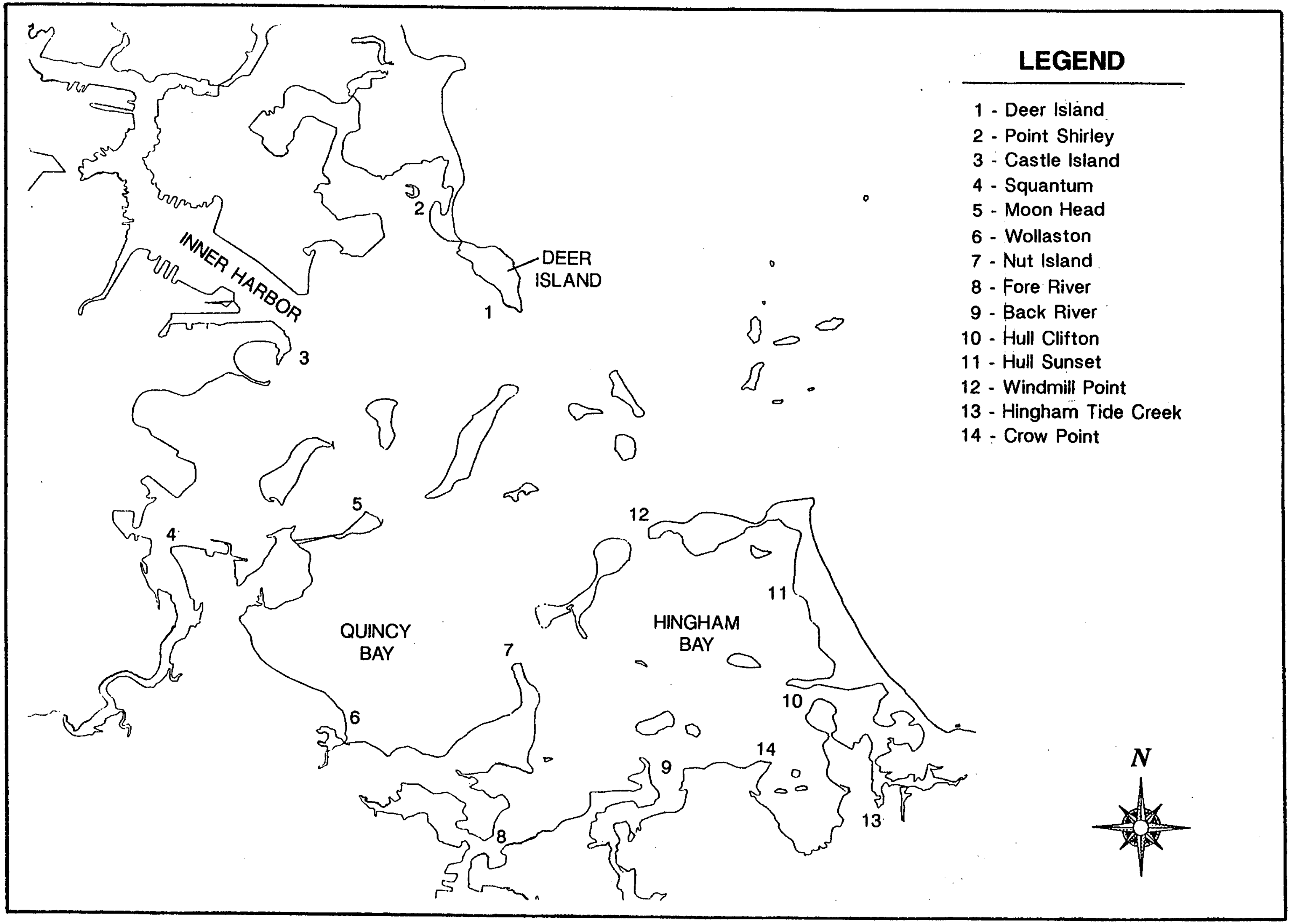


Figure 2-4. Stations sampled as part of MDMF's shellfish monitoring program.

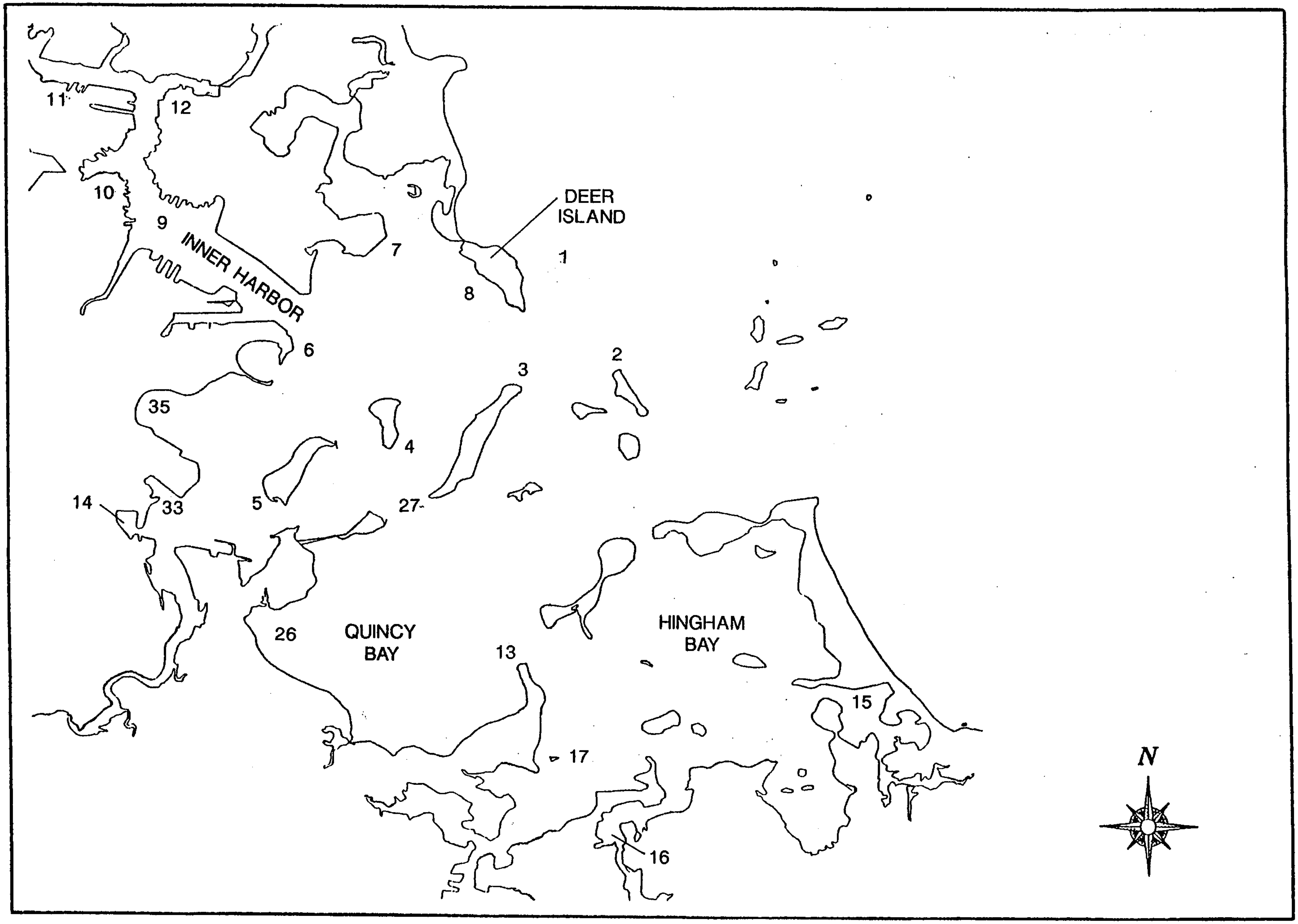


Figure 2-5. Station locations for Boston Harbor Study conducted by DWPC in 1972.

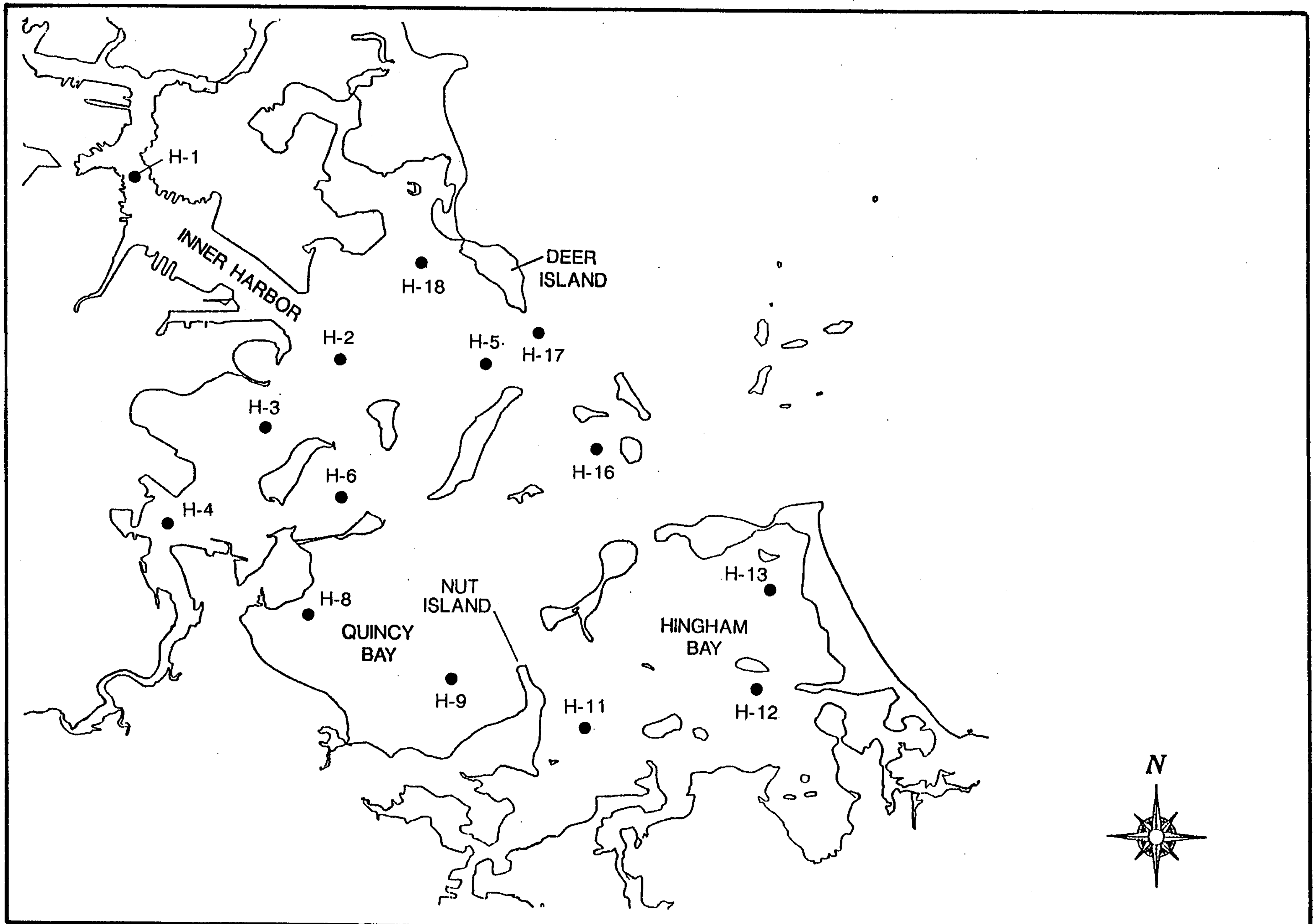


Figure 2-6. Station locations for Boston Harbor Study conducted by FWPC in 1967.

The data collected by MDC for beach monitoring represented a unique case because fecal coliform bacterial counts exceeding 4000 per 100 ml were not reported. When statistics were computed, values listed as ">4000" were given a value of 4001. Thus, some of the average MDC counts underestimate the true number of fecal coliforms. However, counts of greater than 4000 were not common. Although Swampscott, Kings, Lynn, Short, Constitution, Carson, Wollaston and Tenean Beaches had counts exceeding 4000, in all cases these occurred less than 12.5% of the time, and at all but two beaches (Wollaston, Constitution) only occurred once or twice (between 37 and 192 samples were collected). We used parametric statistics to analyze these data since counts rarely exceeded 4000.

Spatial patterns for data collected in the 1980s were investigated using the analysis of variance (ANOVA) or nonparametric analyses. A two-way analysis by year and station using log (x+1) transformed coliform counts was employed for all data analyzed using the membrane filter (MF) method. This included data collected by MDC for beach monitoring, DEP for water quality monitoring, and MWRA for CSO monitoring. Differences among mean values were tested for significance using the Duncan-Waller K-ratio t-test (Waller and Duncan 1969). This test was selected because it strikes a balance between more commonly used multiple comparison tests, which are less conservative; and more conservative tests, which often fail to detect significant differences among means even when the ANOVA shows highly significant differences. Ranges for geometric mean coliform counts were computed for the station groups delineated by the means separation test; these were plotted on base maps to evaluate overall spatial trends (overlooking year-to-year differences). A one-way analysis of variance was performed for each year individually when the two-way ANOVA results were confounded by significant year-station interactions.

We used non-parametric statistics to analyze counts derived from the "most probable number" (MPN) method (mainly DMF shellfish monitoring studies in 1987). The Kruskal-Wallis test (Sokal and Rohlf 1969), a nonparametric analogue of a one-way ANOVA, was utilized to test for among-station differences for the one year of shellfish monitoring data analyzed.

The relationship between fecal coliform counts and environmental parameters was investigated by a linear regression (Sokal and Rohlf 1969). Log (x+1) transformed fecal coliform counts were regressed against rainfall (measured by NOAA at Logan Airport and accumulated over 1, 2, 3, and 4 day periods), wastewater treatment plant flows and fecal coliform loadings (measured at both Deer Island and Nut Island plants). Loading amounts were log (x+1) transformed prior to the analysis. Fecal coliform loadings were calculated by multiplying daily plant flow by the fecal coliform concentration in the effluent. Rainfall and flow data were provided by MWRA.

3.0 RESULTS

3.1 SPATIAL TRENDS

3.1.1 Beach Monitoring Program

Results from MDC's summer beach testing suggest that Boston area beaches vary in fecal coliform and *Enterococcus* count levels. Fecal coliform levels at most beaches occasionally reached the 4000 count upper limit of the MDC testing procedure (Figure 3-1). However, only three beaches (Constitution, Tenean, Wollaston) exceeded the 200 count beach closure limit at least 25% of the times sampled. Short and Nantasket Beaches rarely exceeded the beach closure limit. There was no consistent difference between areas in the northern part of the harbor (Swampscott, Kings, Lynn, Nahant, Revere, Short, Yirrell) and those to the south (Pleasure Bay, Carson, Malibu, Tenean, Wollaston, Nantasket) (Figures 3-1, 3-2). *Enterococcus* bacteria counts exceeded the EPA criterion of 104 in less than 25% of the sampling events at all stations (Figure 3-3). Geometric mean counts of *Enterococcus* were highest at Swampscott, Lynn, and Kings Beaches to the north and Tenean and Wollaston Beaches to the south.

A two-way analysis of variance indicated that both (log-transformed) fecal coliform and *Enterococcus* levels varied significantly among years and stations (Table 3-1). Fecal coliform levels were higher in 1989 than 1988 and 1987. Station differences were not clear cut and differences among stations closely overlapped. Furthermore, the year-station interactions were significant, suggesting that spatial trends were not consistent among years. To clarify the spatial trends, a one-way analysis of variance by year was performed, and results of the means separation testing are shown in Appendix Table 1. Fecal coliform levels were consistently highest at Tenean, Wollaston and Constitution Beaches; and lowest at Revere, Yirrell, Short, and Nantasket Beaches. Year-to-year variability in fecal coliform levels was most evident at Malibu, Lovells Island, Swampscott and Lynn Beaches, which were highest

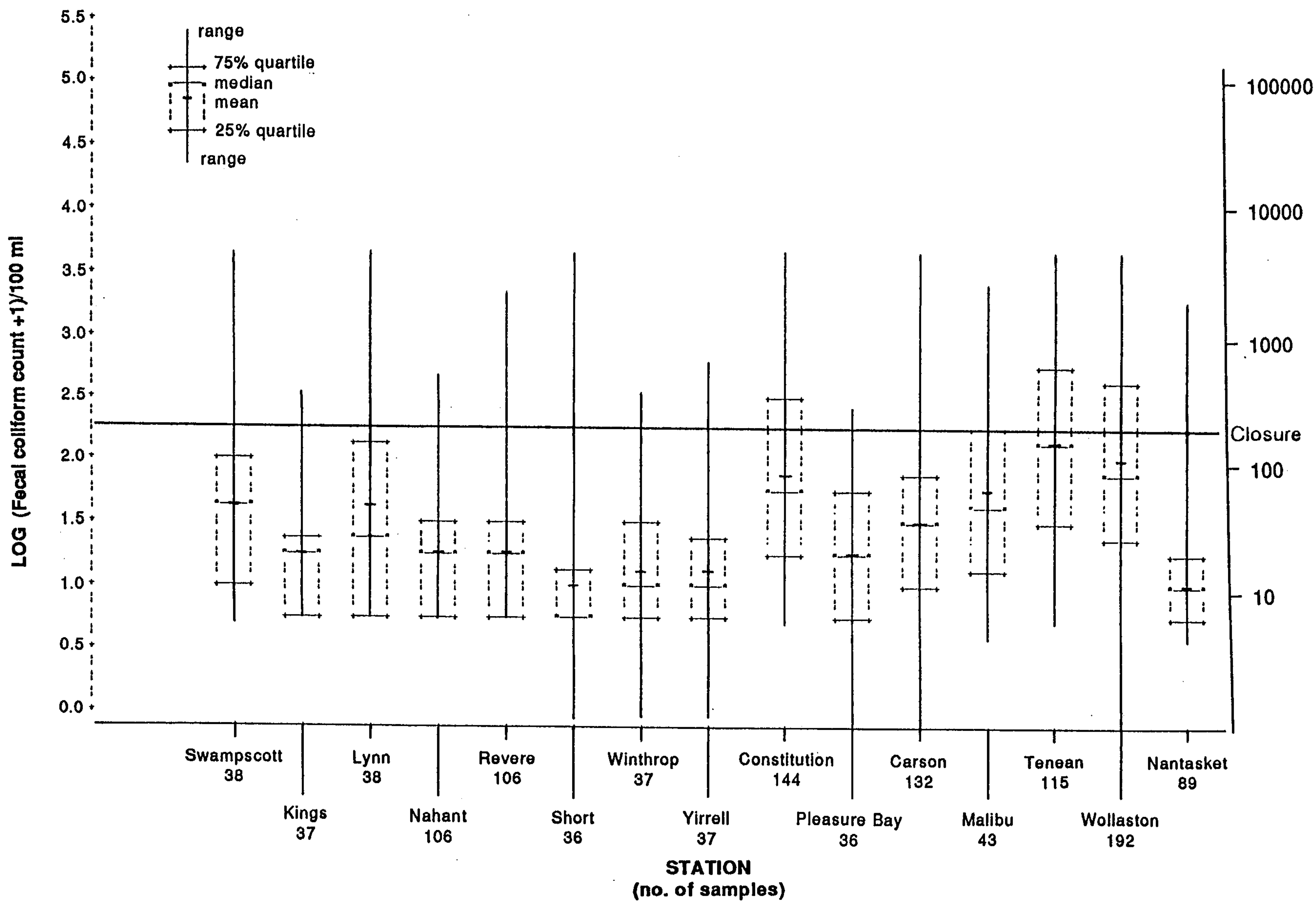


Figure 3-1. Mean, median, range, 25% and 75% quartiles of log (fecal coliform count +1)/100ml (membrane filter method) collected at Boston Harbor beaches from 1985-1987 by Metropolitan District Commission.

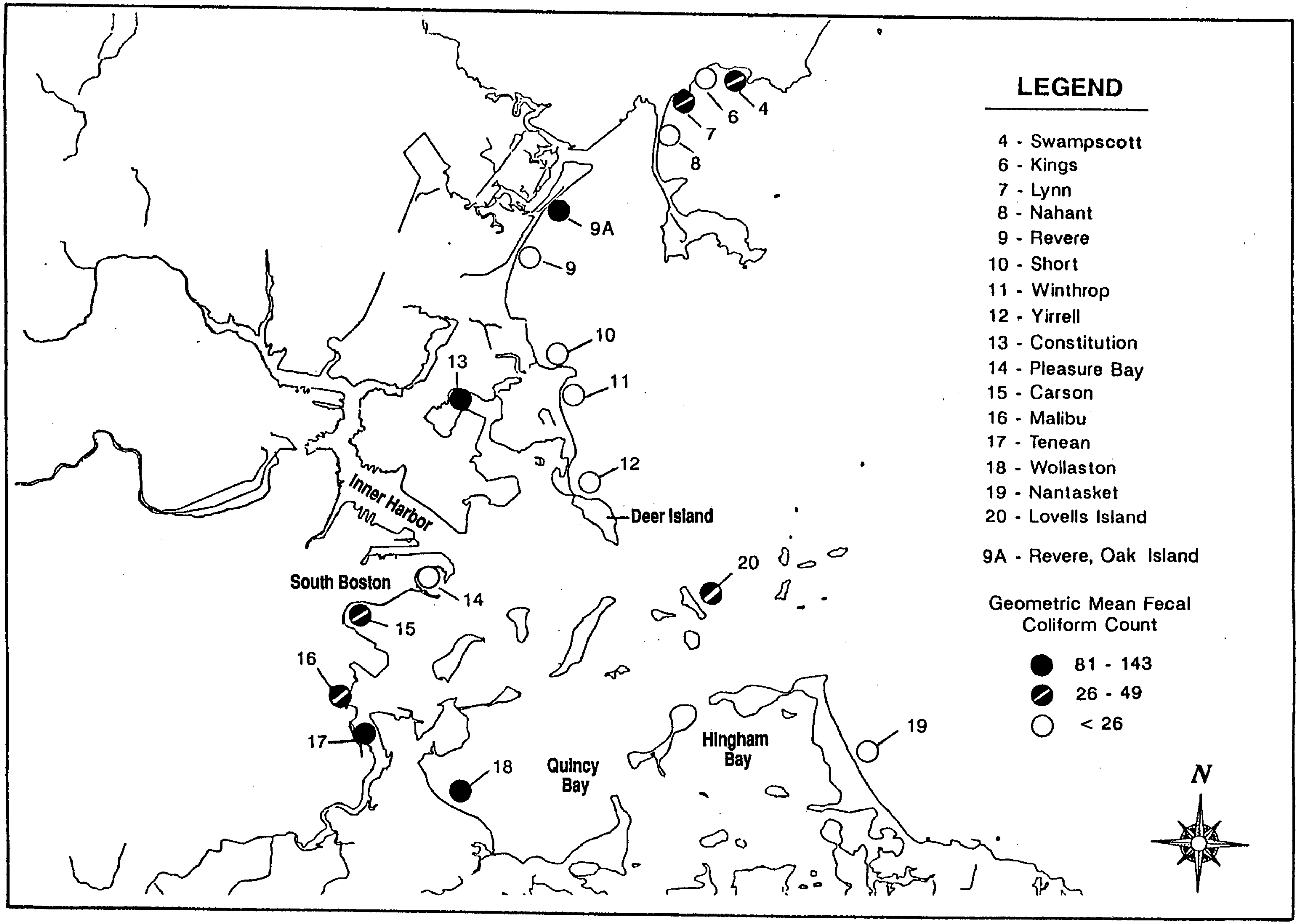
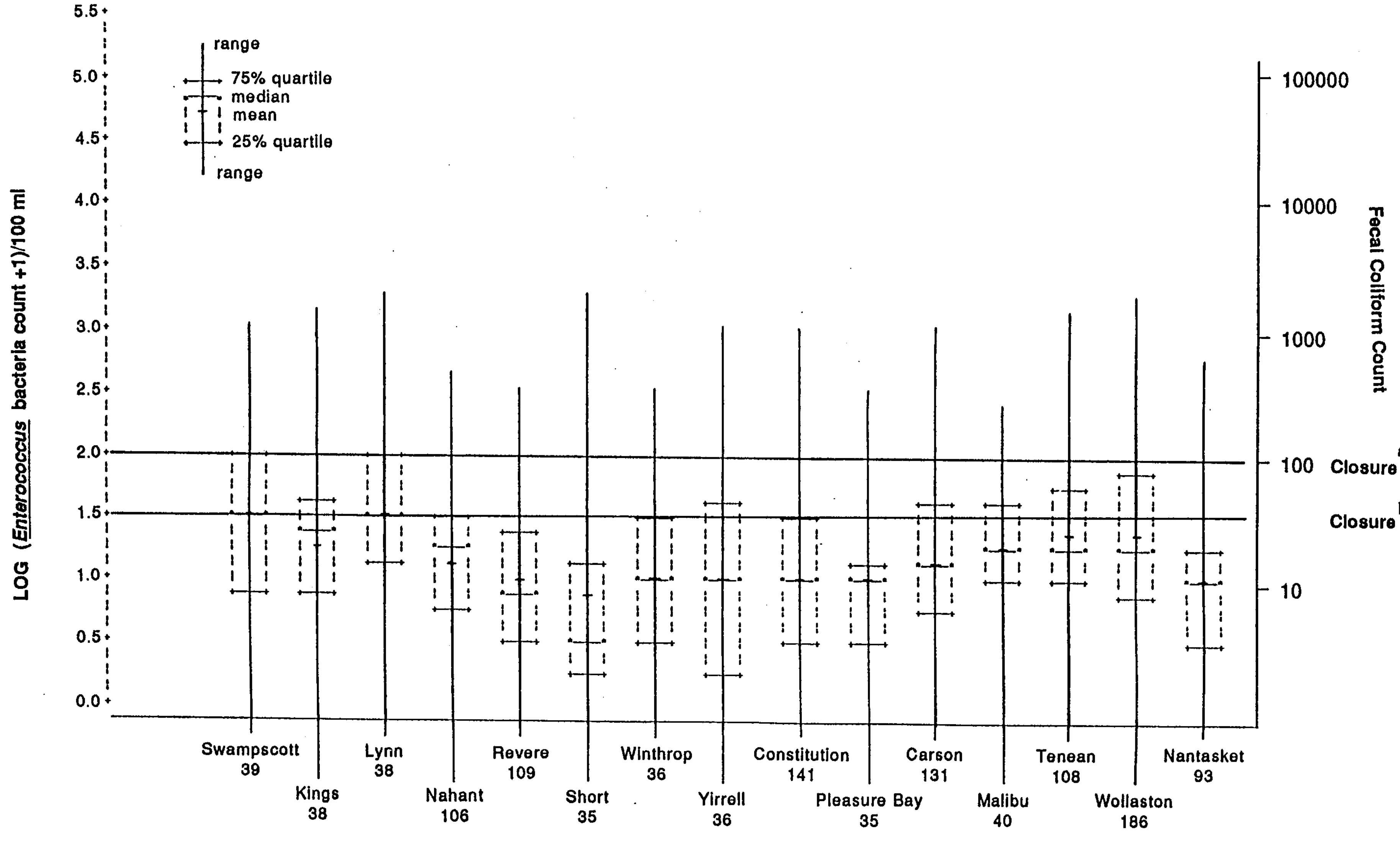


Figure 3-2. Geometric mean fecal coliform count collected at Boston Harbor beaches by MDC from 1987-1989.



[a] based on maximum single sample
[b] based on geometric mean

Figure 3-3. Mean, median, range, 25% and 75% quartiles of log (*Enterococcus* bacteria count +1)/100 ml (membrane filter method) measured at Boston Harbor beaches from 1987-1989 by Metroplolitan District Commission.

TABLE 3-1. RESULTS OF EVALUATION OF SPATIAL ANALYSIS OF FECAL COLIFORM AND *ENTEROCOCCUS* USING TWO-WAY (YEAR X STATION) ANALYSIS OF VARIANCE (MDC, DEP, MWRA STUDIES) OR NONPARAMETRIC ANALOGUE (DMF STUDY).

STUDY	SOURCE	df	SS	F	P
MDC beach stations					
Fecal coliform	year	2	27.6	28.3	<.0001
	station	17	158.5	19.1	<.0001
	year x station	33	34.2	2.1	<.0002
Enterococcus	year	2	5.8	7.0	<.0009
	station	17	43.1	6.2	<.0001
	year x station	33	30.6	2.3	<.0001
DEP water quality monitoring					
Fecal coliform	year	3	2.9	3.3	<.02
	station	18	74.9	14.0	<.0001
	year x station	33	18.0	1.8	<.005
MWRA CSO					
Fecal coliform	year	1	28.3	43.4	<.0001
	station	47	405.2	13.2	<.0001
	year x station	24	12.5	0.8	0.74
Enterococcus	year	1	0.2	0.5	0.49
	station	47	136.4	5.7	<.0001
	year x station	23	22.9	2.0	<.0047
DMF shellfish monitoring					
Fecal coliform	year	13	-	45.3[1]	<.0001

[1]Kruskal-Wallis test result (Chi square approximation) for nonparametric one-way ANOVA

in 1989 in comparison to previous years. *Enterococcus* levels did not always show the same patterns as fecal coliform levels. Lynn and Swampscott Beaches had highest overall *Enterococcus* counts (Figure 3-3) primarily because of high levels in 1989 (Appendix Table 2). When compared to all beaches, Wollaston and Tenean Beaches also had relatively high overall *Enterococcus* levels in 1988 but had lower-than-average levels in 1989. Revere and Short Beaches had consistently lower *Enterococcus* levels than other beaches.

3.1.2 Boston Harbor Water Quality Monitoring

Water quality samples collected by Massachusetts Department of Environmental Protection (DEP [formerly DEQE]) also showed spatial differences in the range and frequency of coliform counts (Figure 3-4). The highest fecal coliform counts were observed in the Inner Harbor and Charles, Mystic, and Neponset River Stations. The geometric mean counts were above the SB marine water quality criterion of 200 (for a representative set of samples in waters not designated for shellfishing) in at least 50% of the samples collected at the Neponset River Station. More than 10% of the samples collected at the Neponset River exceeded the 400 per 100 ml SB water quality criterion for multiple sets of samples. Sites in Dorchester, Quincy, and Nantasket were among the cleanest: the majority of fecal coliform counts were less than 10 (Figures 3-4, 3-5).

A two-way ANOVA of fecal coliform levels indicated significant differences among years and between stations. Significant year-station interactions confounded the results of the analysis (Table 3-1). A one-way ANOVA by year clarified some of the trends (Appendix Table 3). Stations located in the northern half of Quincy Bay, Dorchester Bay, and Nantasket Roads consistently had significantly lower fecal coliform levels than other stations sampled as part of this program. The stations exhibiting the highest levels of fecal coliforms differed among the three study years. The Neponset River had significantly higher

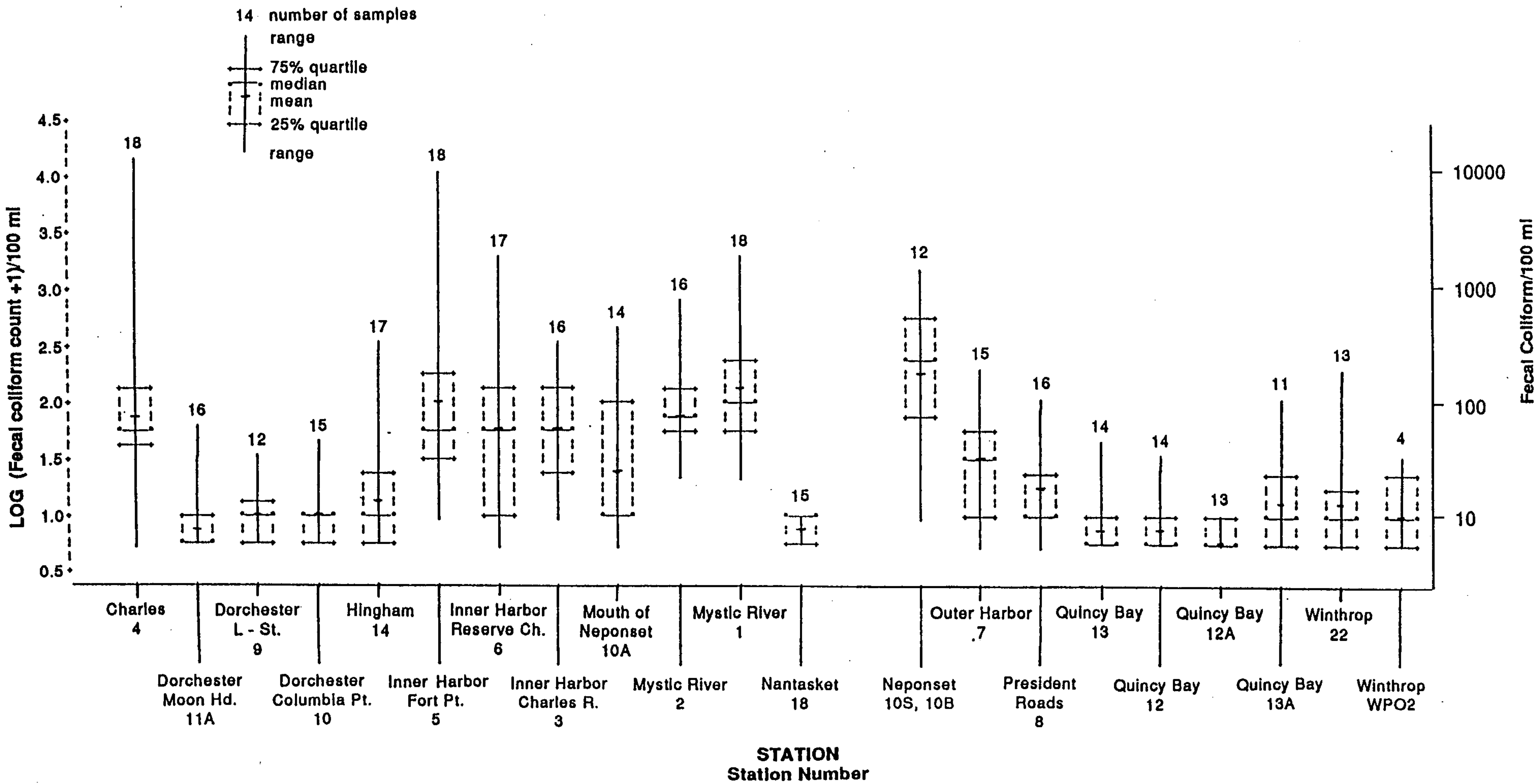


Figure 3-4. Mean, median, range, 25% and 75% quartiles of log (fecal coliform count +1)/100 ml at Boston Harbor Stations sampled by MDEP from 1985-1988.

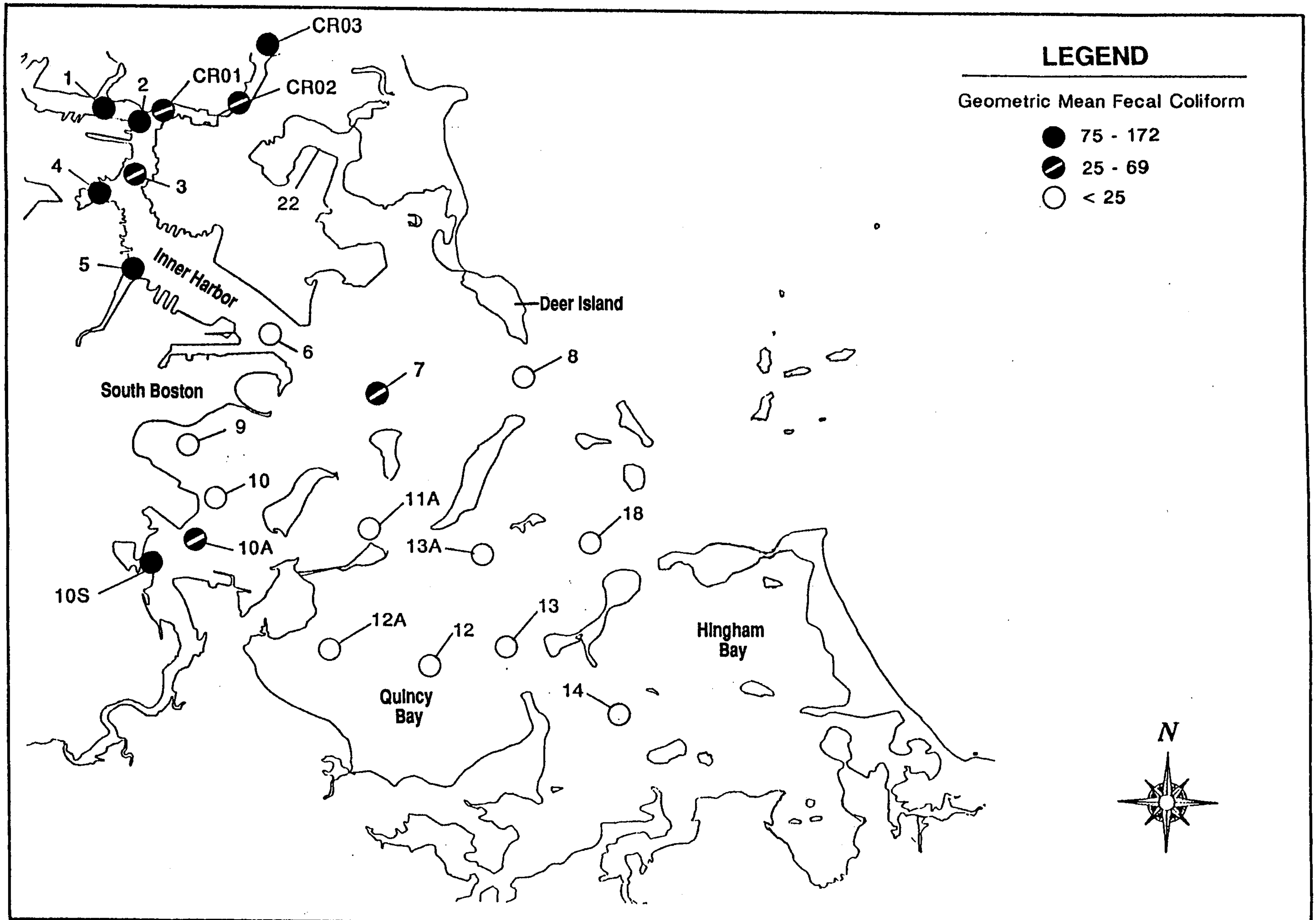


Figure 3-5. Geometric mean fecal coliform count at stations in Boston Harbor sampled by DEP.

fecal coliform levels in 1985 in comparison to other stations; Mill Creek's (CR03) levels were higher in 1986 and 1987. Inner Harbor stations, including those in the Mystic, Charles, and Chelsea Rivers, had highest levels in 1985, in comparison to subsequent years, contributing to the higher average coliform levels observed harbor-wide in 1985 as part of this study (Appendix Table 3).

3.1.3 CSO Monitoring Program

Fecal coliform and *Enterococcus* levels showed pronounced spatial and annual differences, as indicated by analysis of variance of data collected during MWRA's CSO monitoring program (Table 3-1). Station differences were significant, as were annual differences for *Enterococcus* counts. Significant year-station interactions complicated spatial patterns for *Enterococcus*. Results of the means separation tests for each year divided fecal coliform counts at the stations into many overlapping groups, indicating that spatial differences were not distinct (Appendix Table 4). In general, Inner Harbor stations had higher coliform levels than stations located in Dorchester and Quincy Bays (Figure 3-6). Not all of these differences were significant, however. *Enterococcus* bacterial levels varied significantly among stations and between years; however, significant year-station differences were also detected (Table 3-1). *Enterococcus* counts were generally higher in 1989. As with fecal coliform levels, significant differences among individual stations were not clear-cut; the means comparison test for each year separated stations into many overlapping groups (Appendix Table 5). *Enterococcus* were most numerous at Inner Harbor stations, the Chelsea River, and at the mouth of the Neponset River.

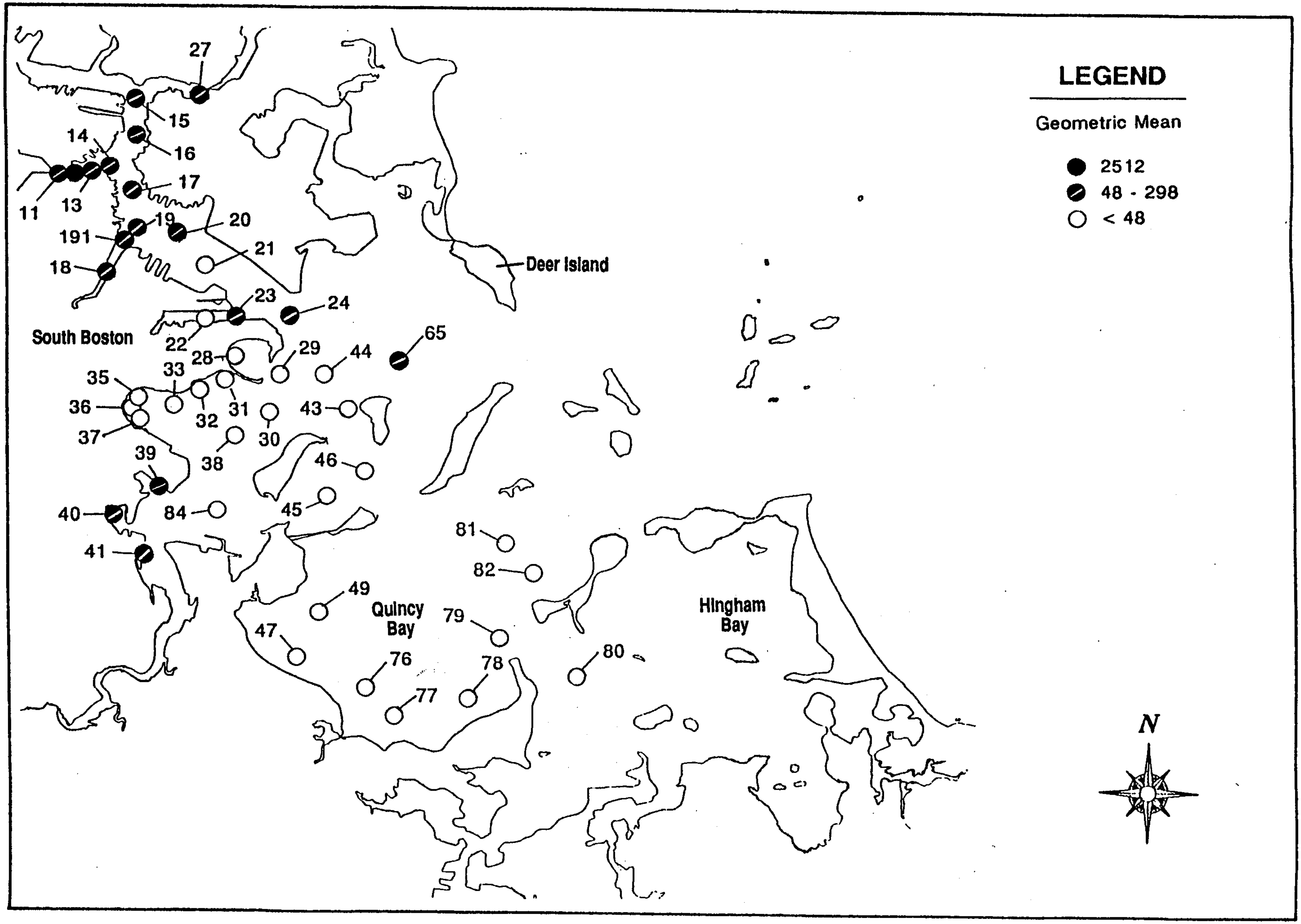


Figure 3-6. Geometric mean fecal coliform count at Boston Harbor stations sampled by MWRA in 1989 and 1990.

3.1.4 Shellfish Monitoring

The Massachusetts Department of Marine Fisheries ensures the safety of harvested shellfish by monitoring fecal coliform counts in the waters surrounding shellfish beds. State regulations require that shellfish-growing waters have an MPN fecal coliform count less than 88 colonies per 100 ml.

Fecal coliform counts measured in 1987 varied widely among stations (Figures 3-7, 3-8). Beds at Hingham's Crow Point, Weymouth's Fore River, and, to a lesser extent, Quincy's Moon Head and Squantum, and Winthrop's Deer Island were consistently higher than the geometric mean or median count limit of 88 for bed closure. Stations in the Town of Hull had consistently lower counts and were frequently below 88. Beds located in Quincy near Wollaston Beach had highly variable coliform counts. Spatial differences in coliform counts were tested using the Kruskal-Walls test, a nonparametric ANOVA (Sokal and Rolf 1969). The results indicated that fecal coliform levels varied significantly among stations (Table 3-1). Median counts were highest (>10,000) at the tide gate in Hingham (1 observation), at Crow Point, the mouth of Weymouth's Fore River, and Moon Head (Figures 3-7, 3-8). The remaining median coliform counts were less than 1000; of these, two-thirds were less than 100 (Figure 3-8).

3.2 RELATIONSHIP OF FECAL COLIFORM COUNTS WITH ENVIRONMENTAL PARAMETERS

The relationships of fecal coliform counts with rainfall (accumulated over 1, 2, 3 and 4 day periods) and flow and coliform loadings from Deer Island and Nut Island Wastewater Treatment Plants were investigated for the water quality monitoring study performed by DEP and beach monitoring study carried out by MDC. The water quality sampling effort conducted by DEP took place more or less monthly from

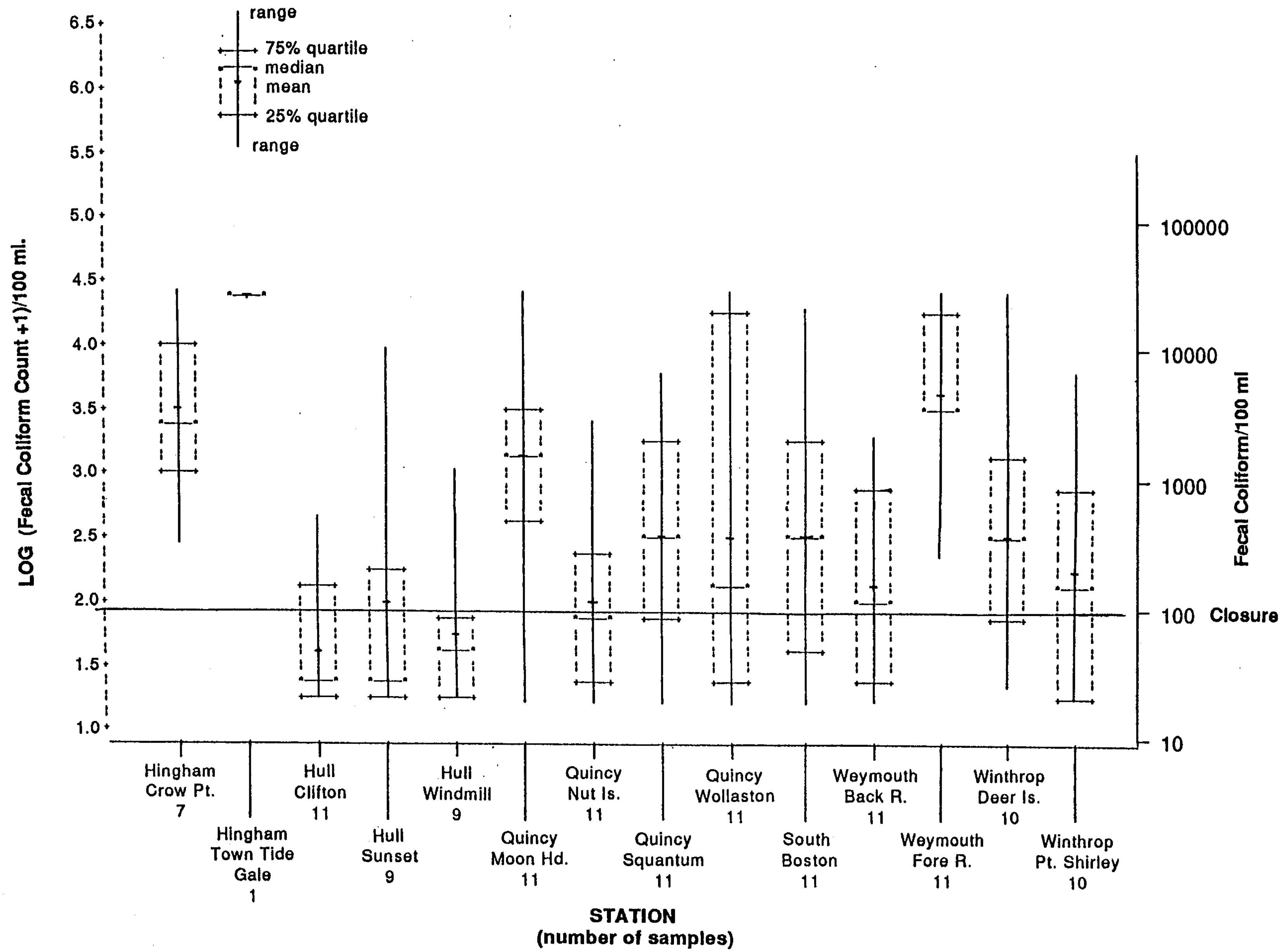


Figure 3-7.. Mean, median, range, 25% and 75% quartiles of log (fecal coliform count +1)/100 ml (MPN Method) collected at Boston Harbor area sampled by Mass. Division of Marine Fisheries for Shellfish Monitoring.

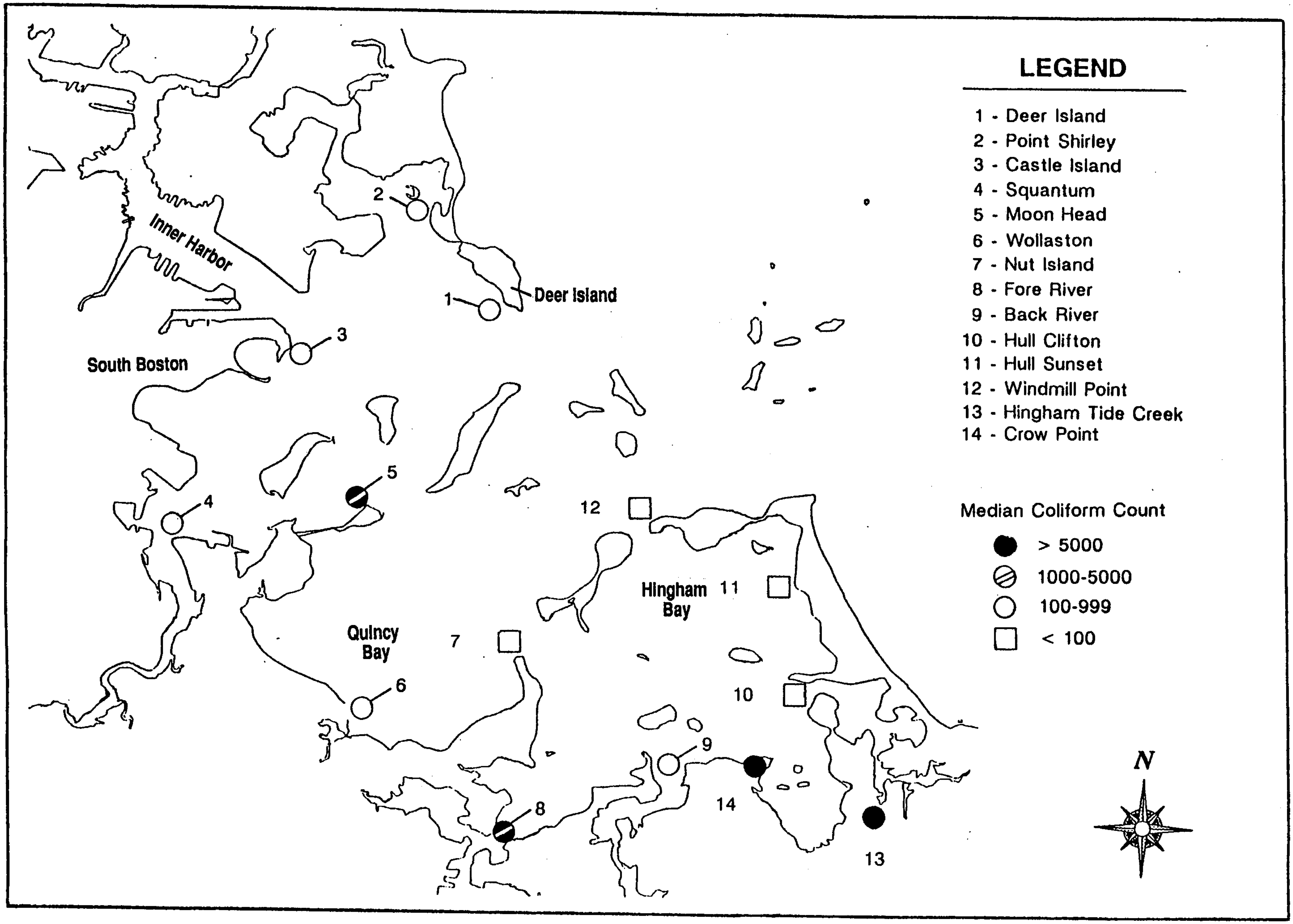


Figure 3-8. Median fecal coliform counts (MPN) at stations sampled by MDMF for shellfish monitoring.

June through October over a 2 to 3 year period. As rainfall totalled more than 0.5 inches on only two of the 18 dates sampled, data collected from this study cannot be expected to demonstrate whether there is a relationship between rainfall and fecal coliform. Fecal coliform counts were significantly correlated with rainfall at only two stations of the 20 sampled in the DEP study, both located in Quincy Bay (Appendix Table 6). The length of time that rainfall was measured (1, 2, 3, or 4 days) did not change the results. Fecal coliform counts were significantly correlated with Nut Island wastewater treatment plant flow at three stations. Fecal coliform concentrations were significantly and positively correlated with fecal coliform loadings at four stations. Coliform counts were not affected by Deer Island effluent flow or coliform loading (Appendix Table 6). Because of the large number of tests performed, some of these significant results could be due to chance alone.

The effects of rainfall and wastewater treatment plant effluent flows and fecal coliform loadings were more apparent from the beach monitoring study. At seven of the 16 beaches, increased fecal coliform counts were positively related to rainfall over a 1, 2, 3, or 4 day period (Appendix Table 7, Appendix Figure 1). The relationship held true for only the 4-day rainfall at two of the seven beaches. Fecal coliform counts at eight beaches were positively related to Deer Island flow (Appendix Table 7). There were no significant and positive relationships between fecal coliform counts in the water and Deer Island effluent fecal coliform loadings. Fecal coliform counts at 10 beaches were significantly and positively related to Nut Island flow (Appendix Table 7, Appendix Figure 1). Counts at three of these beaches were significantly and positively related to fecal coliform loadings from Nut Island. No significant relationship between fecal coliform counts in the water and rainfall or treatment plant flow was detected at three of the beaches. Because of the large number of tests performed, some significant results (particularly at significance levels between .01 and .05) could be due to chance alone.

The larger number of significant findings in the beach monitoring program in comparison to the DEP program is probably due to two factors. The beach monitoring program, which took place weekly during summer months, encountered more rainfall. Furthermore, the beach monitoring program collected all samples in nearshore areas, while the DEP's Water Quality Program stations were farther offshore. It is probable that any rainfall-induced coliform effects would be more noticeable in nearshore areas because they are closer to the presumed sources.

3.4 LONG TERM TRENDS IN FECAL COLIFORM COUNTS

Long term trends in fecal coliform counts were investigated by comparing values from studies performed in 1939 and from 1960 to 1990. Comparisons of counts derived using MPN encompass a longer time frame (1930's-1980's) because most studies prior to the 1970's used this method. As fecal coliform bacteria are operationally defined (ie. counts are derived based on the organism's characteristics under laboratory conditions), the analytic methodology employed is particularly important to consider when interpreting results. Counts of *B.coli*, used in the earliest study, are only roughly comparable to fecal coliform counts. Furthermore, the most probable number (MPN) method generally yielded higher counts than the membrane filter (MF) method (Table 3-2). Initial comparisons were made among studies that used the same methodology. We focused on the mean or median values in our evaluation. However, examination of the range (for counts generated using the MPN method) or standard deviation (MF Method) helped to separate long term trends from natural variability. In addition, the range and variance estimates provided insight into the maximum public health risks.

TABLE 3-2. GEOMETRIC MEAN (MEMBRANE FILTER METHOD) OR MEDIAN (MOST PROBABLE NUMBER METHOD) FECAL COLIFORM BACTERIA COUNTS PER 100 ML. COLLECTED IN THE 1980s, 1970s, 1960s, AND 1930s FROM BOSTON HARBOR.

STATION	1980's MF/100 ml ($\bar{x}$)	1980's MPN/100 ml (md)	1970's MPN/100 ml (md)	1960's MF/100 ml ($\bar{x}$)	1960's MPN/100 ml (md)	1930's no./100 ml ($\bar{x}$)[3]
Deer Island		330	230	2724,13000[2]	4750	5012
Governor Island Flats		137	930	1216	9450	1735
Chelsea River/ East Boston	37		12150			
Mystic River	101		22700			
Charles River	75		33500			
Inner Harbor	64		4300	10022	28000	
Pleasure Bay	18	330	36-330			30
Carson Beach	32		36		1400	159
Dorchester Bay	9		36-430	296	790-1300	435
Malibu Beach	49		35-430		495	256
Tenean Beach	143				450	1512
Moon Island		1300		2629	11000	4010
Nut Island		68	35	40		2526
President Roads	14		930	1994	6250	1889
North/South Channel	29		930	470	3000	1490
Wollaston	90	130		<2		2696

(continued)

TABLE 3-2. (Continued)

STATION	1980's MF/100 ml ($\bar{x}$)	1980's MPN/100 ml (md)	1970's MPN/100 ml (md)	1960's MF/100 ml ($\bar{x}$)	1960's MPN/100 ml (md)	1930's no./100 ml ($\bar{x}$)[3]
Neponset River	25		930			1292
Quincy Bay	7		36	8	20	2660
Hingham Bay	13	2400	35			
Hull	20		540	8	50-80	317
Nantasket	8			18		1900
Fore River		3500		26	270	109
Back River		110				157

[1]median values reported for separate studies as a range

[2]13000 count occurred at effluent outfall

[3]mean reported without method but assumed to be MPN/100 ml

Comparison of recent fecal coliform counts (MF method) collected as part of DEP's Boston Harbor Water Quality Study, MDC's Beach Monitoring Study, or the New England Aquarium Study (Robinson et al. 1990), taking into account the variance estimates, suggests that coliform counts have decreased in certain areas when compared to FWPC's 1967 study. Geometric mean coliform counts were 2-3 orders of magnitude lower at Governors Island, the Inner Harbor, Spectacle Island, President Roads and Moon Head in studies conducted in the 1980's in comparison to 1967 (Tables 3-2, 3-3). Counts at Nut Island, Quincy Bay (except Wollaston Beach) and Hingham Bay were similar (and characterized by low counts) among the three studies. Coliform counts at Tenean and Wollaston Beaches from the MDC study and the Neponset River site from the N.E. Aquarium study were higher than those observed from DEP's water quality monitoring stations, probably reflecting small scale temporal differences. The standard deviations suggest that water quality criteria were exceeded in these nearshore areas.

Fecal coliform counts estimated using the MPN method give a somewhat different picture of bacterial contamination in Boston Harbor (Table 3-4). These estimates are generally higher than counts estimated using the MF method. Use of the median count and range of MPN counts gives an idea of the frequency of occurrence of a value and the upper limits of the range gives an idea of maximum public health risks.

Historical comparisons of fecal coliform counts using the MPN method suggest that, overall, coliform levels have decreased over the decades in some areas, but that water quality criteria were exceeded in almost all of the areas that were studied (Tables 3-2, 3-4; Figure 3-9). The decrease, usually an order of magnitude change, was not as dramatic as that observed for the counts estimated using the MF method. Decreases occurred at Deer Island, Governors Island, the Neponset River, Nut Island, and Quincy Bay from the 1930's to the 1980's. These decreases had occurred by the 1967 survey in the Neponset River, Nut Island,

TABLE 3-3. GEOMETRIC MEAN AND STANDARD DEVIATION OF FECAL COLIFORM COUNTS (MEMBRANE FILTER METHOD) COLLECTED IN BOSTON HARBOR.

AREA	1960's		1980's					
	SOURCE:FWPC		DEQE		MDC		AQUARIUM	
(STATION NUMBER)	X̄	SD	X̄	SD	X̄	SD	X̄	SD
Deer Island	4148 (H17)	11	--	--	--	--	--	--
Governors Island	1215 (H18)	4	14 (WP02)	4	11 (Yirrell)	3	14 (4)	5
Inner Harbor	10027 (H-1)	3	55 (3)	2	--	--	44 (1)	9
Spectacle Island	2009 (H-2)	3	29 (7)	2	--	--	54 (3)	18
President Roads	3566 (H-5)	3	15 (8)	1	--	--	54 (3)	18
Moon Head	2627 (H-6)	7	6 (11A)	1	--	--		
Dorchester Bay	324 (H-3)	3	8 (9)	1	32 (Carson)	5		
Neponset River	271 (H-4)	3	25 (10A)	4	143 (Tenean)	5	146 (9)	8
Nut Island	6 (H-9)	3	7 (12)	1	--	--		
Quincy Bay	8 (H-8)	5	6 (12A)	1	90 (Wollaston)	7	8 (8)	2
Outer Harbor	470 (H-16)	3	--	--	26 (Lovells)	5	32 (5)	15
Hingham Bay	26 (H-11)	7	13 (140)	2	--	--	8 (7)	2
Hull	7 (H-12)	3	--	--	--	--	5 (6)	1
Nantasket Roads	470 (H-16)	3	7 (18)	1	10 (Nantasket)	2		

Sources: FWPC = FWPC 1967.
DEQE = DEQE Water quality monitoring, 1985-1988.
MDC = MDC beach monitoring, 1987-1989.
Aquarium = New England Aquarium, 1987-1989.

TABLE 3-4. MEDIAN OR MEDIAN AND RANGE OF FECAL COLIFORM COUNTS (MPN METHOD) COLLECTED IN BOSTON HARBOR.

SOURCE AREA	1930's SENATE MEAN[2]	1930's SENATE RANGE (UPPER LIMIT ONLY)	1960's FWPC MEDIAN	1960's FWPC RANGE	1970's DEQE MEDIAN	1970's DEQE RANGE	1980's DMF MEDIAN	1980's DMF RANGE
Deer Island	5012	10,000	4750 (H-17)	2300-540,000	230 (8)	35-930	330 (1)	20-24,000
Governors Island	1735	10,000	9450 (H-18)	500-33,000	930	230-93,000	138 (2)	20-4,900
Spectacle Island	1839	10,000	545 (H-2)	10-40,000	680 (47)	35-43,000	--	--
President Roads	1889	10,000	6250 (H-5)	2300-22,000	930 (3)	25-23,000	--	--
Castle Island	30	100	--	--	330 (6)	91-9,300	330 (3)	20-16,000
Moon Head	4010	10,000	11,000 (H-6)	200-54,000	36 (27)	35-230	1,300 (5)	20-24,000
Dorchester Bay	435	1,000	1300 (H-3)	790-17,000	473 (35)	35-930	338 (3)	20-16,000
Neponset River	1292	10,000	790 (H-4)	330-11,000	930 (33)	430-2300	331 (4)	20-5,400
Nut Island	2526	10,000	80 (H-9)	70-1,100	35 (13)	35-91	68 (7)	20-2,400
North/South Channel	1490	10,000	3,000 (H-16)	1,700-1,900	930 (2)	35-15,000	--	--
Quincy Bay	2,660	10,000	20 (H-8)	14-490	36 (26)	35-36	269 (6)	20-24,000
Hingham Bay	--	--	270 (H-11)	110-1700	--	--	2400 (14)	330-24,000
Hull	317	10,000	50 (H-12)	19-460	540 (15)	36-2,400	20 (10)	20-450
Back River	157	1,000	--	--	--	--	110 (9)	19-1,700
Fore River	--	--	270 (H-11)	110-1,700	--	--	3500 (8)	230-24,000

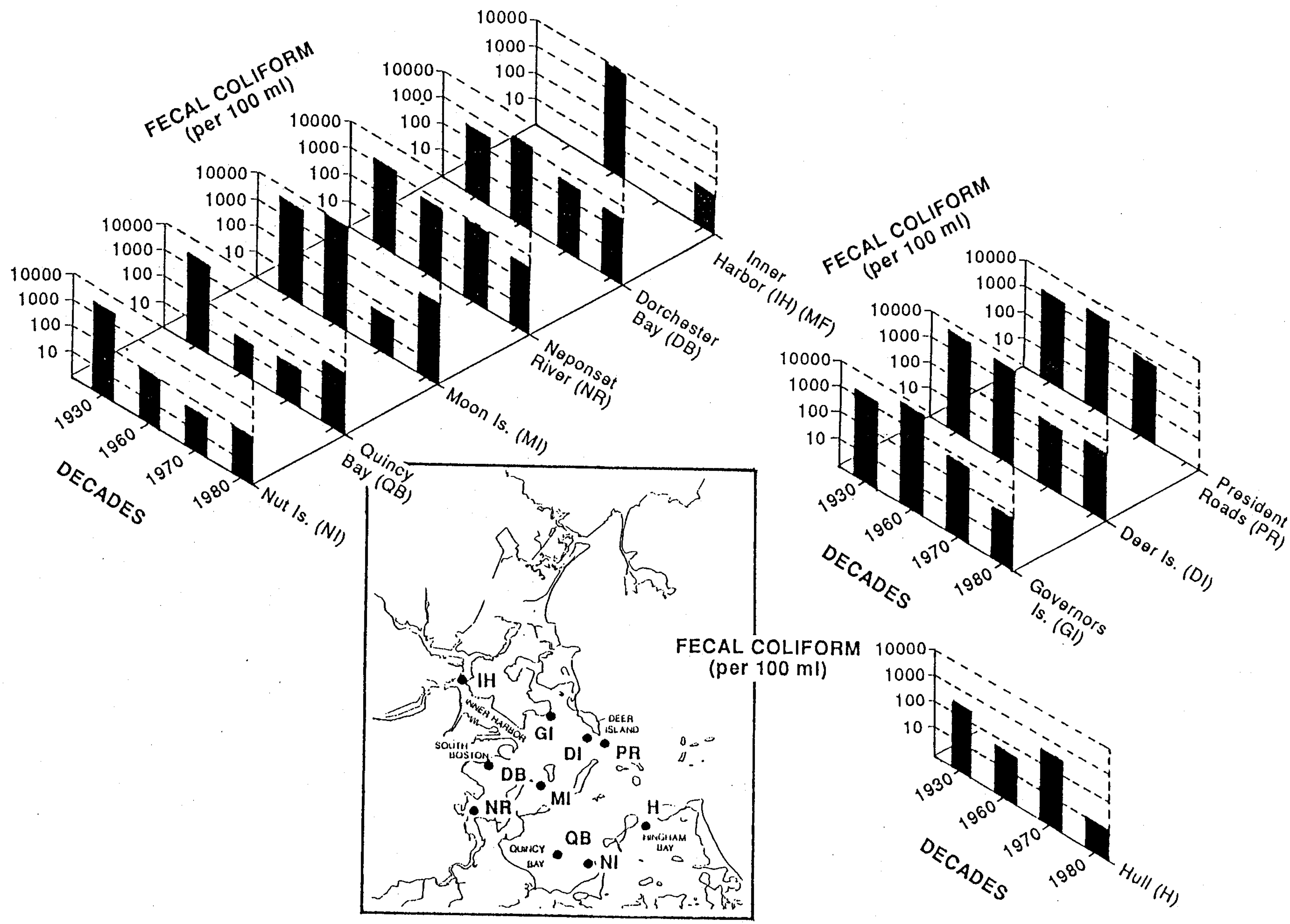


Figure 3-9. Long term trends in fecal coliform counts (MPN per 100 ml except for Inner Harbor, which is MF) collected in the 1930's, 1960's, 1970's, and 1980's.

Spectacle Island and Quincy Bay. In other areas, 1967 counts were higher than those observed in the 1930's, particularly President Roads, Moon Head and North/South Channel. Maximum counts in the 1980's had decreased by an order of magnitude at Deer Island and Governors Island, but still remained high. As all areas surveyed in the 1980's represent shellfish beds, maximum counts in these nearshore areas might be higher than those sampled farther offshore in earlier studies. Castle Island and Hingham Bay had higher median and maximum counts in comparison to historical studies. Quincy Bay, Hingham Bay, and the Fore River had increased coliform counts in the 1980's in comparison to the 1930's.

4.0 DISCUSSION

There has been an extensive amount of information collected on fecal coliform levels in the waters of the greater Boston area. Most studies have been short term, conducted to address very specific objectives of state agencies having particular environmental missions. In evaluating the long-term data base for fecal coliform bacteria, there are a number of issues that have direct implications for the interpretation of results. These are:

- How do the analytic methods employed affect the results?

  In general, the MPN (most probable number) method produces higher counts than the MF (membrane filter) method. *B.coli* counts are only roughly comparable to fecal coliform. Therefore, whenever possible, results from studies using the same methodology were compared.

- What level of precision is associated with fecal coliform counts?

  Replicate samples, which would provide an estimate of the precision, were rarely collected. However, results generated using the MPN method do have associated confidence limits. Because the level of precision was unknown, a conservative approach in drawing conclusions was used.

- What are the effects of small-scale patchiness and short-term changes (on the order of hours or days)?

  Each sample provided a "snapshot in time" of fecal coliform counts within the small volume of water that was sampled. Bacteria, like other plankton, would be influenced by tide, wind, and water mass movements, and therefore can have a patchy distribution. Since data were collected on very broad spatial and temporal scales, the effect of patchiness on the data is unknown.

In order to accurately represent long-term trends in the data, conclusions were made based on orders-of-magnitude changes resulting from numerous sample collections. Conclusions about spatial trends also were derived from numerous samples and are discussed in a general way.

4.1 Spatial Variability

The data analyzed for this report are best suited for describing general spatial trends. Precise statements about the level of fecal coliform or *Enterococcus* in specific areas are difficult to make with available data and analyses because of the substantial seasonal and annual variability. However, the data can give an idea of relative contamination among areas. The MDC beach monitoring program, which includes sites outside the harbor, showed generally low counts at beaches to the north and south of Boston Harbor; exceptions were Oak Island (Revere), Swampscott and Lynn. Within the harbor, Constitution, Tenean and Wollaston Beaches showed the highest counts and the most frequent postings. Pleasure Bay was the only beach sampled within the harbor showing low counts similar to those outside the harbor. *Enterococcus* counts tended to be highest at Swampscott, Lynn, Tenean and Wollaston; however, *Enterococcus* counts at Constitution were no higher than Yirrell and Nantasket, where fecal coliform counts were low. Swampscott, Lynn, Wollaston, Kings and Tenean Beaches were those that were most frequently closed based on *Enterococcus* counts.

The Massachusetts DEP water quality monitoring program (1985-1988) provides a view of spatial differences that is restricted to the harbor proper. Results underscore what is generally known about the harbor. The Inner Harbor (particularly Fort Point Channel and the Reserve Channel), the Charles River, and the Neponset River showed the highest counts. The Outer Harbor, including Quincy Bay, Dorchester Bay, and Nantasket, had noticeably lower counts.

The Massachusetts DMF 1987 shellfish monitoring data, based on MPN analysis, added more information on spatial variability. Some areas, not sampled in other studies, such as Fore River and Hingham, showed higher coliform counts and lower variability than other stations. Counts at Wollaston showed very high variability with a 75% quartile as high as any station, verifying this as a "problem" area. Moon Head Station had higher MPN coliform counts than many other DMF stations, in contrast to the DEP study.

Results obtained from New England Aquarium's monitoring program (Robinson et al. 1990) were consistent with results from other studies for the Inner Harbor and some of the Outer Harbor areas. Fecal coliform counts in the Aquarium study were lowest in Hingham Bay, Fore River, and Quincy Bay, and higher in the Inner Harbor. However, unlike other studies, the highest and most variable counts in the New England Aquarium study occurred in the Outer Harbor areas near President Roads/Spectacle Island and Lovells Island, two stations nearest to the Deer Island outfall. High counts were attributed to insufficiently chlorinated effluent (Robinson et al. 1990). Because the Aquarium study had a more frequent sampling regime (monthly over a 2½ year period) in comparison to that of DEP, it probably encountered more of these events.

Spatial trends in Boston Harbor have changed over the decades. The 1939 study revealed that Deer Island, Moon Head, Nut Island, Wollaston, and Quincy Bay had the highest annual mean counts of *B.coli* (2,000->5,000 per 100 ml). Governors Island, Spectacle Island, President Roads, the Neponset River, Nantasket and the North/South Channel had moderately high levels of *B.coli* (1,000-2,000/100 ml). All of the above areas had maximum *B.coli* counts of 10,000. Four stations had mean counts less than 500; of those, Castle Island was relatively cleanest

(Tables 3-2,4).

In the 1960's, fecal coliform counts were consistently high in the Inner Harbor, averaging over 10,000 per 100 ml (MF method, Table 3-3). Areas near Deer Island, Governors Island, President Roads, Moon Head, and Spectacle Island also had high fecal coliform counts; mean values exceeded 1000/100 ml (MF, Table 3-3). Prior to the Deer Island WWTP's opening in 1968, coliform levels at Deer Island reached levels of 540,000 (MPN) and did not drop below 2,300 during the course of the study (Table 3-4). Quincy Bay, Hull, and Nut Island had the lowest fecal coliform counts, <10/100 ml (MF, Table 3-3). The opening of Nut Island WWTP in 1952 probably accounts for the improvement of coliform levels in this area in comparison to levels in the 1930's.

Spatial differences were less pronounced in DEQE's 1970 study (Table 3-4). Median fecal coliform counts were highest in the areas near Governors Island, President Roads, North/South Channel, and the Neponset River but did not exceed 1,000/100 ml (MPN). Maximum counts exceeded 10,000 at all of these sites except for the Neponset River, indicating high fecal coliform levels occurred at least once. Quincy Bay, Moon Head, and Nut Island had consistently low counts (36/100 ml MPN, Table 3-4). Coliform levels at Deer Island, once among the highest in the harbor, were now moderate in comparison to other stations. The improvement in coliform counts coincided with the opening of the Deer Island WWTP.

Fecal coliform levels in the 1980's were highest at Moon Head and Hingham Bay and lowest in Hull in the DMF study (Table 3-4). Other studies performed in the 1980's show average fecal coliform counts less than 10/100 ml (MF) at Moon Head, Dorchester Bay (except Carson Beach), Nut Island, Quincy Bay (except Wollaston Beach) and Hull (Table 3-3). Inconsistencies in fecal coliform levels at Moon Head among studies performed in the 70's and 80's may be the result of sporadic sewage discharges. Moon Head was activated when the flow to Deer Island WWTP exceeded its pumping capacity, usually during rainstorms. Highest fecal coliform counts averaged between 90 and 200/100 ml (MF) and occurred at Tenean and Wollaston Beaches (the latter in the MDC study only, Table 3-3).

Our review of previous studies confirms harborwide differences in coliform levels, and shows station similarity and associated variability. This information can help identify areas most suitable for monitoring the effects of improved WWTP and CSO facilities and indicate where sampling efforts could be focused. These data could be used to help avoid redundant or unnecessary stations and help focus a long-term monitoring plan. MWRA can also determine the utility of sampling programs conducted by other agencies in determining harborwide improvements in coliform levels.

4.2 Temporal Variability

Temporal variability can be short-term (e.g., daily, weekly) or long-term (e.g., yearly or longer). Both can affect the ability to detect an improvement in water quality. Short-term temporal variability is best documented by studies that sample the same areas with high frequency. MWRA's CSO monitoring, based on sampling 4-6 days/week, showed short-term variability in fecal coliform counts within stations ranging over three orders of magnitude in some cases (MWRA 1991, in prep.). MDC beach monitoring, which takes place at least weekly during the summer months, also provides information on short-term variability. For example, Short and Nantasket Beaches typically had low fecal coliform counts, with an annual mean of less than 10 per 100 ml (MF) over the 1985-1987 period. However, there were occasional instances of high fecal coliform counts that necessitated beach closure (Figure 3-1). Similarly, high coliform counts have led to shellfish bed closure in Hull, an area that generally has had low coliform counts (Figure 3-7). Thus it is important when assessing long term trends to use averages based on large numbers of samples.

Short-term changes have been linked to episodic events such as rainfall and WWTP effluent flow and fecal coliform loading. Rainfall, which results in combined sewer overflows, stormwater inputs, and, occasionally, wastewater treatment plant bypass, is the most likely cause of short-term changes in water quality. Our analysis indicated that rainfall and wastewater treatment flows and fecal coliform loadings were related to bacterial levels at some of the beaches monitored by MDC. Several studies have identified rainfall as one of the major causes of beach closing (MDC 1987), and have predicted the amount of rainfall necessary to cause a closing (CH2M Hill 1989). Results from MWRA's CSO monitoring study indicate that the effect of rainfall on fecal coliform levels varies spatially within the harbor. In the Inner Harbor, rainfall is of clear importance in its effect on fecal coliform levels, while in offshore areas, rainfall has less effect (MWRA 1991, in prep.). The Division of Marine Fisheries, using information collected during rainfall events, has established a protocol for shellfish bed closure based on the amount of rainfall and whether a treatment plant bypass has occurred (DMF internal memo, undated). DMF studies indicate that other factors interact with rainfall, including season, tidal height, wind velocity, amount of runoff generated, and CSO operation. All of these factors increase the variation in bacteria counts associated with rainfall.

Long-term temporal variability was investigated by comparing fecal coliform counts from the same general area collected over a period of years or decades. Despite the methodological differences in historical studies, a long-term trend of improving water quality was evident in order-of-magnitude changes. The installation of the Deer Island treatment plant, chlorination of the Moon Head effluent and ultimate closure, and decreases in coliform loading from CSO's coincided with dramatically improved coliform counts at Deer, Nut, Moon, and Governors Islands and the Inner Harbor. Mean coliform counts at Governors Island, the Inner Harbor, Spectacle Island, President Roads, and Moon Head decreased from levels in the thousands per 100 ml (MF method) in the 1960's to under 100 per 100 ml in the 1980's (Table 3-3). However, while there was a trend of general improvement, extremely high fecal coliform counts still occurred in the 1980's. For example, fecal coliform counts exceeding 16,000 per 100 ml (MF method) were recorded at Spectacle Island (Robinson et. al 1990), Deer Island, Castle Island and Moon Head (MPN Method) (Table 3-4). Some areas showed inconsistent results among studies. Fecal coliform counts in Dorchester Bay measured by DEQE in the 1980's averaged less than 10/100 ml (MF method) (Table 3-3), yet a median count of 338 was measured by DMF with a maximum of 16,000/100 ml (MPN method) (Table 3-4). Median fecal coliform counts, when measured by the MPN method, increased at three areas in the past 20-30 years: Quincy Bay, Hingham Bay and the Fore River (Table 3-4). However, other studies using the MF method (Table 3-3) show little change in fecal coliform count in Hingham and Quincy Bays (no data were available from these studies for the Fore River). These results underscore the fact that fecal coliform counts in some areas vary tremendously within relatively small distances and time frames. These areas may present more difficulty in determining whether significant improvements in water quality have occurred as a result of improvements in the Deer Island facility and utilization of the offshore outfall.

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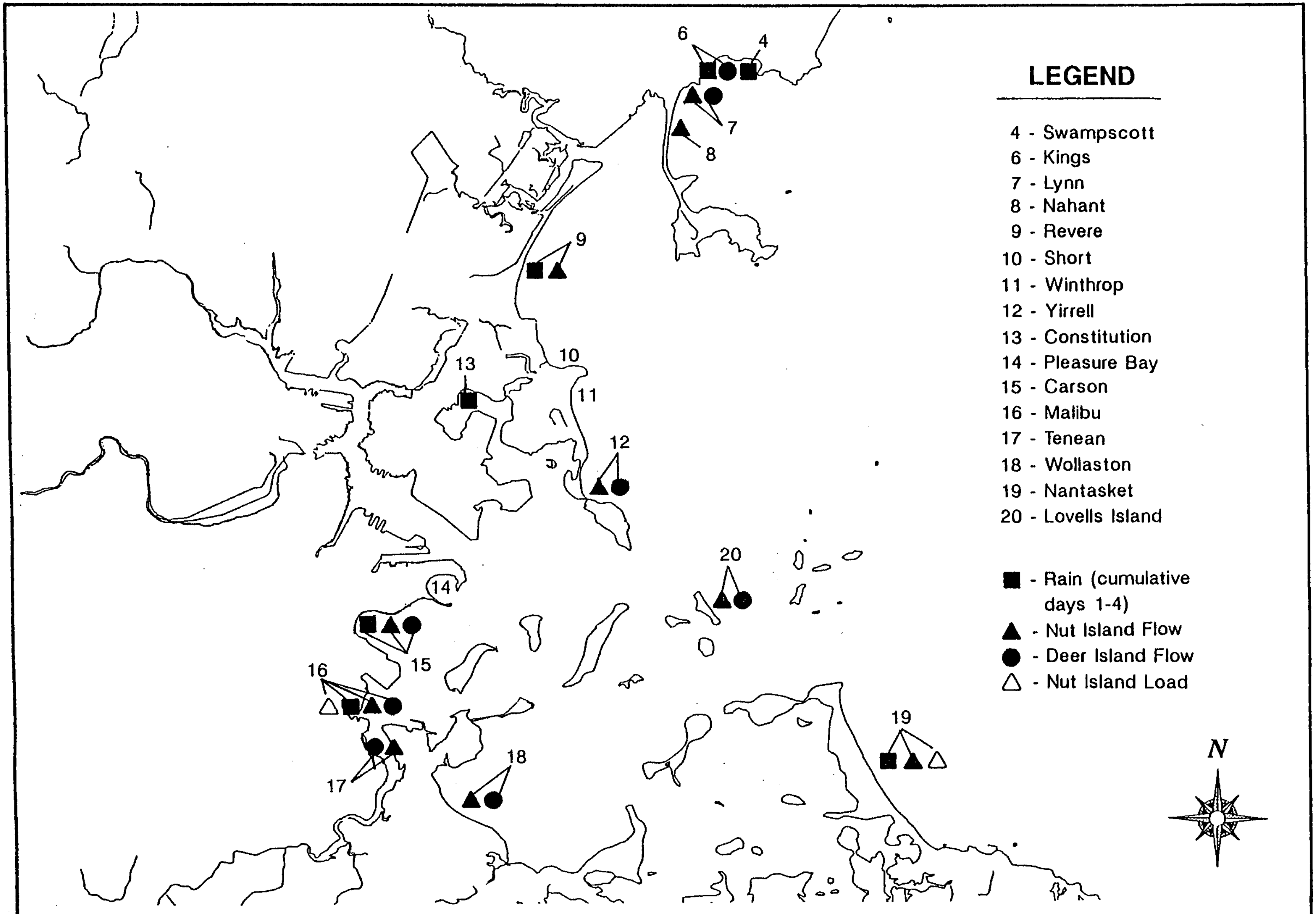
SPATIAL AND TEMPORAL ANALYSIS
OF BOSTON HARBOR MICROBIOLOGICAL DATA

APPENDIX FIGURE 1



Appendix Figure 1. Beaches sampled during MDC beach monitoring program with fecal coliform counts that are significantly and positively related with 1, 2, 3 or 4 day rainfall, Deer Island or Nut Island wastewater treatment plant flows and fecal coliform loads.

SPATIAL AND TEMPORAL ANALYSIS
OF BOSTON HARBOR MICROBIOLOGICAL DATA

APPENDIX TABLES 1 THROUGH 7

APPENDIX TABLE 1. SPATIAL DIFFERENCES IN LOG (x+1) FECAL COLIFORM COUNTS COLLECTED DURING MDC'S BEACH MONITORING STUDY FROM 1987 THROUGH 1989 AS INDICATED BY MEANS SEPARATION TEST OF TWO-WAY ANOVA (year x station).

YEAR=1987

General Linear Models Procedure

Waller-Duncan K-ratio T test for variable: L_FECAL

NOTE: This test minimizes the Bayes risk under additive loss and certain other assumptions.

Kratio= 100 df= 439 MSE= 0.377253 F= 10.09713
Critical Value of T= 1.82933
Minimum Significant Difference= 0.3757
WARNING: Cell sizes are not equal.
Harmonic Mean of cell sizes= 17.88901

Means with the same letter are not significantly different.

Waller Grouping				Mean	N	COMMONID
		A		2.151	57	WOLLASTON BEACH
		B		1.755	36	TENEAN BEACH
		B				
C		B		1.722	44	CARSON BEACH
C		B				
C		B	D	1.632	45	CONSTITUTION BEA
C		B	D			
C		B	D	1.538	14	PLEASURE BAY, BR
C		B	D			
C	E	B	D	1.408	15	KINGS BEACH
C	E		D			
C	E		D	1.379	14	LYNN
C	E		D			
C	E		D	1.348	15	SWAMPSCOTT
	E		D			
	E		D	1.338	7	LOVELLS ISLAND
	E		D			
	E	F	D	1.309	15	REVERE OAK ISLAN
	E	F	D			
G	E	F	D	1.256	15	MALIBU BEACH
G	E	F				
G	E	F		1.156	43	NAHANT BEACH
G	E	F				
G	E	F		1.138	14	WINTHROP BEACH
G	E	F				
G	E	F		1.066	53	NANTASKET BEACH
G	E	F				
G	E	F		1.062	14	SANDY BEACH
G	E	F				
G	E	F		1.046	28	REVERE BEACH
G		F				
G		F		0.948	14	YIRREL
G						
G				0.895	14	SHORT BEACH

APPENDIX TABLE 1. (Continued)

YEAR=1988

General Linear Models Procedure

Waller-Duncan K-ratio T test for variable: L_FECAL

NOTE: This test minimizes the Bayes risk under additive loss and certain other assumptions.

Kratio= 100 df= 295 MSE= 0.475709 F= 6.287167
Critical Value of T= 1.89633
Minimum Significant Difference= 0.5289
WARNING: Cell sizes are not equal.
Harmonic Mean of cell sizes= 12.22921

Means with the same letter are not significantly different.

Waller Grouping					Mean	N	COMMONID
			A		2.247	24	TENEAN BEACH
			A				
	B		A		1.939	33	CONSTITUTION BEA
	B		A				
	B		A	C	1.802	42	WOLLASTON BEACH
	B			C			
	B		D	C	1.648	11	MALIBU BEACH
	B		D	C			
	B	E	D	C	1.616	10	SWAMPSCOTT
	B	E	D	C			
F	B	E	D	C	1.492	33	CARSON BEACH
F	B	E	D	C			
F	B	E	D	C	1.455	9	REVERE OAK ISLAN
F	B	E	D	C			
F	B	E	D	C	1.417	9	LYNN
F		E	D	C			
F	G	E	D	C	1.326	7	LOVELLS ISLAND
F	G	E	D				
F	G	E	D		1.173	9	SANDY BEACH
F	G	E	D				
F	G	E	D		1.163	10	KINGS BEACH
F	G	E					
F	G	E			1.112	8	YIRREL
F	G	E					
F	G	E			1.098	18	REVERE BEACH
F	G	E					
F	G	E			1.090	27	NAHANT BEACH
F	G						
F	G				1.044	36	NANTASKET BEACH
F	G						
F	G				1.019	9	PLEASURE BAY, BR
	G						
	G				0.881	9	WINTHROP BEACH
	G						
	G				0.878	9	SHORT BEACH

APPENDIX TABLE 1. (Continued)

YEAR=1989

General Linear Models Procedure

Waller-Duncan K-ratio T test for variable: L_FECAL

NOTE: This test minimizes the Bayes risk under additive loss and certain other assumptions.

Kratio= 100 df= 450 MSE= 0.605637 F= 7.95834
Critical Value of T= 1.85817
Minimum Significant Difference= 0.5818
WARNING: Cell sizes are not equal.
Harmonic Mean of cell sizes= 12.35405

Means with the same letter are not significantly different.

Waller Grouping				Mean	N	COMMONID
		A		2.384	55	TENEAN BEACH
		A				
B		A		2.151	2	LOVELLS ISLAND
B		A				
B		A	C	2.116	17	MALIBU BEACH
B		A	C			
B		A	C	2.092	66	CONSTITUTION BEA
B		A	C			
B		A	C	2.086	15	LYNN
B		A	C			
B	D	A	C	1.910	93	WOLLASTON BEACH
B	D	A	C			
B	D	A	C	1.880	13	SWAMPSCOTT
B	D		C			
B	D	E	C	1.765	12	REVERE OAK ISLAN
	D	E	C			
F	D	E	C	1.549	12	SANDY BEACH
F	D	E				
F	D	E		1.425	36	NAHANT BEACH
F	D	E				
F	D	E		1.380	55	CARSON BEACH
F		E				
F		E		1.270	12	KINGS BEACH
F		E				
F		E		1.263	14	WINTHROP BEACH
F		E				
F		E		1.206	24	REVERE BEACH
F						
F				1.169	13	PLEASURE BAY, BR
F						
F				1.164	15	YIRREL
F						
F				1.077	13	SHORT BEACH

APPENDIX TABLE 2. SPATIAL DIFFERENCES IN LOG (x+1) *ENTEROCOCCUS* COUNTS COLLECTED DURING MDC'S BEACH MONITORING STUDY FROM 1987 THROUGH 1989 AS INDICATED BY MEANS SEPARATION TEST OF TWO-WAY ANOVA (year x station).

YEAR=1987

General Linear Models Procedure

Waller-Duncan K-ratio T test for variable: L_ENTCOC

NOTE: This test minimizes the Bayes risk under additive loss and certain other assumptions.

Kratio= 100 df= 438 MSE= 0.350323 F= 5.151136
Critical Value of T= 1.93972
Minimum Significant Difference= 0.3849
WARNING: Cell sizes are not equal.
Harmonic Mean of cell sizes= 17.79185

Means with the same letter are not significantly different.

Waller Grouping						Mean	N	COMMONID
			A			1.569	57	WOLLASTON BEACH
			A					
	B		A			1.371	36	TENEAN BEACH
	B		A					
	B		A	C		1.341	13	LYNN
	B		A	C				
	B	D	A	C		1.258	44	CARSON BEACH
	B	D	A	C				
E	B	D	A	C		1.221	15	KINGS BEACH
E	B	D		C				
E	B	D	F	C		1.140	15	MALIBU BEACH
E	B	D	F	C				
E	B	D	F	C		1.131	43	NAHANT BEACH
E	B	D	F	C				
E	B	D	F	C	G	1.052	15	SWAMPSCOTT
E	B	D	F	C	G			
E	B	D	F	C	G	1.002	15	REVERE OAK ISLAN
E		D	F	C	G			
E		D	F	C	G	0.975	14	SANDY BEACH
E		D	F	C	G			
E		D	F	C	G	0.968	45	CONSTITUTION BEA
E		D	F	C	G			
E		D	F	C	G	0.963	14	PLEASURE BAY, BR
E		D	F		G			
E		D	F		G	0.887	14	WINTHROP BEACH
E			F		G			
E			F		G	0.862	53	NANTASKET BEACH
			F		G			
			F		G	0.775	28	REVERE BEACH
			F		G			
			F		G	0.760	14	YIRREL
					G			
					G	0.692	7	LOVELLS ISLAND
					G			
					G	0.673	14	SHORT BEACH

YEAR=1988

General Linear Models Procedure

Waller-Duncan K-ratio T test for variable: L_ENTCOC

NOTE: This test minimizes the Bayes risk under additive loss and certain other assumptions.

Kratio= 100 df= 306 MSE= 0.385113 F= 2.337795
Critical Value of T= 2.34570
Minimum Significant Difference= 0.5766
WARNING: Cell sizes are not equal.
Harmonic Mean of cell sizes= 12.74754

Means with the same letter are not significantly different.

Waller Grouping				Mean	N	COMMONID
		A		1.572	24	TENEAN BEACH
		A				
B		A		1.467	11	SWAMPSCOTT
B		A				
B		A	C	1.369	10	LYNN
B		A	C			
B	D	A	C	1.330	42	WOLLASTON BEACH
B	D	A	C			
B	D	A	C	1.243	33	CONSTITUTION BEA
B	D	A	C			
B	D	A	C	1.194	10	REVERE OAK ISLAN
B	D	A	C			
B	D	A	C	1.096	11	KINGS BEACH
B	D	A	C			
B	D	A	C	1.094	33	CARSON BEACH
B	D	A	C			
B	D	A	C	1.062	10	SANDY BEACH
B	D	A	C			
B	D	A	C	1.054	40	NANTASKET BEACH
B	D	A	C			
B	D	A	C	0.997	8	YIRREL
B	D		C			
B	D		C	0.977	7	LOVELLS ISLAND
B	D		C			
B	D		C	0.969	11	MALIBU BEACH
B	D		C			
B	D		C	0.968	27	NAHANT BEACH
	D		C			
	D		C	0.822	20	REVERE BEACH
	D		C			
	D		C	0.799	9	WINTHROP BEACH
	D					
	D			0.788	9	SHORT BEACH
	D					
	D			0.783	9	PLEASURE BAY, BR

APPENDIX TABLE 2. (Continued)

```
------------------------------------ YEAR=1989 ------------------------------------

                    General Linear Models Procedure

          Waller-Duncan K-ratio T test for variable: L_ENTCOC

NOTE: This test minimizes the Bayes risk under additive loss and certain other assumptions.

        Kratio= 100  df= 427  MSE= 0.488125  F= 3.556042
                  Critical Value of T= 2.06445
             Minimum Significant Difference= 0.5874
               WARNING: Cell sizes are not equal.
             Harmonic Mean of cell sizes= 12.05853

Means with the same letter are not significantly different.

     Waller Grouping            Mean      N  COMMONID

                 A              1.930    13  SWAMPSCOTT
                 A
         B       A              1.872    15  LYNN
         B       A
         B       A   C          1.621    14  MALIBU BEACH
         B       A   C
         B   D   A   C          1.548    12  KINGS BEACH
         B   D   A   C
     E   B   D   A   C          1.485    13  SANDY BEACH
     E   B   D   A   C
     E   B   D   A   C          1.377    36  NAHANT BEACH
     E   B   D   A   C
     E   B   D   A   C          1.365    13  WINTHROP BEACH
     E   B   D       C
     E   B   D       C          1.332    14  YIRREL
     E   B   D       C
     E   B   D       C          1.330    48  TENEAN BEACH
     E   B   D       C
     E   B   D   F   C          1.310    12  REVERE OAK ISLAN
     E       D   F   C
     E       D   F   C          1.267    87  WOLLASTON BEACH
     E       D   F   C
     E       D   F   C          1.187    12  PLEASURE BAY, BR
     E       D   F   C
     E       D   F   C          1.043    12  SHORT BEACH
     E       D   F
     E       D   F              1.013    63  CONSTITUTION BEA
     E       D   F
     E       D   F              0.974    24  REVERE BEACH
     E           F
     E           F              0.960    54  CARSON BEACH
                 F
                 F              0.724     2  LOVELLS ISLAND
```

APPENDIX TABLE 3. (Continued)

YEAR=1986

General Linear Models Procedure

Waller-Duncan K-ratio T test for variable: L_FCOL

NOTE: This test minimizes the Bayes risk under additive loss and certain other assumptions.

Kratio= 100 df= 110 MSE= 0.184964 F= 10.00402
Critical Value of T= 1.84341
Minimum Significant Difference= 0.4529
WARNING: Cell sizes are not equal.
Harmonic Mean of cell sizes= 6.129535

Means with the same letter are not significantly different.

Waller Grouping				Mean	N	COMMONID
		A		2.632	3	Mill Creek (mile
		A				
B		A		2.393	5	Neponset River,
B						
B		C		2.046	6	Mystic River, ne
B		C				
B		C	D	1.943	5	Mouth of Neponse
		C	D			
E		C	D	1.873	6	Charles River, 5
E		C	D			
E	F	C	D	1.846	6	Inner Harbor, ju
E	F	C	D			
E	F	C	D	1.823	12	Inner Harbor, at
E	F	C	D			
E	F	C	D	1.695	6	Mystic River, 25
E	F		D			
E	F	G	D	1.507	6	Outer Harbor, no
E	F	G				
E	F	G	H	1.440	9	Chelsea River (m
	F	G	H			
	F	G	H	1.412	6	President Roads,
		G	H			
I		G	H	1.118	6	Winthrop Bay off
I			H			
I			H	1.018	6	Hingham Bay, sou
I			H			
I			H	1.005	17	Dorchester Bay,
I						
I				0.910	6	Quincy Bay, sout
I						
I				0.856	6	Nantasket Roads,
I						
I				0.835	12	Quincy Bay, midw
I						
I				0.819	5	Quincy Bay, nort

APPENDIX TABLE 3. SPATIAL DIFFERENCES IN LOG (x+1) FECAL COLIFORM COUNTS COLLECTED DURING MDEP WATER QUALITY STUDY FROM 1985 THROUGH 1987 AS INDICATED BY MEANS SEPARATION TEST OF TWO-WAY ANOVA (year x station).

YEAR=1985

General Linear Models Procedure

Waller-Duncan K-ratio T test for variable: L_FCOL

NOTE: This test minimizes the Bayes risk under additive loss and certain other assumptions.

Kratio= 100 df= 144 MSE= 0.431421 F= 6.123317
Critical Value of T= 1.90858
Minimum Significant Difference= 0.6728
WARNING: Cell sizes are not equal.
Harmonic Mean of cell sizes= 6.944272

Means with the same letter are not significantly different.

Waller Grouping					Mean	N	COMMONID
			A		2.253	5	Neponset River,
			A				
	B		A		2.181	8	Mystic River, 25
	B		A				
	B		A		2.155	8	Mystic River, ne
	B		A				
	B		A		2.151	16	Inner Harbor, at
	B		A				
	B		A	C	2.065	14	Chelsea River (m
	B		A	C			
	B		A	C	2.058	8	Charles River, 5
	B		A	C			
	B	D	A	C	1.835	8	Inner Harbor, ju
	B	D	A	C			
E	B	D	A	C	1.741	6	Mill Creek (mile
E	B	D		C			
E	B	D	F	C	1.538	3	Quincy Bay, sout
E		D	F	C			
E		D	F	C	1.451	7	Outer Harbor, no
E		D	F				
E	G	D	F		1.313	6	Hingham Bay, sou
E	G	D	F				
E	G	D	F		1.210	7	Winthrop Bay off
E	G		F				
E	G		F		1.075	7	Mouth of Neponse
	G		F				
	G		F		1.064	8	President Roads,
	G		F				
	G		F		1.053	4	Winthrop Bay, mi
	G		F				
	G		F		0.924	13	Quincy Bay, midw
	G		F				
	G		F		0.906	7	Nantasket Roads,
	G		F				
	G		F		0.897	22	Dorchester Bay,
	G						
	G				0.749	6	Quincy Bay, nort

APPENDIX TABLE 3. (Continued)

```
------------------------------------ YEAR=1987 ------------------------------------

                         General Linear Models Procedure

                 Waller-Duncan K-ratio T test for variable: L_FCOL

  NOTE: This test minimizes the Bayes risk under additive loss and certain other assumptions.

               Kratio= 100  df= 36  MSE= 0.119061  F= 7.296646
                        Critical Value of T= 1.95429
                    Minimum Significant Difference= 0.6017
                      WARNING: Cell sizes are not equal.
                     Harmonic Mean of cell sizes= 2.511873

  Means with the same letter are not significantly different.

       Waller Grouping           Mean      N  COMMONID

                     A          3.029      2  Mill Creek (mile

                     B          1.995      4  Mystic River, ne
                     B
             C       B          1.813      2  Neponset River,
             C       B
             C       B    D     1.638      2  Mystic River, 25
             C       B    D
             C    E  B    D     1.545      4  Charles River, 5
             C    E  B    D
          F  C    E  B    D     1.523      2  Outer Harbor, no
          F  C    E       D
          F  C    E  G    D     1.246      2  Mouth of Neponse
          F       E  G    D
          F       E  G    D     1.166      7  Inner Harbor, at
          F       E  G    D
          F       E  G    D     1.161      2  Inner Harbor, ju
          F       E  G
          F       E  G          1.021      2  President Roads,
          F          G
          F          G          0.935      4  Dorchester Bay,
                     G
                     G          0.870      2  Nantasket Roads,
                     G
                     G          0.849      2  Hingham Bay, sou
                     G
                     G          0.849      2  Quincy Bay, nort
                     G
                     G          0.849      4  Quincy Bay, midw
                     G
                     G          0.849      2  Quincy Bay, sout
                     G
                     G          0.822      8  Chelsea River (m
```

APPENDIX TABLE 4. SPATIAL DIFFERENCES IN LOG (x+1) FECAL COLIFORM COUNTS COLLECTED DURING MWRA'S CSO MONITORING PROGRAM FROM 1989 THROUGH 1990 AS INDICATED BY MEANS SEPARATION TEST OF TWO-WAY ANOVA (year x station).

General Linear Models Procedure

Waller-Duncan K-ratio T test for variable: L_MFC

NOTE: This test minimizes the Bayes risk under additive loss and certain other assumptions.

Kratio= 100 df= 1023 MSE= 0.650825 F= 12.14536
Critical Value of T= 1.81182
Minimum Significant Difference= 0.6178
WARNING: Cell sizes are not equal.
Harmonic Mean of cell sizes= 11.19338

Means with the same letter are not significantly different.

Waller Grouping					Mean	N	STATION
			A		2.477	15	13
			A				
			A		2.453	23	41
			A				
			A		2.399	26	39
			A				
			A		2.388	45	18
			A				
	B		A		2.324	27	16
	B		A				
	B		A	C	2.293	59	11
	B		A	C			
	B		A	C	2.237	43	19
	B		A	C			
	B		A	C	2.225	22	27
	B		A	C			
	B		A	C	2.201	42	17
	B		A	C			
	B		A	C	2.199	58	14
	B		A	C			
	B		A	C	2.178	14	20
	B		A	C			
	B	D	A	C	1.996	45	15
	B	D	A	C			
E	B	D	A	C	1.966	40	21
E	B	D	A	C			
E	B	D	A	C	1.906	2	65
E	B	D	A	C			
E	B	D	A	C	1.890	13	83
E	B	D	A	C			
E	B	D	A	C	1.869	15	23
E	B	D		C			
E	B	D	F	C	1.756	43	24
E		D	F	C			
E	G	D	F	C	1.694	21	40
E	G	D	F				
E	G	D	F	H	1.457	13	43
E	G		F	H			
E	G	I	F	H	1.367	41	22

APPENDIX TABLE 4 (continued).

General Linear Models Procedure

Waller Grouping						Mean	N	STATION
E	G	I	F	H				
E	G	I	F	H		1.351	60	44
	G	I	F	H				
J	G	I	F	H		1.197	33	37
J	G	I	F	H				
J	G	I	F	H		1.196	51	38
J	G	I	F	H				
J	G	I	F	H	K	1.183	39	36
J	G	I	F	H	K			
J	G	I	F	H	K	1.156	10	32
J	G	I		H	K			
J	G	I		H	K	1.125	12	46
J	G	I		H	K			
J	G	I		H	K	1.086	9	84
J		I		H	K			
J		I		H	K	1.070	25	48
J		I		H	K			
J		I		H	K	0.971	13	45
J		I		H	K			
J		I		H	K	0.959	14	33
J		I		H	K			
J		I	L	H	K	0.933	31	35
J		I	L	H	K			
J		I	L	H	K	0.902	11	80
J		I	L	H	K			
J		I	L	H	K	0.901	3	85
J		I	L	H	K			
J		I	L	H	K	0.890	10	81
J		I	L	H	K			
J		I	L	H	K	0.885	8	29
J		I	L	H	K			
J		I	L	H	K	0.857	11	79
J		I	L	H	K			
J		I	L	H	K	0.856	10	31
J		I	L		K			
J		I	L		K	0.796	25	30
J		I	L		K			
J		I	L		K	0.777	11	76
J		I	L		K			
J		I	L		K	0.758	15	28
J		I	L		K			
J		I	L		K	0.754	10	82
J			L		K			
J			L		K	0.700	3	87
J			L		K			
J			L		K	0.694	3	88
J			L		K			
J			L		K	0.682	24	47
J			L		K			
J			L		K	0.636	3	86

APPENDIX TABLE 4 (continued).

General Linear Models Procedure

Waller Grouping			Mean	N	STATION
J	L	K			
J	L	K	0.635	24	49
	L	K			
	L	K	0.566	11	77
	L				
	L		0.319	10	78

APPENDIX TABLE 5. SPATIAL DIFFERENCES IN LOG (x+1) *ENTEROCOCCUS* BACTERIA COUNTS COLLECTED DURING MWRA's CSO MONITORING STUDY FROM 1989 THROUGH 1990 AS INDICATED BY MEANS SEPARATION TEST OF ONE-WAY ANOVA (BY YEAR).

YEAR=1990

General Linear Models Procedure

Waller-Duncan K-ratio T test for variable: L_MENT

NOTE: This test minimizes the Bayes risk under additive loss and certain other assumptions.

Kratio= 100 df= 622 MSE= 0.547658 F= 4.143362
Critical Value of T= 2.00020
Minimum Significant Difference= 0.7951
WARNING: Cell sizes are not equal.
Harmonic Mean of cell sizes= 6.932102

Means with the same letter are not significantly different.

Waller Grouping									Mean	N	STATION
					A				1.795	13	83
					A						
	B				A				1.690	14	16
	B				A						
	B				A		C		1.494	13	27
	B				A		C				
	B		D		A		C		1.342	36	18
	B		D		A		C				
	B		D		A		C		1.341	8	40
	B		D		A		C				
E	B		D		A		C		1.321	3	85
E	B		D		A		C				
E	B		D		A		C	F	1.273	9	41
E	B		D		A		C	F			
E	B		D		A	G	C	F	1.221	47	11
E	B		D		A	G	C	F			
E	B		D		A	G	C	F	1.205	3	86
E	B		D		A	G	C	F			
E	B		D	H	A	G	C	F	1.111	26	17
E	B		D	H	A	G	C	F			
E	B	I	D	H	A	G	C	F	1.051	44	14
E	B	I	D	H	A	G	C	F			
E	B	I	D	H	A	G	C	F	1.025	29	15
E	B	I	D	H	A	G	C	F			
E	B	I	D	H	A	G	C	F	1.021	26	19
E	B	I	D	H		G	C	F			
E	B	I	D	H		G	C	F	0.998	26	21
E	B	I	D	H		G	C	F			
E	B	I	D	H		G	C	F	0.986	11	79
E	B	I	D	H		G	C	F			
E	B	I	D	H		G	C	F	0.965	3	87
E		I	D	H		G	C	F			
E		I	D	H	J	G	C	F	0.893	41	38
E		I	D	H	J	G	C	F			
E		I	D	H	J	G	C	F	0.882	45	44
E		I	D	H	J	G	C	F			
E		I	D	H	J	G	C	F	0.866	3	88

APPENDIX TABLE 5 (continued).

YEAR=1990

General Linear Models Procedure

Waller Grouping	Mean	N	STATION
E I D H J G C F			
E I D H J G C F	0.840	26	22
E I D H J G C F			
E I D H J G C F	0.816	9	84
E I D H J G C F			
E I D H J G C F	0.811	25	24
E I D H J G C F			
E K I D H J G C F	0.764	11	80
E K I D H J G F			
E K I D H J G F	0.685	31	36
E K I D H J G F			
E K I D H J G F	0.664	10	82
E K I D H J G F			
E K I D H J G F	0.645	10	81
E K I D H J G F			
E K I D H J G F	0.638	11	77
E K I H J G F			
E K I H J G F	0.537	11	48
K I H J G F			
K I H J G F	0.525	23	37
K I H J G F			
K I H J G F	0.503	11	76
K I H J G F			
K I H J G F	0.488	11	49
K I H J G			
K I H J G	0.463	11	47
K I H J			
K I H J	0.326	23	35
K I J			
K I J	0.276	10	78
K J			
K J	0.162	16	30
K J			
K J	0.134	9	28
K			
K	0.000	1	39
K			
K	0.000	1	33

APPENDIX TABLE 6. SUMMARY OF LINEAR REGRESSION RESULTS (R^2,P) TO DETERMINE THE RELATIONSHIP BETWEEN FECAL COLIFORM (MF METHOD) COUNTS AND 1-, 2-, 3-, 4-DAY CUMULATIVE RAINFALL, DAILY DEER ISLAND AND NUT ISLAND WASTEWATER TREATMENT PLANT FLOWS AND FECAL COLIFORM LOADS AT STATIONS SAMPLED AS PART OF DEP'S WATER QUALITY MONITORING PROGRAM FROM 1985 THROUGH 1988.

STATION NAME	STATION #	1-DAY RAIN	2-DAY RAIN	3-DAY RAIN	4-DAY RAIN	DEER ISLAND FLOW	DEER ISLAND LOAD	NUT ISLAND FLOW	NUT ISLAND LOAD
Charles River, Charlestown Bridge	4	0	0	0	0	.03	.01	.24	.01
Chelsea River,									
Meridian Street	CR01	.22	.22	.22	.22	.10	.17	.01	.45*
Chelsea Street	CR02	.09	.09	.09	.09	.28	.27	.27	.09
Dorchester Bay,									
Moon Head	11A	.02	.02	.02	.02	.01	.56	.11	.01
Old Harbor	9	.11	.11	.11	.11	.62	.35	.0	.04
Columbia Point	10	0	0	0	0	.20	.05	.39*	.01
Hingham Bay	14	.41**	.41**	.41**	.43**	.37	.003	.0	.28*
Inner Harbor,									
Fort Point Channel	5	.01	.01	.01	.01	.17	.14	.21	.003
Reserved Channel	6	.15	.15	.15	.15	.10	.06	.12	.36*
nr. Charles River	3	.04	.04	.04	.06	0	.29	.37*	.004
Mill Creek	CR03	.22	.22	.22	.22	.46	.19	.0	.46*(-)
Neponset River mouth	10A	.05	.05	.05	.05	.10	.05	.60**	.003
Mystic River,									
Tobin Bridge	2	.01	.01	.01	0	.42	.01	.03	.006
Island End R.	1	.01	0	0	.02	.01	.04	.05	.007
Nantasket Roads	18	.07	.07	.07	.07	.18	.12	.08	.15
Neponset River,									
Neponset R. Bridge	10B	.03	.03	.03	.03	.34	.005	.36	.02
Outer Harbor	7	0	0	0	0	.05	.003	.0	.03
President Roads	8	.02	.02	.02	.02	.17	.05	.27	.01
Quincy Bay, Midway, Hangman & Nut Is.	13	.18	.18	.18	.18	.01	.56	.03	.45
Midway between Hangman Is. & Black Crk	12	.06	.06	.06	.06	.54	.08	.08	.09
Wollaston Yacht Club	12A	.05	.05	.05	.05	.02	.55	.28	.04
SE Rainsford Island	13A	.53*	.53*	.53*	.53*	.22	.003	.02	.48*
Winthrop Bay, Constitution Beach	22	.06	.06	.06	.06	.42	.09	.34	.03

*0.01 <p ≤0.05 **.001 <p ≤.01

Sifnificant regression results showed a positive relationship unless otherwise noted by (-).

APPENDIX TABLE 7. SUMMARY OF LINEAR REGRESSION RESULTS (R^2,P) TO DETERMINE THE RELATIONSHIP BETWEEN FECAL COLIFORM (MF METHOD, 4000 COUNT LIMIT) COUNT AND 1-, 2-, 3-, 4-DAY CUMULATIVE RAINFALL, DAILY DEER ISLAND AND NUT ISLAND WWTP FLOWS AND FECAL COLIFORM LOADS AT BEACHES SAMPLED AS PART OF MDC'S BEACH MONITORING PROGRAM FROM 1987 THROUGH 1989.

BEACH	1-DAY RAIN	2-DAY RAIN	3-DAY RAIN	4-DAY RAIN	DEER ISLAND		NUT ISLAND	
					FLOW	LOAD	FLOW	LOAD
Swampscott	0.15*	0.15*	0.15*	0.15*	0.017	.10	0.075	.12
Kings	0.086	0.086	0.088	0.12*	0.14*	.08	0.027	.02
Lynn	0.0025	0.0025	0.0025	0.0046	0.10*	.12(*)-	0.12*	.01
Nahant	0.033	0.033	0.033	0.033	0.098	.15(*)-	0.28**	.02
Revere	0.13*	0.13*	0.13*	0.13*	0.10	.12(*)-	0.18*	.14*
Short	0.00037	0.00037	0.00037	0.00037	0.032	.01	0.029	.0004
Winthrop	0.10	0.10	0.10	0.10	0.050	.07	0.018	.01
Yirrell	0.071	0.071	0.071	0.071	0.25**	.07	0.33**	.10
Lovells Island	0.00091	0.00091	0.00091	0.00091	0.38*	.12	0.42**	.02
Constitution	0.18**	0.18**	0.15**	0.14**	0.043	.02	0.030	.07
Pleasure Bay	0.0097	0.0097	0.0097	0.0097	0.0049	.002	0.0018	.08
Carson	0.046	0.16**	0.17**	0.17**	0.24***	.02	0.10*	.06
Malibu	0.032	0.032	0.032	0.10*	0.37***	.35**(-)	0.43***	.25**
Tenean	0.057	0.057	0.057	0.092	0.20**	.17**(-)	0.28***	.11
Wollaston	0.013	0.024	0.028	0.030	0.16**	.005	0.084*	.04
Nantasket	0.41**	0.41**	0.41**	0.41**	0.12	.13	0.42**	.36**

*<.01 p ≤.05 **.001 ≤p ≤0.01 ***p <.001 All significant linear regression results showed a positive relationship unless noted by (-)

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