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WATER QUALITY DATA ASSESSMENT FOR BUZZARDS BAY, MASSACHUSETTS

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FINAL REPORT

TO

MASSACHUSETTS EXECUTIVE OFFICE
OF ENVIRONMENTAL AFFAIRS

WATER QUALITY DATA ASSESSMENT FOR BUZZARDS BAY, MASSACHUSETTS

SEPTEMBER 27, 1988

by

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1. INTRODUCTION TO WATER QUALITY DATA CHARACTERIZATION

In 1985, the Buzzards Bay Project, managed by the Commonwealth of Massachusetts Executive Office of Environmental Affairs (EOEA) and the U.S. Environmental Protection Agency (EPA), Region I, began an effort to characterize the health of the Buzzards Bay estuary, located in southeastern Massachusetts and west of Cape Cod. As part of this program, historical data sets were collected by several investigators for the following topics: water quality and nutrients, coliform bacteria, toxic substances in organisms and sediments, lobster landings (Battelle, 1986); shellfish landings (Alber, 1987); and finfish resources (Moss and Hoff, 1987).

One of the highest priorities of the National Estuary Program and the Buzzards Bay Project has been to develop basinwide planning and management with focus on resource impact including living resources, water quality, and sediment quality of the Bay. Initial characterization efforts have included analysis and synthesis of historical and current data on topics such as pollutant loads, water and sediment quality, and living resources. The purpose of characterizing these data is to investigate whether spatial and temporal trends can possibly be determined in the estuary. However, before examining these trends for any given parameter, it is important that data be reviewed for overall quality, including both the usefulness and the limitations of the data examined.

The decline in water quality, identified in the Long-Term Management Plan for Buzzards Bay (EPA, 1986), has threatened the use of the fisheries and other Bay resources. Toxic contamination, coliform contamination, and the resulting shellfish bed closures have been identified as priority problems. Contamination from point and nonpoint sources, including nutrient enrichment, was also identified as a problem.

The purpose of this project was to review historical data, available at the EPA National Computer Center (NCC), on coliform

bacteria and nutrients in Buzzards Bay. This review included identifying relevant parameters for characterization, assessing the methods used in collecting the data sets, and summarizing coverage of data for coliform bacteria and nutrients over time and space in Buzzards Bay. This report is an assessment of nutrient and coliform data and should be used in drafting future management recommendations for Buzzards Bay. As the first systematic review of assembled Buzzards Bay data, this report is a model for reviewing data before incorporating it into a regional water quality database management system for analysis.

2. REVIEW OF WATER QUALITY DATA SETS

2.1 OVERVIEW OF DATA SETS

Historical water quality and nutrient data sets were collected and ranked in order of priority as part of a data set summary for Buzzards Bay (Battelle, 1986). Several of these data sets were later selected for entry into the EPA National Computer Center (NCC). The first step in selecting data sets for use in this study was to review the historical data sets relevant to coliform bacteria and nutrients. Twelve data sets (Table 1) from EPA's NCC data system were identified and are summarized below. Parameters reported for each data set were reviewed to determine which types of data were included, whether the data were comparable, and whether the data could be used for trend analysis (Table 2). A review of methods used in generating these data is provided in Section 2.2 of this report, and a more detailed discussion of methods for several of the data sets can be found in Battelle (1987).

It should be noted that these data represent most of the data collected for coliform bacteria and nutrients in Buzzards Bay. Additional data from DEQE-DWPC's 1986 sampling is being entered into the EPA database, but was not used in this study. The current assessment uses only those data available in the EPA NCC system at the beginning of this study, as shown in Table 1.

2.1.1 Coliform Bacteria Data Sets

A total of 10 data sets for coliform bacteria in Buzzards Bay were identified in the EPA database system. These data were compiled from several sources including surveys conducted by the Massachusetts Department of Environmental Quality Engineering (DEQE), the U.S. Food and Drug Administration (FDA), and the Barnstable County Health Department.

TABLE 1. DATA SETS FOR COLIFORM BACTERIA AND NUTRIENTS IN BUZZARDS BAY.

Data Set Abbreviation	Data Set Name/Report Title
DEQE-LAKEVILLE	Massachusetts Department of Environmental Quality and Engineering, Shellfish Sanitation Branch, Lakeville, MA. Bacteriological Monitoring Data. (1971-1986).
FDA	U.S. Food and Drug Administration, Northeast Technical Services Branch.
	1972 Sanitary Surveys: Chase Garden, Scorton Creek, Wareham River, and Mattapoisett Harbor.
	1981 Cape Cod Shellfish Area Survey.
	1985 Buttermilk Bay Sanitary Survey.
	1985 Westport River Watershed and Shellfish Growing Area Survey.
DEQE-DWPC	Massachusetts Department of Environmental Quality and Engineering, Division of Water Pollution Control, Westborough, MA.
	1972. New Bedford Harbor and Acushnet River Water Quality Study. Prepared by the Water Quality Management Section, Boston, Pub. No. 6046.
	1976. Buzzards Bay 1975 Water Quality Survey Data. Prepared by the Water Quality Managment Section. Publication No. 13510-140-25-1-84-CR.
	1982. Buzzards Bay and Outer New Bedford Harbor 1980 Water Quality Survey Data. Technical Services Branch, Westborough, MA. Publication No. 12673-45-50-1-82-CR.
	1987. Part A. Buzzards Bay 1985 Water Quality Survey Data. Prepared by Lawrence W. Gil, Technical Services Branch, Westborough, MA. Publication No. 14, 712-158-75-2-87-CR.
BARNSTABLE COUNTY HEALTH/ BOSTON UNIVERSITY	Heufelder, G.R. 1987. Bacteriological Monitoring in Buttermilk Bay. Submitted to U.S. EPA Region I. 98 p.
	Valiela, I and J. Costa. 1986. Eutrophication of Buttermilk Bay, a Cape Cod Coastal Embayment: Concentrations of Nutrients and Watershed Nutrient Budgets. Draft Report submitted to EPA Region I. 27 p.
ROSENFELD	Rosenfeld, L.K., R.P. Signell, and G.G. Gawarkiewz. 1984. Hydrographic Study of Buzzards Bay, 1982-1983. Technical Report, WHOI-84-5. Coastal Research Center, Woods Hole Oceanographic Institution, Woods Hole, MA.

TABLE 2. PARAMETERS IN BUZZARDS BAY DATA SETS.

	Data Set												
	A	B	C	D	E	F	G	H	I	J	K	L	M
STATION PARAMETERS													
Station i.d.			X	X	X	X	X	X	X	X		X	X
Lat/Long. coord.	X	X			X		X	X	X	X	X	X	X
State plane			X										
Date	X	X	X	X	X	X	X	X	X	X	X	X	X
Time	X	X		X	X	X				X	X		X
Person	X												
Tide stage	X				X			X				X	
Tide time	X				X								
Salinity	X	X	X	X			X		X			X	
Temperature		X	X	X	X	X		X		X	X		X
Depth			X				X		X	X	X	X	
Wind		X											X
Town		X											
Rain	X											X	X
SAMPLE PARAMETERS													
E. coli		X			X								X
Fecal coliforms	X	X	X	X	X	X	X		X			X	X
Fecal streptococci	X			X				X				X	
Total coliforms	X	X		X	X	X	X	X	X			X	
Clostridium SP.			X										
Sample number									X				
Analysis date	X												
Dissolved oxygen			X			X		X	X	X			
Ammonium (-ia)			X		X		X	X	X	X			
Nitrite			X				X		X	X			
Nitrate			X		X		X	X	X	X			
Kjeldahl-nitrogen					X			X	X	X			
Orthophosphate			X		X				X				
Phosphorus							X	X	X	X			
Silicate										X			
Alkalinity						X	X						
pH						X	X	X					
BOD							X	X					
Chlorides							X	X					
COD							X						
Metals							X	X	X				
PCBs								X					
Chlorophyll-a							X		X				
Transmissivity											X		

A= DEQE-LAKEVILLE
B= FDA 1985
C= BARNSTABLE COUNTY HEALTH/ BOSTON UNIVERSITY
D= FDA 1981
E= FDA 1972
F= DEQE-DWPC 1972
G= DEQE-DWPC 1975
H= DEQE-DWPC 1980
I= DEQE-DWPC 1985-86
J= NATIONAL MARINE FISHERIES SERVICE
K= ROSENFELD 1981
L= DEQE-LAKEVILLE
M= FDA 1985-86

2.1.1.1 DEQE-Lakeville Annual Water Quality Surveys

The Shellfish Sanitation Branch of the Lakeville, Massachusetts, DEQE has been sampling Buzzards Bay waters for coliform bacteria since 1975. (Beginning in 1988, this responsibility will be transferred to the Massachusett's Division of Marine Fisheries.) The Shellfish Sanitation Branch has been collecting these data to classify shellfish growing areas. Prior to 1975, the Department of Public Health controlled this program. Data currently available in EPA's database span the years 1970 to 1986. During that time there were periods when data were reported for total coliform bacteria only, then for both total and fecal coliform bacteria, and finally for fecal coliform bacteria alone.

In this data assessment we present and discuss primarily the data on total coliform bacteria. We decided to focus on this measurement because the Shellfish Sanitation Branch used these data to decide when to close shellfish beds and because the total coliform levels were the most continuously reported data. Historically, DEQE-Lakeville measured total coliform bacteria and used that as the basis for their decisions. In the early 1980s they began to measure total and fecal coliform concentrations, but still based decisions on the total levels. Since 1986, they have measured and used fecal coliform levels as closure criteria (Tena Davies, DEQE-Lakeville, personal communication, December 18, 1987). Even with this recent shift to fecal levels, we thought it most appropriate to assess the historical data based on the total coliform levels that were most commonly and continuously used. Where possible, we also present summary statistics on the fecal coliform data from this and other studies described in the following sections.

Many types of auxiliary data that are less consistently available. These include region name, collector, tidal state, wind direction, and days since last rain (Table 2). These results have not been published, but the raw data were entered into the EPA database management system in 1987.

2.1.1.2 DEQE-Division of Water Pollution Control Monitoring Data

The Division of Water Pollution Control (DWPC) of Massachusetts DEQE periodically collected coliform and auxiliary data to monitor the water quality of Buzzards Bay. These sampling efforts include special water quality surveys conducted in New Bedford Harbor and the Acushnet River in 1971 and 1980, and larger surveys conducted throughout the western shores (and to a lesser extent the eastern shores) of the Bay in 1975 and 1985-86. Total and fecal coliform bacteria levels were reported. Additional parameters were reported, including water temperature, dissolved oxygen, pH, biological oxygen demand, alkalinity, total solids, turbidity, chlorides, and salinity (Table 2). Data for these sampling efforts were compiled from water quality survey reports and data sheets. The data were entered into four data sets according to years.

2.1.1.3 U.S. Food and Drug Administration, Shellfish Area Data

The Northeast Technical Services Unit of the Food and Drug Administration (FDA) has also collected coliform bacteria data in Buzzard's Bay. The FDA's data were intended to supplement existing water quality data and to confirm existing shellfish classifications for Buzzards Bay. Most data are from short-term studies and are specific to areas with water quality problems. Data from four FDA survey reports were compiled and entered into the EPA system. These data include results of Sanitary Surveys conducted in 1972 for Mattapoisett Harbor and the Wareham River, in 1985 for Buttermilk Bay and Little Buttermilk Bay, and in 1985 for the Westport River. In addition, FDA surveyed several stations on the eastern shores of the Bay in 1981 as part of the Cape Cod Shellfish Survey. These reports usually included only coliform data (fecal/total), salinity, and temperature (Table 2).

2.1.1.4 Barnstable County Department of Health, Buttermilk Bay

Beginning in September 1985, a year-long study was conducted to assess bacterial contamination in Buttermilk Bay (Heufelder,

1986). Data were collected in an effort to clarify sources of bacterial contamination such as stormwater, septic systems, marinas, wildlife, freshwater inputs, and point discharges. Fecal coliform and fecal streptococcus densities were reported for routine sampling stations in Buttermilk Bay and Little Buttermilk Bay during 1986. Densities of Escherichia coli and Clostridium perfringens were occasionally measured. Supporting data include salinity and temperature (Table 2).

2.1.2 Nutrient Data Sets

Six studies containing nutrient data for Buzzards Bay have been included in the EPA database system. Of these six data sets, four comprise data collected by the Division of Water Pollution Control (DEQE-DWPC). The two other studies include data collected by Boston University and the National Marine Fisheries Service.

2.1.2.1 DEQE-Division of Water Pollution Control Monitoring Data

As mentioned previously, the DEQE-DWPC'S most spatially comprehensive water quality surveys date from 1975 and 1985. Special surveys were conducted in the Acushnet River and New Bedford Harbor during 1971 and 1980. A variety of water quality parameters are included in the DEQE data, although all parameters were not measured at each station. Nutrient parameters reported include ammonia, nitrite, nitrate, Kjeldahl-nitrogen, orthophosphate, and total phosphorus (Table 2).

2.1.2.2 Boston University Buttermilk Bay Study

Scientists from Boston University collected nutrient data for Buttermilk Bay in 1985-86. Nutrient levels were reported for the Bay, and for streams and groundwater entering the Bay. Budgets for nutrient inputs into the watershed and the Bay were calculated, and various nutrient sources were evaluated. Concentrations of ammonium, nitrate plus nitrite, and phosphate were measured (Table 2).

2.1.2.3 National Marine Fisheries Service Monitoring Station

The National Marine Fisheries Service (NMFS) collected nutrient data for Buzzards Bay during 1980 as part of the Northeast Monitoring Program. Data for stations located at 41° 29'N, 70° 53'W, southeast of Wilkes Ledge, are included in the EPA system. Nutrient data available from this program include ammonium, nitrite, nitrate, Kjeldahl nitrogen, phosphorus, and silicate. Dissolved oxygen, salinity, temperature, and chlorophyll were also reported (Table 2).

2.2 METHODS REVIEW

Methods were reviewed to assess the comparability between data sets. Methods used to generate data on coliform bacteria and nutrients were identified from data reports and telephone interviews. Sampling practices used for field collections and laboratory analytical techniques are discussed for those data sets where the information was obtainable. It is important to recognize that this review is by no means a scientific critique of methods used to analyze bacteria and nutrients. The purpose of reviewing methods is to screen data for comparability in evaluating spatial and temporal trends in Buzzards Bay.

2.2.1 Coliform Methods

2.2.1.2 Coliform Analytical Methods

Analytical methods used to measure total and fecal coliform bacteria include the multiple tube fermentation technique (MPN) and the membrane filtration technique (MF). With the exception of the most recent water quality survey conducted by the Division of Water Pollution Control (DEQE-DWPC, 1987), coliform contamination was analyzed using the American Public Health Association (APHA) multiple tube fermentation technique (APHA, 1980). MF and MPN

methods were both used to analyze samples collected by FDA in 1981.

The multiple tube fermentation technique reports results in an index of the most probable number that represents results from laboratory examination. Results are expressed as MPN (most probable number) because the tests are based on statistical analysis of a set of tubes in a series of serial dilutions. MPN is by definition related to a sample volume of 10 ml; hence an MPN of 10 means 10 coliforms per 100 ml of water (Hammer, 1986).

Total coliform bacteria is analyzed using presumptive, confirmed, and completed phase testing. Positive tubes from each phase are submitted to additional testing to verify the presence of bacteria. Total coliform counts are calculated from the MPN table (APHA; 1980, Section 908D). Positive tubes from total coliform tests are also used to test for fecal coliform bacteria. Specific media EC or A-1 are inoculated, incubated, and tested for gas production indicating the presence of fecal coliform bacteria. Historically, DEQE-Lakeville, DEQE-DWPC, FDA, and Barnstable County Department of Health used A-1 media for fecal coliform analyses. Different dilution series were used in each of the data sets (3, 4, 5, and 12 tube dilution series) and the analyses have not been consistent over time. Consequently, the data for coliform bacteria are reported with differing levels of confidence (variability) around the probable count and are reported with varying levels of detail.

Another consequence of using MPN data is that quantitative statistical methods become less accurate because of the probabilistic nature of the data. MPN values are often reported as minimum or maximum thresholds instead of as absolute values. For example, low values appear as "probably <36" or high values may appear as "probably >1600." The problem of accuracy arises because the SAS software does not account for the "<" or ">" when calculating values, causing both conservative overestimates of the minimum levels and underestimates of the maximum levels.

One method we used to correct for the lack of precision when absolute values were not used was to define categories of MPN

value ranges. These categories are one means of utilizing the historical coliform data to assess spatial or temporal trends. The categories were defined to account for regulatory criteria and the most commonly reported "<" or ">" values. The relevant water quality criteria for Class SA (primary and secondary contact, shellfish harvesting without depuration) are that "Total Coliform Bacteria shall not exceed a median value of 70 MPN/100 ml and not more than 10% of the samples shall exceed 230 MPN/100 ml in any monthly sampling period" (Commonwealth of Massachusetts Regulations, 314 CMR 1.00 - 7.00). Additionally, if an area is to be designated as a restricted shellfish area "...not more than 20% of the samples shall exceed 1000 MPN/100 ml." The categories that correspond to these levels were defined with the following MPN value ranges:

A = 0 - 70
B = 71 - 230
C = 231 - 1000
D = > 1000

Category A encompasses the majority of the "<" values and represents the total number of observations that comply with the criteria of less than 70 MPN/100 ml. Category B represents all observations above A, but less than the 230 MPN/100 ml threshold. The C and D categories bracket the 1000 MPN/100 ml threshold. The results of using this method of grouping total coliform data are discussed in Section 3.1.3 and Figures 2, 3, and 4.

An alternative to the MPN method of reporting coliform levels is to use a membrane filter to get an actual coliform count. The MF technique is based on drawing a measured volume of water through a filter membrane fine enough to take out bacteria, and then placing the filter on a growth medium in a petri dish. Each bacterium retained then grows and forms a small colony. The number of coliforms present in a filtered sample is determined by counting the number of colonies and expressing this value in terms of number per 100 ml of water.

The MF technique is often used because it requires less laboratory apparatus than the MPN method. The main steps of the MF technique are filtration, incubation, and enumeration. Coliform density is calculated in terms of coliforms per 100 ml by multiplying the colonies counted by 100 and dividing this by the milliliters of sample filtered (Hammer, 1986). Coliform data reported in 1985-86 samples collected by the DEQE-DWPC were analyzed using the MF method. FDA also used the MF technique in conjunction with the MPN method (FDA, 1981).

2.2.1.3 Coliform Field Sampling Methods

The methods and objectives of the field sampling programs greatly influence the comparability of the coliform data from the different studies. As discussed below, certain programs were trying to collect "worst possible case" coliform levels. Such intentional bias toward higher coliform levels limits the assumptions that can be made when these data are combined with randomly sampled data. For this assessment we will discuss the possible biases and demonstrate the resultant variability when the data are compared. In addition, we will show how environmental management decisions can be misdirected based on the questions asked and the sampling strategy used to collect supporting data.

DEQE-Lakeville and FDA used similar sampling techniques and occasionally used the same sampling teams. The Boston University and Barnstable County Department of Health also collected coliform samples in accordance with the FDA guidelines followed by DEQE-Lakeville. This consistency in collection methods allows their data to be combined.

However, the timing and environmental conditions of DEQE-Lakeville sampling made their data less comparable with the other studies. For many years the DEQE-Lakeville office sampled over large areas without a set schedule. Sampling was instead performed as crisis management; i.e., samples were taken during times of adverse conditions and in areas of maximum potential impact such as shellfish beds.

An example of sampling for maximum potential impact was that DEQE-Lakeville often sampled for coliforms following a rain event. Fortunately, the number of days since the rain event was usually included in the DEQE-Lakeville field data report. Unfortunately, there was no indication of the amount of rain. Based on the available data for rain we found that, with the exception of 1985, DEQE-Lakeville collected most of their samples within 2 days of rain. It would have been ideal if all the sampling efforts included data for time and amount of last rain, but without such data it is impossible to normalize the data for this sampling condition. It may be possible to go back and integrate historical precipitation information if the data system recommendations below are implemented. Recently, DEQE-Lakeville has started to collect samples from smaller areas and each station is supposed to be sampled more regularly throughout each year.

The DEQE-DWPC sampling methods followed in 1985-86 are less similar to the previous three studies, and thus their data cannot be compared directly with data from the other studies. The DEQE-DWPC sampled stations over tidal cycles and at multiple times of the day. These individual samples were then composited and measured as a sample representing the daily sample for that station. Over the years, the exact number and volume of samples has been modified.

With the exception of a few slight variations, data reporting formats have remained relatively consistent since 1970. Beginning in 1984, however, data were also reported on summary data forms. These summary forms provide a condensed version of all of the data reported on the individual data sheets. However, the condensed data sheets did not include some of the finer detailed data such as sampling time. Because sampling time was not always recorded it would not be worth the effort to retrieve these points. However, it is strongly recommended that future sampling descriptions include time of sampling.

2.2.2 Nutrient Methods

2.2.2.1 Nutrient Analytical Methods

Samples collected by the DEQE-DWPC were analyzed by the Lawrence Experiment Station. All procedures have followed those outlined in Standard Methods for the Examination of Water and Wastewater (13th, 14th, and 15th eds.) and EPA's Oceanographic Sampling and Analytical Procedures Manual (1979) (Table 3). Procedures for analyzing nutrients have remained the same for the period considered (George Minasion, Lawrence Experiment Station, personal communication, December 1987). However, no written quality assurance/quality control procedures were specified until the 1985 data report.

Samples collected by Boston University were analyzed using standard methods described in Manual of Chemical and Biological Methods for Seawater Analysis (Parsons et al., 1984). Ammonium concentrations were determined without delay using a modified Solorzano method. Nitrate plus nitrite was measured in a Technicon Autoanalyzer. Phosphate was measured by the molybdate method.

The common forms of nitrogen include organic, ammonia, nitrate, nitrite, and gaseous. Organic nitrogen is determined by digestion of organic matter, thus releasing ammonia, and then proceeding with the ammonia nitrogen test. The sum of these two results is often referred to as total Kjeldhal nitrogen (TKN). Nitrate and nitrite are routinely determined by colorimetric techniques. Methods used to examine nitrogen species (NO_3, NH_3, TKN) are listed in Table 3.

Phosphorus occurs as several compounds including orthophosphates, polyphosphates, and organic phosphorus. The variety of techniques for pretreatment of samples, measurement of phosphorus concentrations, and expression of results can be confusing. The particular procedure used in analysis was usually not recorded with test results. The most common shortcoming in presenting data on phosphorus was to omit documentation of collection technique, filtration, or other pretreatment.

TABLE 3. SAMPLING PARAMETERS AND ANALYTICAL METHODS EMPLOYED DURING DEQE-DWPC BUZZARDS BAY WATER QUALITY SURVEYS

Parameter	Method	Reported As	Detection Limits	Reference
Total Kjeldahl Nitrogen	Acid digestion using Technical BD-40 Block Digester. Colorimeteric analysis (reaction of ammonia, sodium salicylate, sodium nitroprusside, and sodium hypochlorite in buffered alkaline medium) using Technicon Auto Analyzer II	mg/l TKN	0.05 mg/l	EPA 1979 p. 351.2
Ammonia-Nitrogen	Phenate method, automated. Colorimetric analysis using Technicon Auto Analyzer II	mg/l NH_3-N	---	Stnd. Meth. 15 th ed., sec. 417f
Nitrate-Nitrogen	Hydrazine reduction method, automated Colorimetric analysis using Technicon Auto Analyzer II	mg/l NO_3-N	---	EPA 1979, p. 353.1
Total Phosphate	Acid Digestion using Technicon BD-40 Block Digester. Ascorbic acid reduction colorimetric method using technicon Auto Analyzer II	mg/l P	0.02 mg/l	EPA 1979, p. 365.4
Orthophosphate	Ascorbic acid method	mg/l as P	0.01 mg/l	Stnd. Meth. 16 th ed., Sec 424

2.2.2.2 Nutrient Field Sampling Methods

As with the coliform sampling discussed previously, the 1985-86 DEQE-DWPC samples were usually collected at multiple times over a 24-hour period. The samples were composited into one before being sent to the laboratory for analysis. Stations were usually sampled at the surface, but occasionally a water column sample was taken. Samples were most often collected on 1 or 2 sampling days in a single month. These sampling methods exclude this data set from trend analyses.

The major obstacle to comparing the remaining data sets is that the sampling conditions are not adequately described. As seen with the coliform data sets, the time of sampling is inconsistently recorded. Stage of the tide was not routinely included in the data sets, even though tide is a vital parameter in characterizing the processes affecting observed nutrient levels. Likewise, the data sets did not include exact data on sampling depth, current speed, or even station depth. This basic information is absolutely essential for any rigorous compilation and analysis of nutrient trends or dynamics. Unfortunately, lack of this relatively inexpensive information describing details of the sampling conditions decreases the value and utility of analytical results, regardless of the analytical precision or accuracy.

2.3 DATA SET SELECTION FOR ASSESSMENT

After reviewing parameter availability and the methods used in generating each data set, the 12 data sets available in the EPA database management system were screened for spatial and temporal coverage. None of the data sets examined is comprehensive in terms of spatial or temporal coverage. This report documents the coverage and variability that is produced by combining selected data sets.

To screen the data sets for spatial coverage, we used a series of overlays with a digitized map of Buzzards Bay to plot station locations. We also evaluated each data set using frequency histograms of data set observations, for each parameter, relative to spatial and temporal coverage. The DEQE-Lakeville and DEQE-DWPC data sets provide the most complete coverage for coliform bacteria and nutrient data for Buzzards Bay. As described in the previous sections, the methods used to generate these data have remained reasonably consistent and comparable (excluding DEQE-DWPC 1985-86) over the years. Hence, we have focused our assessment of spatial and temporal coverage on these two data sets. We were also able to focus on specific areas and time periods to assess the utility of the data for analyzing trends.

To enable us to refer to and select data on specific areas of Buzzards Bay, we divided the Bay into regional segments as displayed in Figure 1 (EPA, 1986a). We incorporated these segments into the study because they represent major watersheds for the Bay and are functionally discrete and useful. These segments were grouped according to latitude and longitude data for degrees, minutes, and seconds. For optimal assessment of water quality conditions and trends in data, stations must be integrated on a scale of tens or hundreds of meters. Segmentation allowed us to assemble and map the data, but most of the time the data were insufficient to fully characterize individual segments (EPA, 1983).

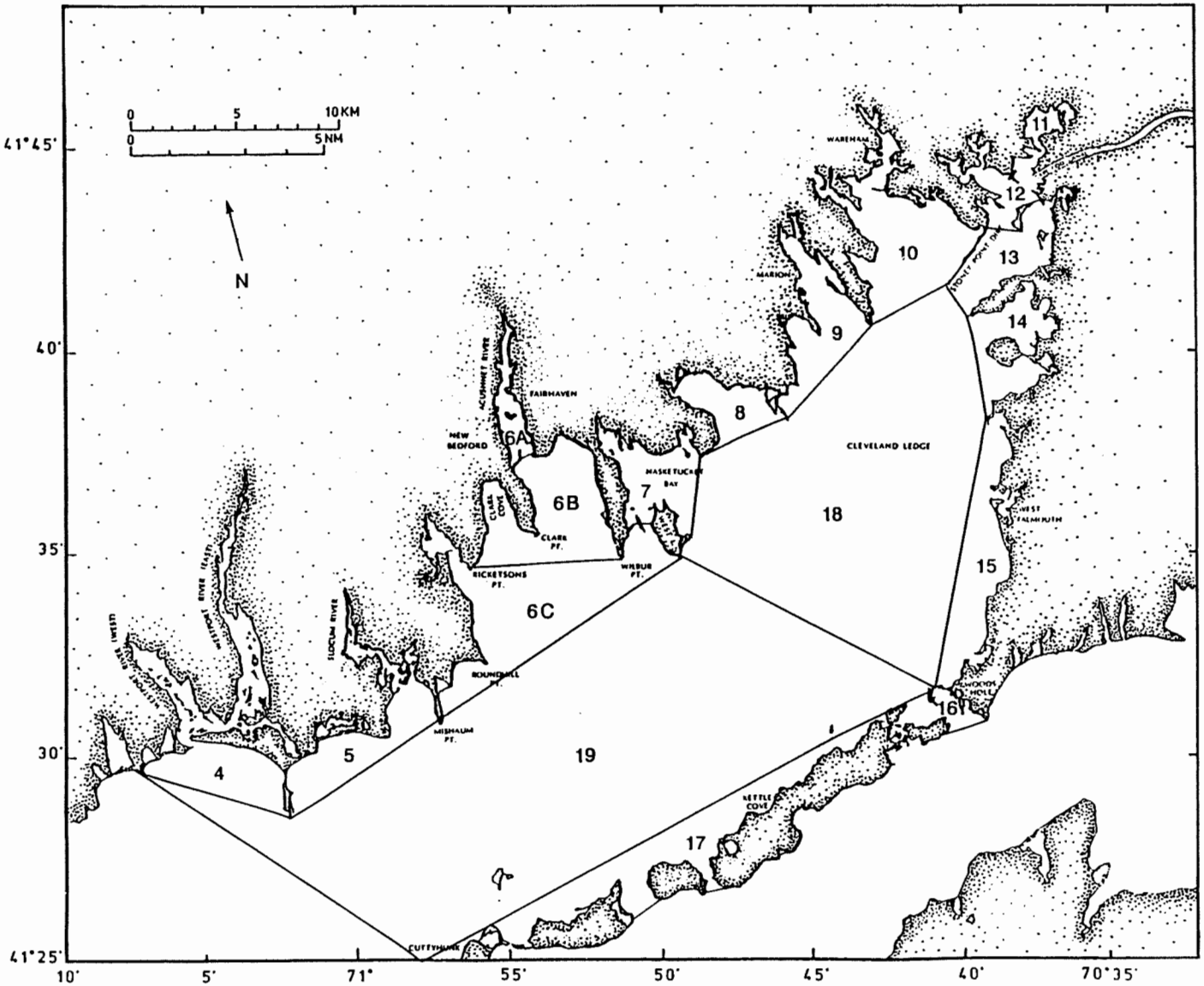

FIGURE 1. MAP SHOWING SEGMENTATION OF BUZZARDS BAY BASED ON MAJOR DRAINAGE BASINS. NUMBERS IDENTIFY SEGMENTS ACCORDING TO EPA (1986).

3. DATA ASSESSMENT AND ANALYSIS OF COVERAGE

3.1 COLIFORM BACTERIA

3.1.1 Summary of Coliform Sampling Stations

The 10 studies that have contributed coliform data for Buzzards Bay occupied approximately 1344 stations between 1970 and 1986. There was significant overlap between the stations used by DEQE-Lakeville and DEQE-DWPC. The total number of stations sampled in each of the contributing studies is shown in Table 4.

TABLE 4. SUMMARY OF STATION SAMPLING FOR COLIFORM DATA SETS.

Study	Number of Stations	Number of Samples	Average Reps	Percent Sampled Once
DEQE-Lakeville	822	3694	4	24
DEQE-DWPC 1975	62	356	6	0
DEQE-DWPC 1980	7	88	13	0
FDA 1985	40	268	7	27
FDA 1972	11	124	11	0
FDA 1981	50	86	2	28
DEQE-DWPC 1972	14	72	5	0
Barnstable	190	388	2	71
DEQE-DWPC 1985-86	148	537	4	1
TOTAL	1344	5613		

Because of the organization of the NCC SAS data system, it was difficult to relate or combine stations by proximity. This limitation caused us to depend on station names and descriptions as the only basis for combining similar stations. Stations were combined only after confirming their similarity by a labor-intensive review of the available data sheets and summary reports.

Use of a geographic information system (GIS) would make it possible to review, combine, and compare sampling stations cost effectively. A GIS could facilitate spatial analyses by allowing proximity testing, selective retrieval by ad-hoc segmentation, and more complex combinations. The stations could be grouped based on additional spatial characteristics such as bathymetry or current regimes. A GIS-based approach, carried out cooperatively with marine scientists and computer analysts, can produce a more comprehensive assessment than is possible through a purely statistical review.

3.1.2 Coliform Station Resampling

The DEQE-Lakeville data set includes samples from 822 stations. Twenty-four percent of these stations were sampled only once. Coliform data from DEQE-DWPC studies (1971, 1975, and 1980) were collected from 83 stations, all of which were sampled more than once. The 1985-86 coliform data collected by DEQE-DWPC (1987)(separated because of different methodology) include data from 85 stations that were all sampled more than once.

Resampling at stations is an important characteristic of the coliform data sets because it indicates which historical data sets could support trend analysis. Because of the unknown and variable extent of spatial heterogeneity, resampled stations become the only historical data that can be used to show changes over time. This is especially true for the coliform data because of the extreme variability in station types. It is difficult to characterize trends in an embayment by combining stations that

may be at an outfall pipe, a beach, a pier, and an offshore location. On the other hand, if a particular station is resampled, the effects of spatial variability are likely to be minimized and temporal trends might be discernible at scales greater than or equal to the resampling frequency.

Re-occupation of stations over time can help assess variability caused by proximity to a point source. For example, a station immediately downstream of an effluent may display variability if samples are collected at varying discharge rates. This variability may become apparent when compared to an upstream station that is less influenced by the discharge. Resampling at control sites further offshore from the potential sources will also produce data that reflect diluted levels of point-source contamination and thus less variability.

If stations are re-occupied in order to assess spatial variability, sampling conditions must be recorded. Unless conditions such as sampling time, recent precipitation, tidal state, exact depth, and current pattern are known, it is impossible to normalize for effects due to these factors. Spatial differences and variability can only be assessed after these data are used to characterize temporal differences.

3.1.3 Summary of Coliform Bacteria Levels Reported

The geometric means, standard deviations, minimum, maximum, and number of observations for total coliform bacteria levels are shown in Appendix A. The extremely high concentrations of fecal and total coliform bacteria made it impossible to use mean values for comparisons. Instead, we present geometric means, calculated according to Sokol and Rohlf (1969), for the coliform data.

Total and fecal coliform levels vary with each study (Appendices A and B), partly as a result of differences in sample collection programs. Some studies sampled at the point of discharge of sewage treatment or residential runoff; others

collected samples during periods of high stormwater runoff. Both conditions result in high coliform concentrations that skew the results of averaging data to obtain mean values for areas or time periods. Consequently, ranges of coliform values can be compared only on a station-by-station basis (see Figure 11 and discussion in Section 3.1.5).

Coliform levels vary depending on the input and dilution processes. The historical data compiled for Buzzards Bay originate from a wide array of sampling environments. Major coliform sources that could have contributed to the observed variability include, but are not limited to, stormwater runoff, sewage treatment outfalls, and farm runoff. These inputs are diluted to various degrees based on location-specific transport processes. Historical stations had different amounts of horizontal advection from stream flow, tidal exchange, residual flow, and wind-driven circulation. These stations were also subject to different degrees of vertical mixing and diffusion depending on upwelling, internal waves, physical constrictions, and topographic disturbances to flow. Unfortunately, the sampling programs being considered in this study, did not consistently report data to adequately describe these input or dilution processes.

Recording the conditions at time of sampling, discussed previously in Sections 2.2.1 and 4.2.1, is the best means of assessing coliform dilution potential. Data describing the immediate conditions at time of sampling provide a "snapshot" to assess the potential dilution variability due to factors such as relative amount of runoff or tidal exchange. Exact data describing the location would also allow the resultant levels to be integrated with information about that particular location.

These factors should be weighed by examining broader types of information that affect the coliform input and dilution processes. A GIS would enable scientists to investigate these processes more comprehensively by adding location-specific information about the bathymetry, tidal currents, adjacent land-use. For example,

marginal coliform levels might not automatically trigger use-restriction decisions if the levels are shown to be at an outfall in a high mixing area that is also downstream of the threatened resource.

Consequences of analyzing the wide range of coliform values must also be addressed. Examination of the percentage of samples with coliform values above any given criteria can lead to conclusions that conflict with the simpler comparisons of means or median values. Regardless of the analysis method, it is imperative that any historical data be used only with a complete understanding of the conditions under which samples were collected and the sampling strategy of the collection program.

A discrepancy in analyzing historical coliform data can be illustrated by comparing total coliform bacteria for segment 12, Wareham. The DEQE-Lakeville study has, over time, observed a mean value of 64 MPN/100 ml for segment 12 (see Appendix A), whereas DEQE-DWPC has reported mean values of 110 MPN/100 ml (from 1975 and 1985, see Appendix A). Based on mean comparisons, the Lakeville results suggest that the shellfish beds in the area have acceptable coliform levels (less than 70 MPN/100 ml). However, the DEWE-DWPC data indicate an unacceptable (much greater than 70 MPN/100 ml) environment.

An alternative approach to shellfish closure decisions, which involves examining the percentage of observations above the threshold criteria, can lead to opposite conclusions. One criterion for acceptability is that no more than 10 percent of the samples shall exceed 230 MPN/100 ml. The DEQE-Lakeville data in Figure 2 show that segment 12 is unacceptable because 24 percent (100 minus 76) of the samples exceeded the 230 MPN/100 ml criteria. Applying this decision process to the DEQE-DWPC data (Figure 3) indicates that segment 12 is acceptable because only 5 percent (100 minus 95) of the samples exceeded the 230 MPN/100 ml criteria. These two decisions are the reverse of the previous decisions based on comparison of means.

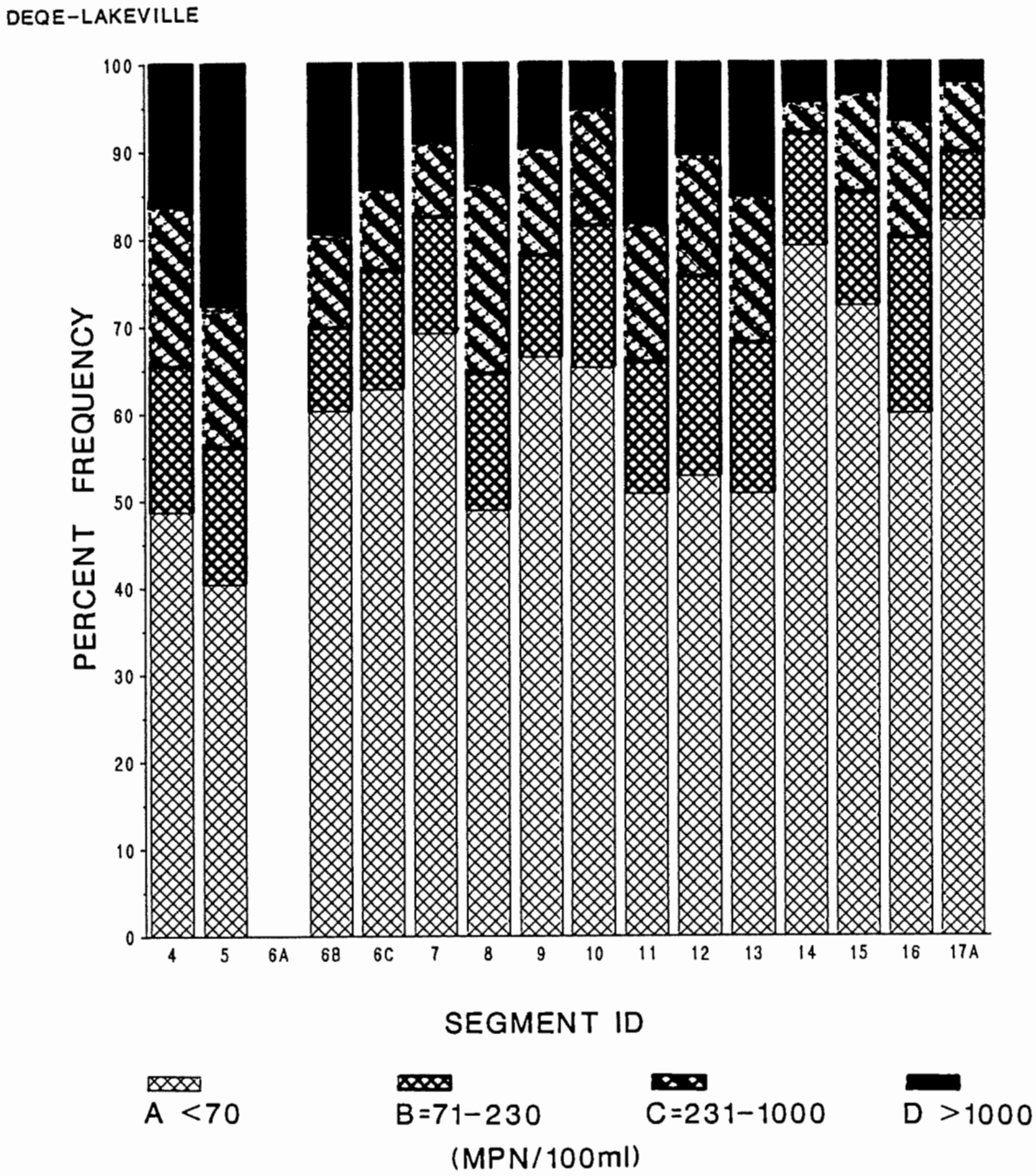

FIGURE 2. FREQUENCY DISTRIBUTIONS OF TOTAL COLIFORM BACTERIA CONCENTRATIONS (MPN/100 ML) FOR EACH SEGMENT FOR ALL DEQE-LAKEVILLE DATA. CLASSES A, B, C, AND D ARE BASED ON SHELLFISH BED CLOSURE REGULATIONS. SEGMENTS CORRESPOND TO THOSE SHOWN IN FIGURE 1.

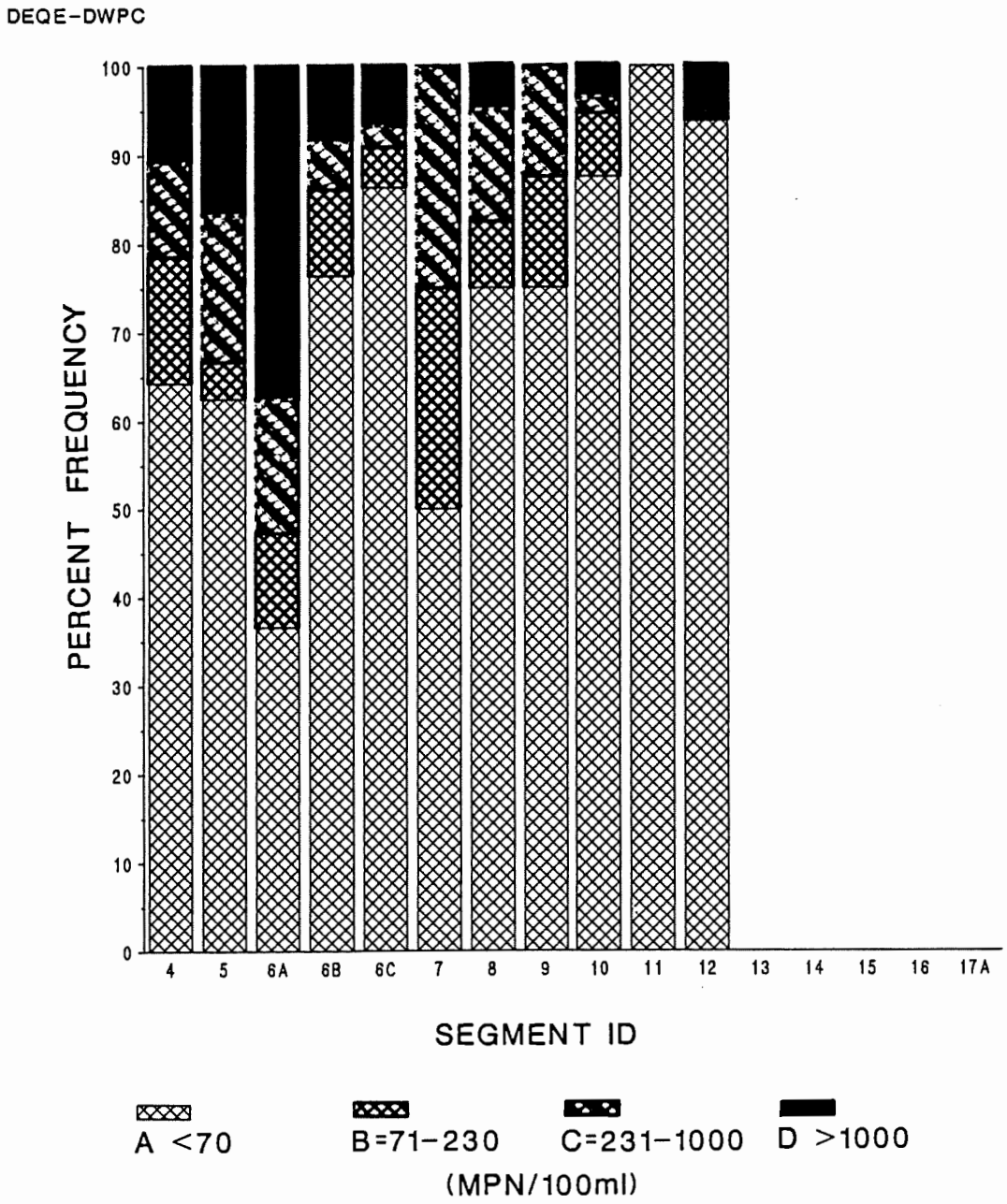

FIGURE 3. FREQUENCY DISTRIBUTIONS OF TOTAL COLIFORM BACTERIA CONCENTRATIONS (MPN/100 ML) FOR EACH SEGMENT FOR ALL DEQE-DWPC DATA. CLASSES A, B, C, AND D ARE BASED ON SHELLFISH BED CLOSURE REGULATIONS. SEGMENTS CORRESPOND TO THOSE SHOWN IN FIGURE 1.

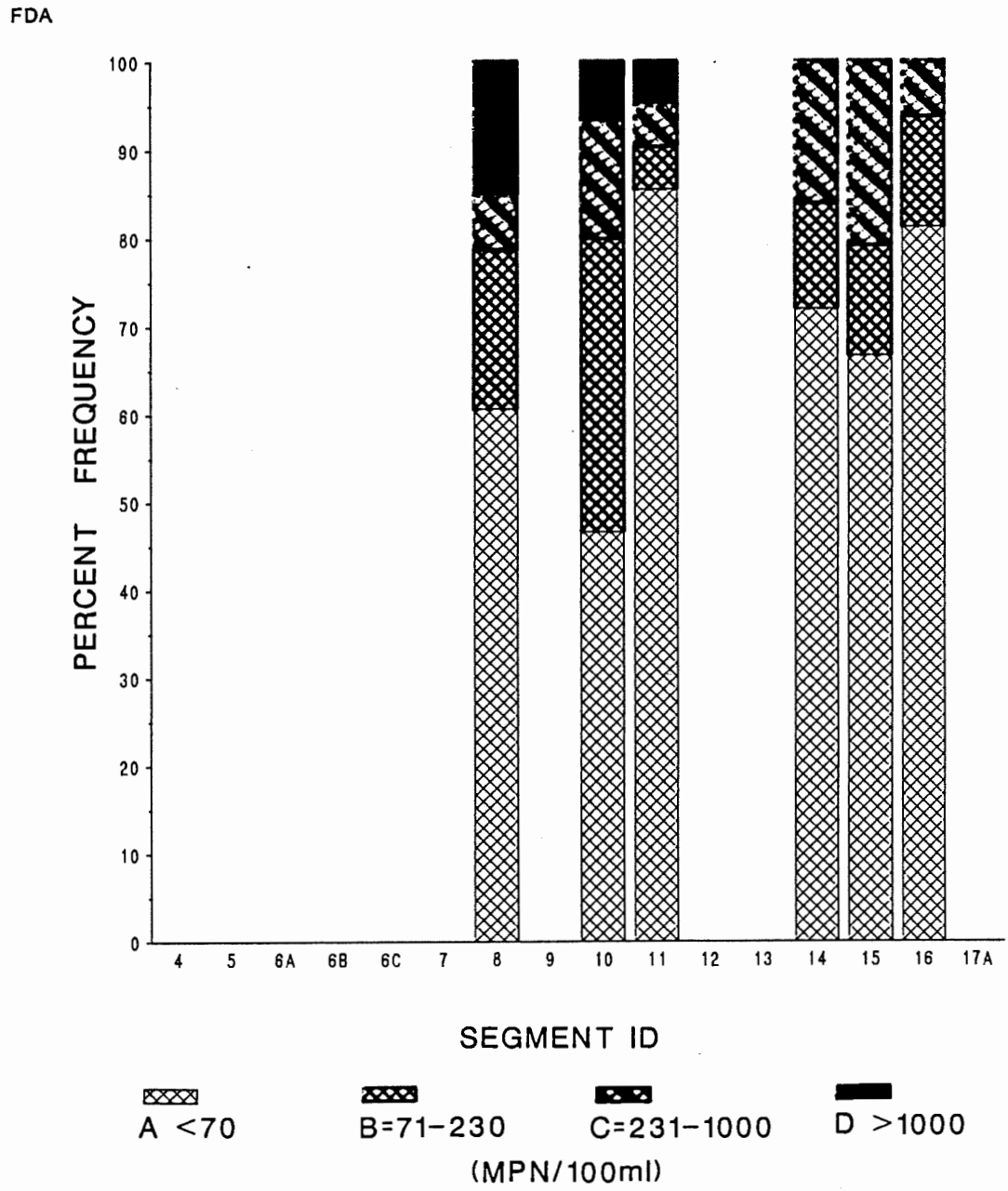

FIGURE 4. FREQUENCY DISTRIBUTIONS OF TOTAL COLIFORM BACTERIA CONCENTRATIONS (MPN/100 ML) FOR EACH SEGMENT FOR ALL FDA DATA. CLASSES A, B, C, AND D ARE BASED ON SHELLFISH BED CLOSURE REGULATIONS. SEGMENTS CORRESPOND TO THOSE SHOWN IN FIGURE 1.

Conflicting decisions based on the same data demonstrate that it is imperative for sound management decisions to consider how the data were collected. In the case of samples collected to represent worst-case conditions (e.g., DEQE-Lakeville's sampling program), a decision to require depuration for the harvest of a shellfish area is more likely when based on percentage of samples in excess of the 230 MPN/100 ml criteria. The sampling methods used by DEQE-DWPC yield mean values that would lead to more shellfish area restrictions than if their data were examined by the percent above 230 MPN/100 ml criteria.

3.1.4 Temporal Coverage of Coliform Data

3.1.4.1 Temporal Distribution of Studies

The studies that have collected coliform data for Buzzards Bay are distributed unevenly between 1970 and 1986. The DEQE-Lakeville data sets contain at least some data for each of these years. The DEQE-DWPC programs have contributed total coliform data for 1971, 1975, 1980, and fecal coliform data for 1985 and part of 1986. FDA collected total and fecal coliform data in 1972, 1981, and 1985. The Barnstable County and Boston University studies collected data in 1985 and 1986. The distribution of data and the segments sampled by the DEQE and FDA studies are presented in Appendices A and B. The temporal coverage of all studies for each segment is shown in Table 5 and in Appendices D and E. Temporally continuous data sets should only be combined if there were no comparability issues raised in the earlier review of coliform analytical methods.

Further assessments of the temporal distribution of the coliform data would be facilitated by combining a water quality database management system (DBMS) with a GIS. A DBMS would allow scientists to easily review the amounts of data available for given time periods. Use of a GIS could further improve reviews by

permitting retrieval of data based on location, and review of coliform data availability for various time periods.

TABLE 5. AVAILABILITY OF TOTAL COLIFORM DATA FOR SEGMENTS OF BUZZARDS BAY. THE "O" DENOTES PRESENCE OF DATA, THE "." DENOTES DATA GAPS.

	Year																
Segment	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86
4	.	O	.	O	.	O	O	.	O	O	O	O	O	O	O	O	.
5	.	.	O	O	.	O	.	.	.	.	O	.	O	O	O	O	O
6A	.	.	O	.	.	O	.	.	.	.	.	.	.	.	.	O	.
6B	O	.	O	O	O	O	.	.	.	O	O	O	O	O	O	O	.
6C	O	.	O	O	.	O	.	.	O	O	O	.	O	O	O	O	.
7	.	O	O	O	.	O	.	O	O	.	O	.	.	.	O	O	.
8	.	O	O	O	.	O	.	.	O	.	O	O	O	O	O	O	O
9	O	O	.	O	O	O	.	.	.	O	O	.	O	.	O	O	.
10	.	.	O	O	.	O	.	.	.	.	O	.	.	.	O	O	O
11	.	O	O	O	.	O	.	.	O	O	O	O	O	O	O	O	O
12	.	O	O	O	.	O	.	.	O	O	O	.	.	O	O	O	O
13	.	O	.	O	.	.	.	.	.	.	O	O	O	O	O	O	.
14	.	O	O	O	.	.	.	.	O	O	O	O	.	.	O	O	.
15	.	O	O	O	.	.	.	.	O	.	.	O	O	O	O	O	O
16	.	.	.	O	.	.	.	.	O	.	.	O	.	.	.	.	.
17	.	.	.	.	.	.	.	.	.	.	.	.	.	.	O	.	.
18	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	O	.
19	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.

3.1.4.2 Utility in Assessing Temporal Trends

To identify trends we need a fairly continuous data set from consistent locations to reduce spatial effects and to separate short-term variation from long-term change. The Lakeville data set covers the longest time period, between 1970 and 1986. However, there is no complete or continuous data set for any individual station.

Assessment of temporal trends depends on the questions being asked and the scales of resolution needed to answer the question. Questions about whether a beach can be open on a given weekend require a resolution of coliform trends across the time scale of days. Within each day, there must be some level

of daily replication in order to compare differences between days (especially because this scale is similar in period to tidal variability). The level of replication required is a function of the magnitude of differences that need to be perceived and the level of confidence that is required (Green, 1979). Daily replication is also required to assess temporal trends because input of coliform bacteria into the system can vary due to daily precipitation.

Longer-term questions, such as whether a farm or a new sewage treatment outfall is contributing to a significant increase in coliform levels, require repetitive sampling on longer time scales. Monitoring of weekly average coliform levels could discern trends at the scale of months, assuming the ability to analyze for the variance due to tides, rain, or both. The historical data sets being reviewed here were collected for the sake of identifying incidences of elevated coliform levels. However, the scattered nature of the sampling times and locations did not produce a continuous data set that could be used to discern trends across periods of days or weeks. The following discussion examines how the data might be broadly grouped for temporal analyses on much longer time scales.

Our first level of data assessment for temporal trends uses segment-wide data. By compiling all stations within a segment we can look at the segment-wide mean and standard deviation of coliform values. The justification is that the variety of station types within each segment might produce a representative average. The annual means for Mattapoisett and Bourne segments are shown in Figures 5 and 6. The horizontal line represents the 70 MPN/100 ml level from the water quality criteria. The 70 MPN/100 ml threshold should actually be applied to median values, but, we present the geometric means for comparison. In general, the yearly variability causes the means not to be significantly different from each other. Part of this variability must be due to the variety of stations types that

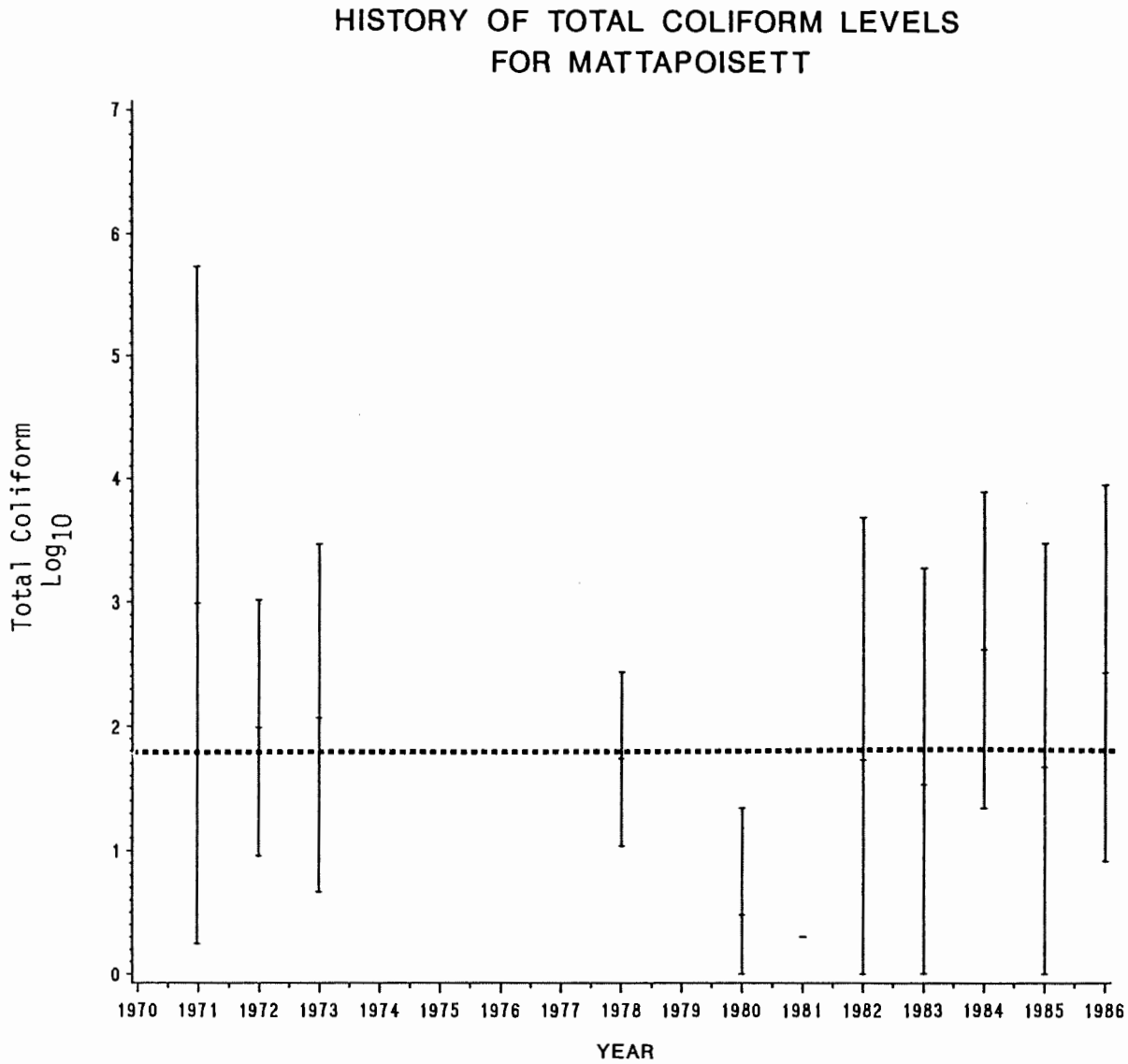

FIGURE 5. TEMPORAL DISTRIBUTION OF MEAN TOTAL COLIFORM CONCENTRATIONS (LOG 10 ± 2 SD). HORIZONTAL LINE DENOTES THE STANDARD 70 MPN VALUE USED IN EVALUATING SHELLFISH BED CLOSURES.

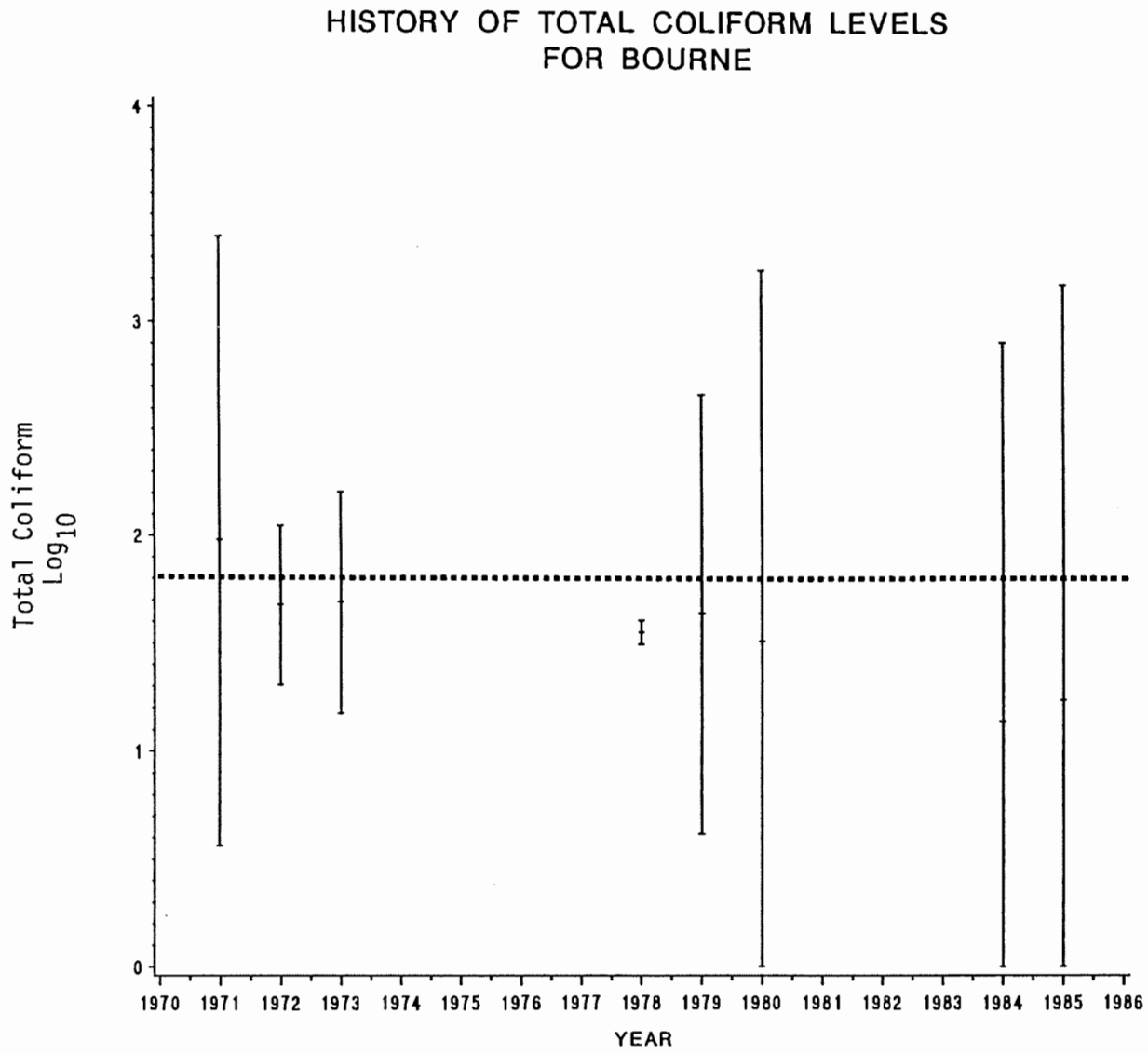

FIGURE 6. TEMPORAL DISTRIBUTION OF MEAN TOTAL COLIFORM CONCENTRATIONS (LOG 10 $\pm$ 2 SD). HORIZONTAL LINE DENOTES THE STANDARD 70 MPN VALUE USED IN EVALUATING SHELLFISH BED CLOSURES.

were combined into the segment-wide value. In addition, the segments do not have the same distribution of contaminated and "clean" stations, nor were the same number of these station types resampled each year. These station differences lead us to conclude that segment-wide comparisons of yearly coliform levels are inadequate for analyzing temporal trends. A brief analysis of the data that could be grouped according to seasons yielded similar results; the variability within seasons was too broad for defensible trend analysis across seasons of successive years. A major inadequacy was that sampling conditions were not described in enough detail to allow analysis of components of variability such as tide or precipitation.

Part of the spatial variability can be avoided by analyzing time series data from specific locations. Sampling at specific locations was very inconsistent over time. Approximately 12 stations had sufficient coliform data for analysis across time periods. The following paragraph discusses how historical data for one site contribute to temporal trend analysis.

The temporal trend of total coliform levels at the Hix Bridge station, in the east branch of the Westport River, is shown in Figure 7. (The other 11 stations for which sufficient data were available are plotted in Appendix F.) Plotting the historical levels of total coliform bacteria at Hix Bridge graphically demonstrates how scattered and patchy the data are, even for this fixed station that was resampled most often. The individual values observed during each year vary as much as 3 orders of magnitude. The variability is probably due, in part, to the varying conditions that contribute to coliform levels, as discussed in Section 3.1.3. The within-year variability, even at the individual station level, is too large to permit discernment of temporal trends, even between years. Within-year variability and the generally patchy data distribution are repeated at the other resampled stations (Appendix F).

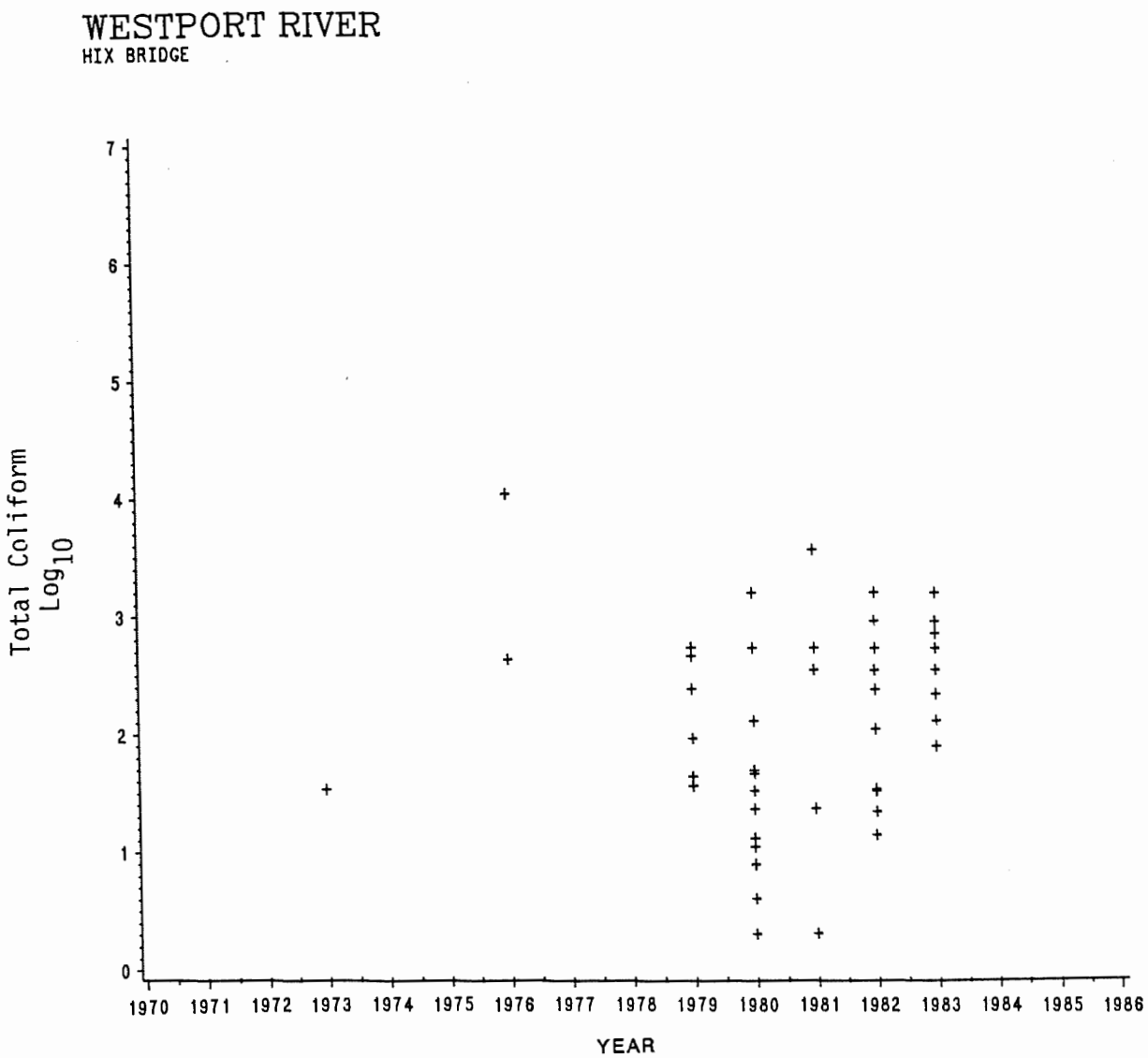

FIGURE 7. INDIVIDUAL DATA POINTS FOR TOTAL COLIFORM (LOG 10) OVER TIME AT HIX BRIDGE ON THE WESTPORT RIVER.

This assessment of temporal variability in total coliform levels for broad segments, and even at particular stations, has implications for environmental resource management. If decisions on shellfish area closures are based on cumulative data, the inevitable temporal variation must be considered. If a cumulative average or median value is calculated for comparison with the criteria levels, then the input data should be weighted according to the elapsed time since collection. Managing coliform data with a DBMS would make shellfish area closure decisions more accurate. A DBMS would allow the most recently observed coliform levels to contribute most heavily to the quantitative measure of the station's acceptability.

3.1.5 Spatial Coverage of Coliform Data

3.1.5.1 Spatial Distribution of Data Sets

The spatial distribution of data the database contains for total and fecal coliform bacteria is shown in Figures 8 and 9. Each map depicts the relative amount of data available for each segment. Each circle has a maximum value of 550. The actual amount of data available for each segment is represented as the proportion of the circle that is shaded. Each circle represents the total number of coliform samples taken for the segments over all years. Total and fecal coliform data have approximately the same coverage between segments.

3.1.5.2 Utility in Assessing Spatial Trends

The usefulness of these data for assessing spatial trends is limited by many of the same variability problems encountered in the temporal assessment. As expected, it is not possible to detect any significant differences between segments because of the wide range of station types and reported values. This variability remains, even when only the summer data are selected from each of the separate studies (Figure 10).

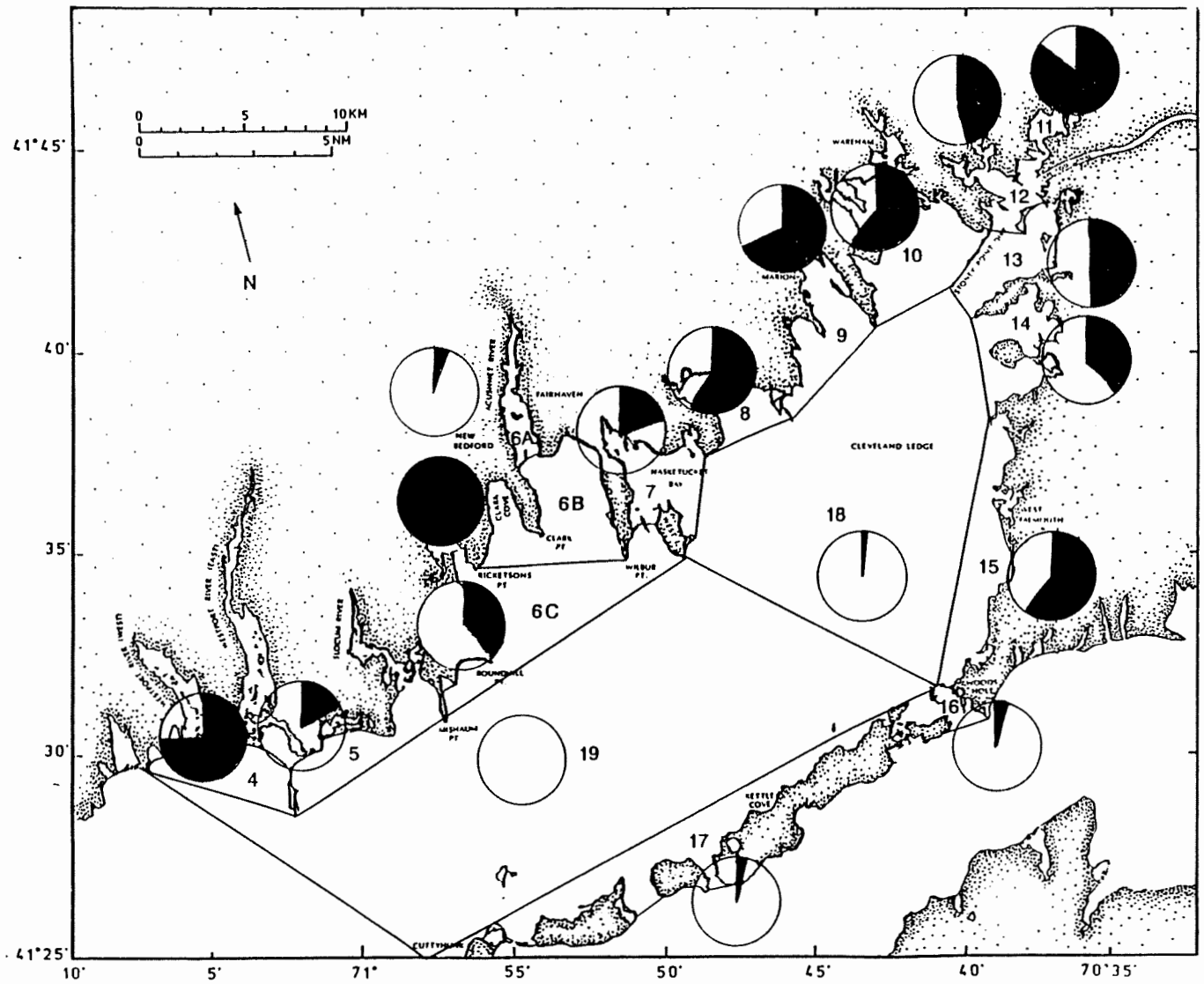

FIGURE 8. SPATIAL COVERAGE OF TOTAL COLIFORM BACTERIA DATA AVAILABLE IN THE DATABASE. EACH CIRCLE HAS A MAXIMUM VALUE OF 550 OBSERVATIONS AND THE ACTUAL AMOUNT OF DATA AVAILABLE FOR EACH SEGMENT IS REPRESENTED AS THE PORTION OF THE CIRCLE THAT IS SHADED.

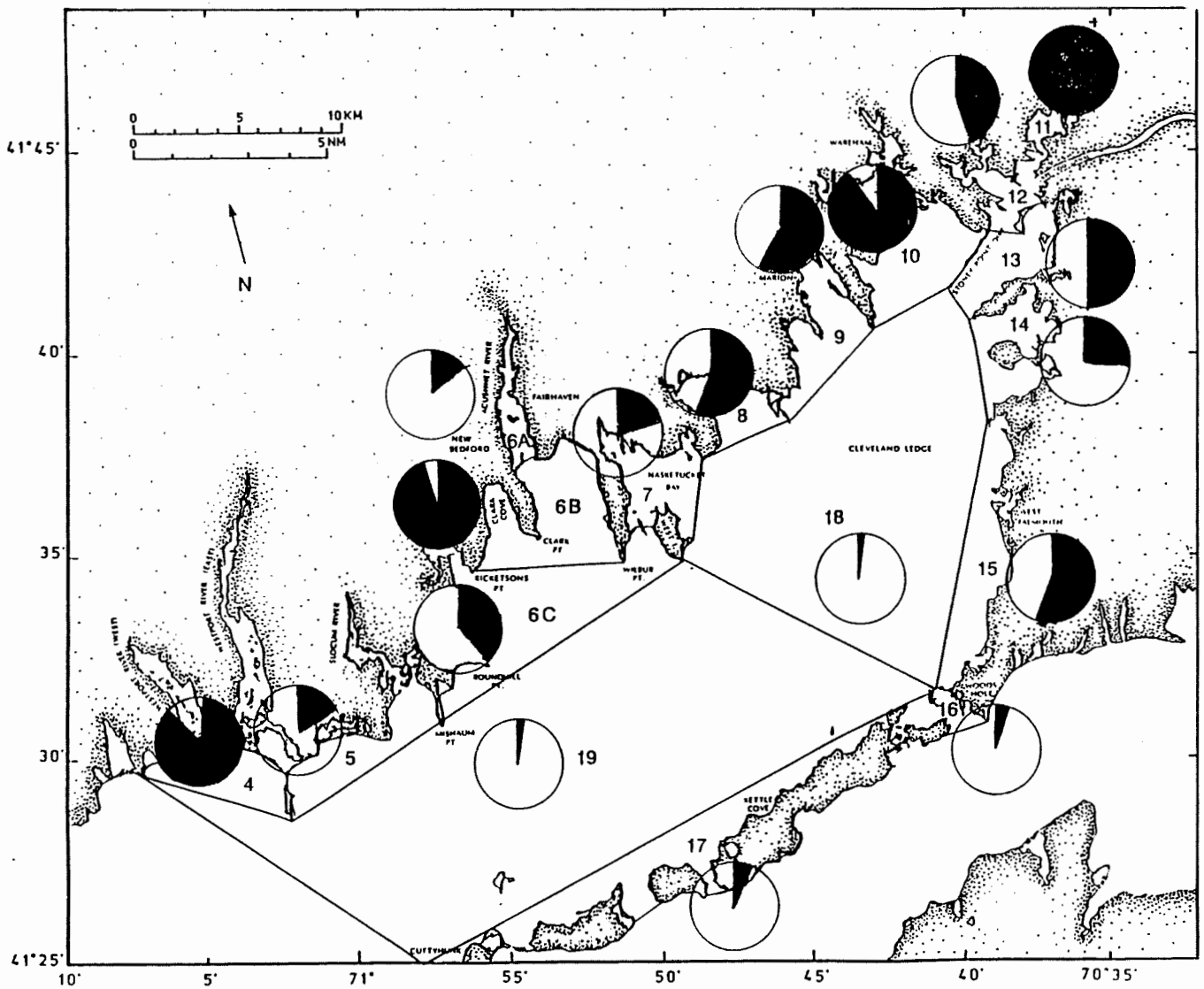

FIGURE 9. SPATIAL COVERAGE OF FECAL COLIFORM BACTERIA DATA AVAILABLE IN THE DATABASE. EACH CIRCLE HAS A MAXIMUM VALUE OF 550 OBSERVATIONS AND THE ACTUAL AMOUNT OF DATA AVAILABLE FOR EACH SEGMENT IS REPRESENTED AS THE PORTION OF THE CIRCLE THAT IS SHADED.

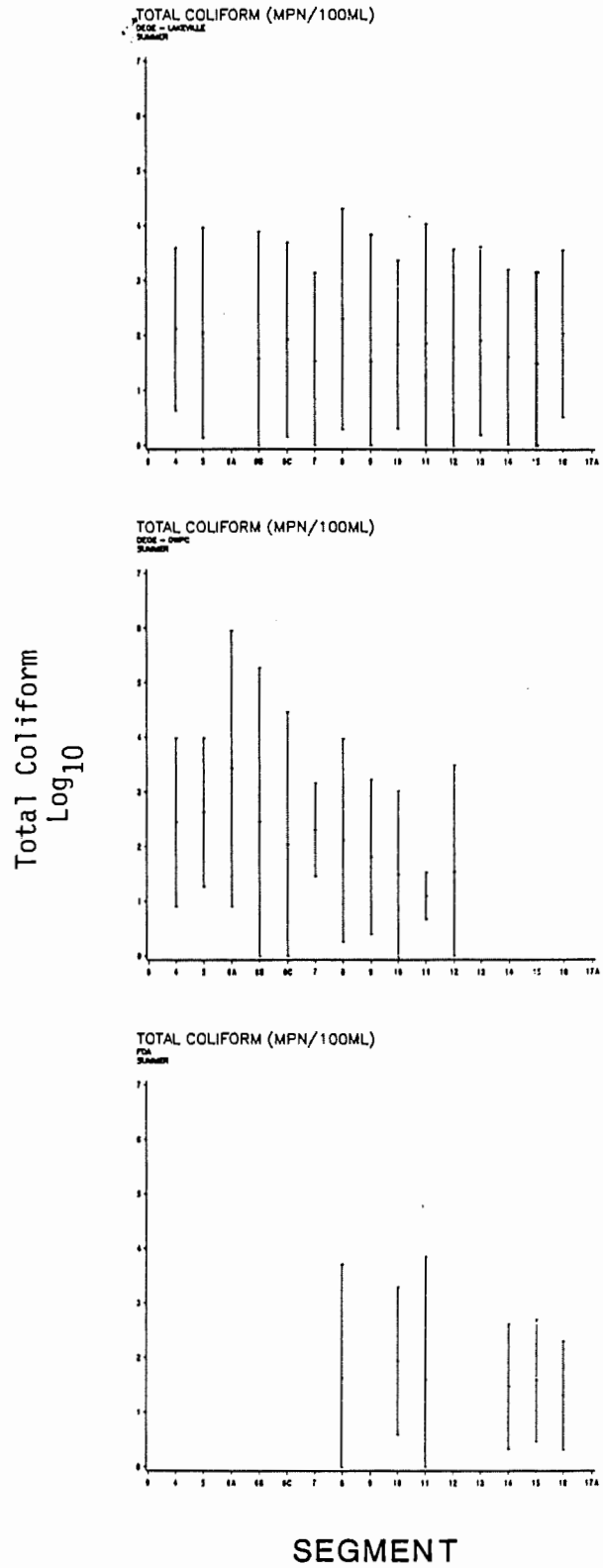

FIGURE 10. MEAN TOTAL COLIFORM LEVELS (LOG 10 ± 2 SD) FOR EACH SEGMENT COLLECTED BY DEQE-LAKEVILLE, DEQE-DWPC, AND FDA DURING THE SUMMER MONTHS.

In an additional assessment of how the coliform data can be integrated and used to analyze for spatial trends, we combined data from three studies at six stations in Buttermilk Bay. The three studies were all from 1985 and included FDA-1985, Barnstable County Health, and DEQE-Lakeville studies. We examined the study maps to confirm that the six stations were in exactly the same location for all three studies. Mean values at the common stations are shown in Figure 11. Examination of these synoptic stations shows differences between locations and, more importantly, between studies.

The apparent differences between stations, as shown in Figure 11, demonstrate that coliform data must be compared on a station-by-station basis in order to analyze for spatial trends. This exercise was effective for these select stations within the intensely sampled region of Buttermilk Bay. A similar effort on a broader scale encompassing Buzzards Bay is beyond the scope of the SAS data system and requires the use of a geographically based data management system.

The general similarity of the FDA and Barnstable County results, and their disparity with the DEQE-DWPC results, is testimony to the importance of the sample collection methods. As discussed earlier, the Barnstable County study adhered to the FDA guidelines for coliform sample collection and analysis. The DEQE-DWPC sampling methods involved compositing multiple samples and thus resulted in dissimilar mean coliform values. Therefore, we recommend that studies be compared only if collection and analysis methods are consistent.

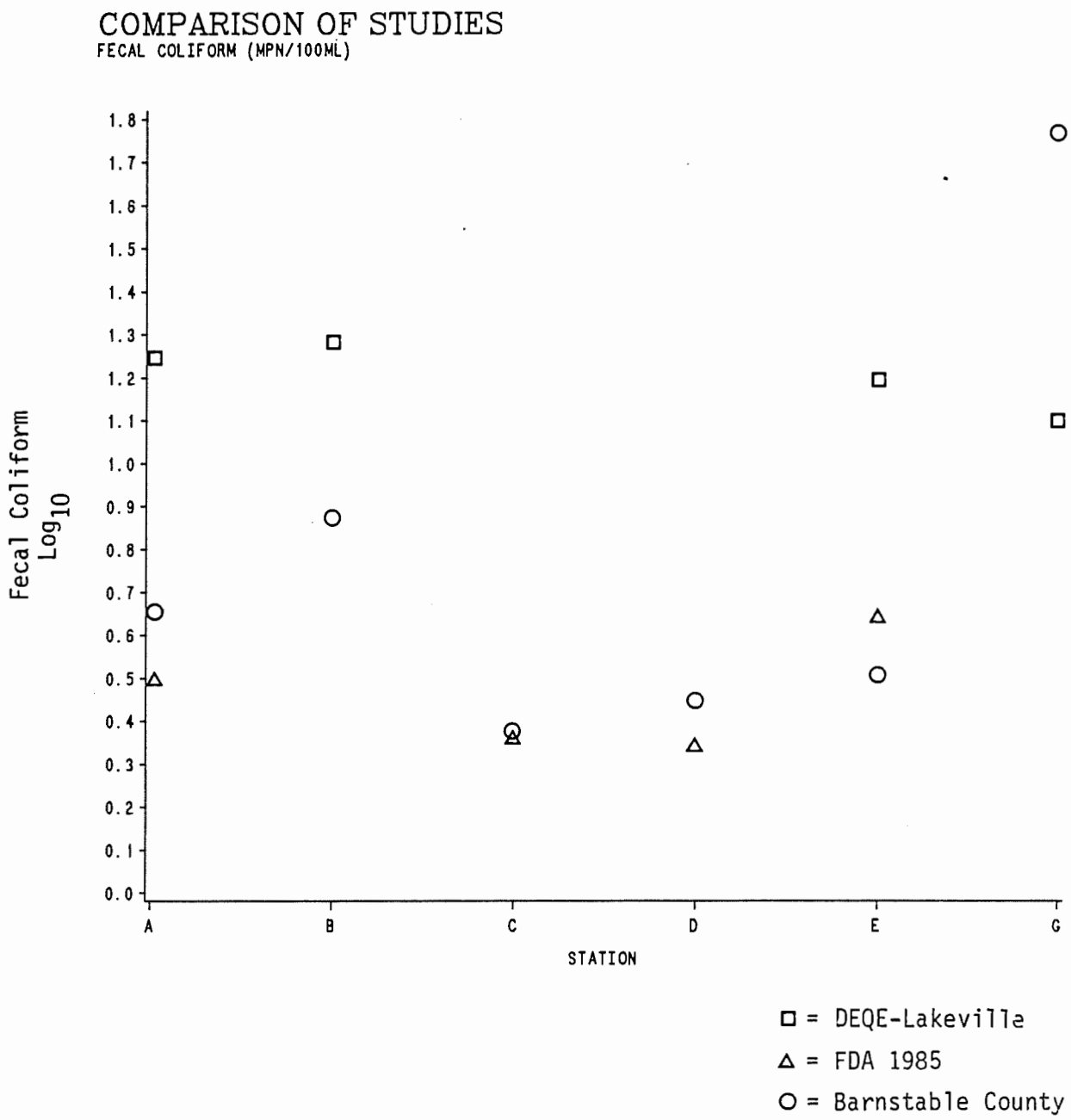

FIGURE 11. MEAN FECAL COLIFORM CONCENTRATIONS (LOG 10 ± 2 SD) FOR SIX STATIONS IN BUTTERMILK BAY FOR THREE DATA SETS.

3.2 CHARACTERIZATION OF NUTRIENTS DATA

3.2.1 Summary of Nutrient Stations

The six studies that collected nutrient samples occupied approximately 240 distinct stations in the Buzzards Bay region between 1971 and 1986. The number of stations was determined by the names given to sites in the data sets for each study. Where possible, we consolidated similar stations by reviewing station location maps. Often it was impossible to confirm station similarities, especially in the DEQE 1985-86 and the Buttermilk Bay studies. For these data sets we report a probable number of stations (see Table 6), as well as the actual number of different stations named.

TABLE 6. SUMMARY OF STATION SAMPLES FOR NUTRIENT DATA. THE * DENOTES AN ESTIMATED NUMBER OF STATIONS WITH THE TOTAL NUMBER OF STATION NAMES SHOWN IN PARENTHESES.

Study	Number of Stations	Number of Samples	Average Number of Reps	Percent Sampled Once
1) DEQE 1971	15	72	5	0
2) DEQE 1975	64	356	5	0
3) DEQE 1980	7	88	12	0
4) NMFS	3	21	7	0
5) DEQE 1985-85	120*(156)	461	3	30
6) Buttermilk Bay	31*(189)	388	2	76
TOTAL	240	1386		

Comparisons of station identifications and locations form the basis for any spatial or temporal integration of separate data sets. Without confirmed spatial references it is virtually impossible to assure that data from various sources can be combined responsibly. For this report, we have integrated

stations on the coarse spatial scale of geographic segments, which were described earlier.

The SAS data storage system for these data sets did not support station grouping at the scale of hundreds of meters or kilometers; therefore, statistical summaries of nutrient data are presented at the regional segment scale. Although these segments could not be used for trend analyses, we have been able to effectively demonstrate data continuities and gaps for segments of the bay.

3.2.2 Nutrient Station Resampling

Because of the different objectives of each study, there were varying amounts of repetitive sampling at nutrient stations. None of the studies were intended to detect wide-scale spatial trends. Some stations were sampled for nutrients often, in particular the DEQE 1980 and NMFS studies. However, many stations were sampled for nutrients only once or twice. The rate of station resampling is shown as the average number of replicates in Table 6. The most useful data for assessing temporal trends in nutrient levels are from the studies with a higher average number of replicates. The data from sporadically sampled stations are most difficult to combine with other studies.

Use of these historical water quality data for environmental management could be greatly enhanced by improved software for storage, retrieval, and analyses. A database management and analysis system, such as EPA's Ocean Data Evaluation System, would allow managers to answer questions such as "How many station replicates do I need to measure a certain magnitude of change in water quality?" The key to this process would be the ability to draw on the observed variability of the historical data for very specific locations.

3.2.3 Summary of Nutrient Levels Reported

The summary statistics for all of the nutrients levels are included in Appendix C. These data are presented to report the wide range of concentrations observed. Caution should be exercised in any review of average concentration levels. The wide range of contributing values at the segment level argues for a very sharp focus in the selection of data for calculating of means. Clearly, lumping data for each segment affords a resolution that is inadequate to support hypothesis testing.

To filter out the extreme nutrient levels, we used minimum and maximum ranges as shown in Table 7. These outlier filters were chosen based on comparative nutrients levels reported in similar estuaries (Tetra Tech, 1987). Any raw data not within these ranges were rejected from the summary statistics.

TABLE 7. RANGES USED TO EXCLUDE OUTLIER VALUES FROM THE NUTRIENT DATA SETS.

Nutrient	Acceptable Range	No. Rejects
NO_3	0.001 - 4.000	4
NH_3	0.001 - 2.000	2
NH_4	0.001 - 2.000	0
TKN	0.100 - 3.000	1
PO_4	0.001 - 0.400	2
P	0.001 - 0.400	0

3.2.4 Temporal Coverage of Nutrient Data

3.2.4.1 Temporal Distribution of Nutrient Studies

The six combined nutrient studies include samples collected between 1971 and 1986. Table 8 shows the years and study codes (from Table 6) of available nutrient data. Note that although there appears to be a relatively continuous set of nitrate data over time, these data do not necessarily overlap spatially.

TABLE 8. TYPES OF NUTRIENT SAMPLES AND YEARS WHEN SAMPLES WERE COLLECTED BY THE SIX STUDIES. THE STUDY CODES ARE AS DEFINED IN TABLE 1.

Nutrient	1971	1975	1980	1985	1986
NO_3	1	2	3,4	5,6	5
NH_3	1	2	3	6	
NH_4				5	5
TKN	1		3,4	6	
PO_4	1	2		5,6	5
P			3,4	6	

Any possible continuities in nutrient data across years for specific locations are shown in Tables 9A (freshwater, salinity < 1 ppt) and 9B (saltwater locations, salinity > 1 ppt). These tables summarize the availability of data for four nutrients at each segment during the time periods covered by the original studies. As discussed below, the most "complete" data exist for lower New Bedford Harbor (segment 6B).

The widest temporal coverage for nutrient data is from upper New Bedford Harbor and Buttermilk Bay. Upper New Bedford Harbor, segment 6A, generally has the most historical coverage with data from 1971, 1975, and 1986, whereas Buttermilk Bay, segment 11, has

the most complete recent coverage with data from 1975, 1985, and 1986. Synoptic collection of NO_3 and NH_3 by most studies produced similar patterns for these nutrients. Kjedahl nitrogen, ammonium, and total phosphorus were sampled less consistently over time.

3.2.4.2 Utility in Assessing Temporal Trends

We determined that there are insufficient data to assess temporal trends in nutrient levels even in regions where there appears to be good coverage. To evaluate the adequacy of the data we selectively retrieved data for frequently sampled stations in Lower New Bedford Harbor and calculated yearly averages for nitrate and ammonia levels. The averages within each year included data that were generally collected during the same month. There was an insufficient number ($N < 3$) of data observations at any station for each time interval to calculate means that could be compared statistically.

More data could be compiled for temporal analyses if we combined proximate stations into generic stations by using a geographic data management system. However, combining stations geographically would also require addressing differences in stations due to tidal stages and station depths. It should also be noted that there were insufficient data because many of the "observations" appearing in the data sets for the New Bedford Harbor region were actually reported as values of zero. These zeros denote values below detection limits and could not be included in the calculations.

Unfortunately, the historical data sets did not include the actual detection limits of the analytical techniques used in each study. Detection limits would have been extremely useful when trying to combine or compare data sets. Differing levels of detection can be factored into statistical tests. Without detection limits it is impossible to account for the reported "zeros," which adds bias to the analyses.

The data can be used as a "snapshot" of the conditions that existed historically during the individual samplings. Therefore, it is important that these temporal summaries be presented to show

time periods for which nutrient data may be available. It is equally important, in assessing the availability of nutrient data, to determine the areas covered during past sampling efforts.

These snapshots of the historical nutrients levels would be even more valuable if accompanied by the types of descriptive data discussed for coliform sampling. For example, time of day is critical to fully understand an observed nutrient level. Diel migrations occur routinely in estuarine systems, therefore time of sampling must be considered when assessing variability.

3.2.5 Spatial Coverage of Nutrient Data

3.2.5.1 Spatial Distribution of Nutrient Data

The extent of spatial coverage that these historical nutrient data sets provide can best be described by presenting base maps depicting the volume of data available for each region. The following five maps (Figures 12 through 16) show the relative amount of data available for each nutrient. All the circles have the same maximum value of 150 observations. The actual amount of data available for each segment is represented as the proportion of the circle that is shaded. Each circle is the total number of nutrient samples collected for that segment over all years.

These maps of total available data points can be viewed in concert with Tables 9A and 9B to ascertain how the nutrient data for a region are distributed over time. For example, Figure 12 shows one-quarter of a circle (37 values) of ammonia for segment 14, and Table 9B shows these saltwater ammonia values were all from 1985.

3.2.5.2 Utility in Assessing Spatial Trends

Spatial trends can be assessed most effectively by comparing synoptic and replicated data for different areas. From Table 9B, it is apparent that the most comprehensive synoptic data sets, covering many segments, are from 1975 and 1985. Figure 17 is a plot of the mean values of nitrate observed within the segments

TABLE 9A. AVAILABILITY OF NUTRIENT DATA OVER TIME AT EACH SEGMENT. THE "O" DENOTES PRESENCE OF DATA, THE "." DENOTES NO DATA. NOTE THAT THE YEARLY INTERVALS ARE NOT EQUALLY SPACED. DATA INCLUDE FRESHWATER STATIONS WITH SALINITY < 1.0 ppt.

	NO_3					NH_3					TKN					PO_4				
	Year																			
	71	75	80	85	86	71	75	80	85	86	71	75	80	85	86	71	75	80	85	86
Segment																				
4	.	O	.	.	.	.	O	.	.	.	.	.	.	.	.	.	.	.	.	.
5	.	O	.	.	O	.	O	.	.	O	.	.	.	.	O	.	.	.	.	O
6A	O	O	.	.	O	O	O	.	.	O	O	.	.	.	O	O	.	.	.	O
6B	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
6C	.	O	.	.	O	.	O	.	.	O	.	.	.	.	O	.	.	.	.	O
7	.	O	.	.	.	.	O	.	.	.	.	.	.	.	.	.	.	.	.	.
8	.	O	.	O	.	.	O	.	O	.	.	.	.	O	.	.	.	.	O	.
9	.	O	.	.	.	.	O	.	.	.	.	.	.	.	.	.	.	.	.	.
10	.	O	.	O	.	.	O	.	O	.	.	.	.	O	.	.	.	.	O	.
11	.	O	.	O	O	.	O	.	O	.	.	.	.	O	O	.	.	.	O	.
12	.	O	.	O	.	.	O	.	O	.	.	.	.	O	.	.	.	.	O	.
13	.	.	.	O	.	.	.	.	O	.	.	.	.	O	.	.	.	.	O	.
14	.	.	.	O	.	.	.	.	O	.	.	.	.	O	.	.	.	.	O	.
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18	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
19	.	.	O	.	.	.	.	O	.	.	.	.	O	.	.	.	.	.	.	.

TABLE 9B. AVAILABILITY OF NUTRIENT DATA OVER TIME AT EACH SEGMENT. THE "O" DENOTES PRESENCE OF DATA, THE "." DENOTES NO DATA. NOTE THAT THE YEARLY INTERVALS ARE NOT EQUALLY SPACED. DATA INCLUDE SALTWATER STATIONS WITH SALINITY > 1.0 ppt.

	NO_3					NH_3					TKN					PO_4				
	Year																			
Segment	71	75	80	85	86	71	75	80	85	86	71	75	80	85	86	71	75	80	85	86
4	.	O	.	.	.	.	O	.	.	.	.	.	.	.	.	.	.	.	.	.
5	.	.	.	.	O	.	.	.	.	O	.	.	.	.	O	.	.	.	.	O
6A	O	O	.	.	.	O	O	.	.	.	O	.	.	.	.	O	.	.	.	.
6B	O	O	O	.	O	O	O	O	.	O	O	.	O	.	O	O	.	.	.	O
6C	.	O	O	.	O	.	O	O	.	O	.	.	O	.	O	.	.	.	.	O
7	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
8	.	O	.	O	.	.	O	.	O	.	.	.	.	O	.	.	.	.	O	.
9	.	O	.	.	.	.	O	.	.	.	.	.	.	.	.	.	.	.	.	.
10	.	O	.	O	.	.	O	.	O	.	.	.	.	O	.	.	.	.	O	.
11	.	O	.	O	O	.	O	.	O	O	.	.	.	O	O	.	.	.	O	.
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16	.	.	.	.	.	.	.	.	.	O	.	.	.	.	.	.	.	.	.	.
17	.	.	.	.	.	.	.	.	.	.	.	.	.	.	O	.	.	.	.	O
18	.	.	.	.	.	.	.	.	O	.	.	.	O	.	O	.	.	.	O	.
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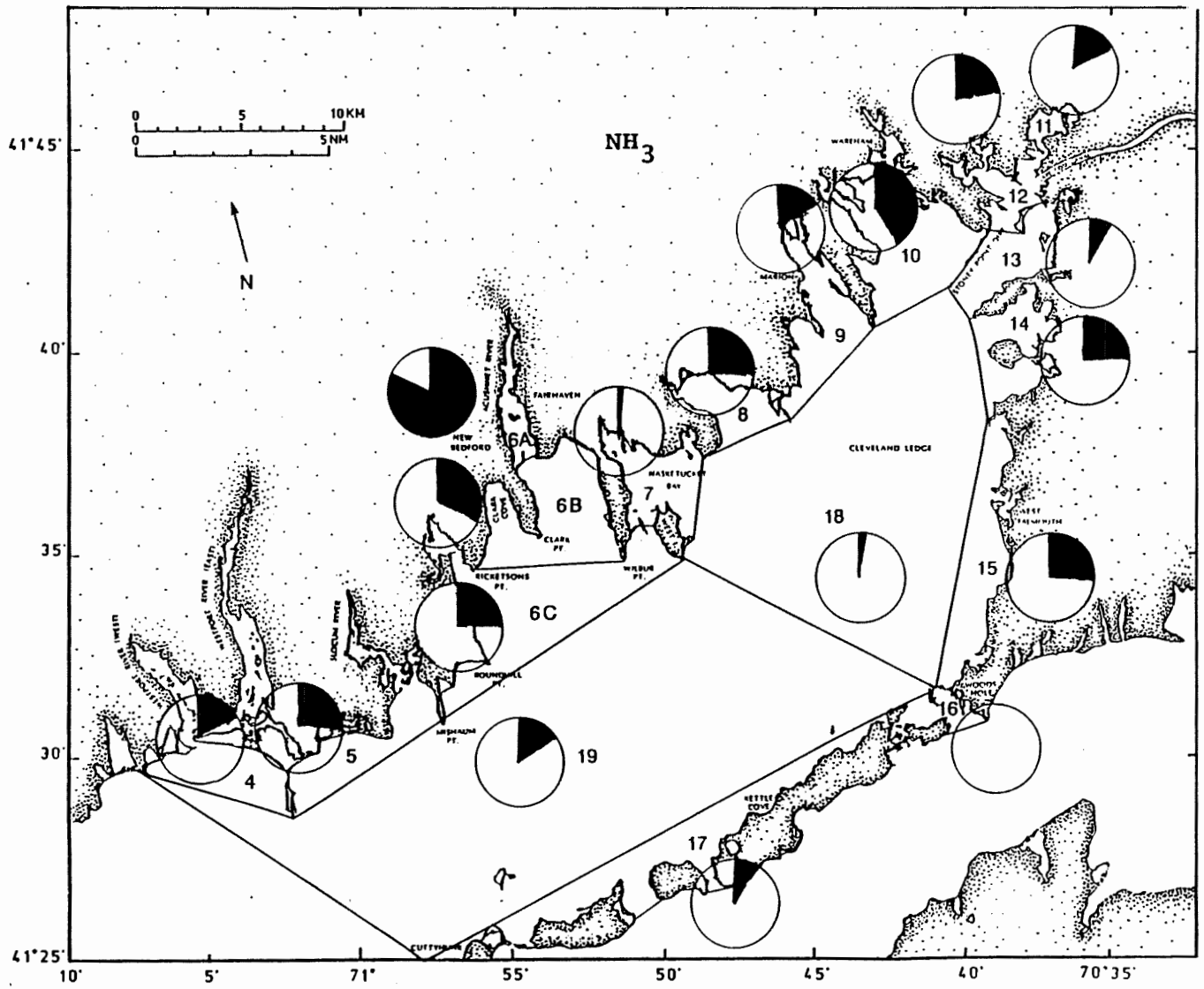

FIGURE 12. SPATIAL COVERAGE OF AMMONIA NITROGEN DATA AVAILABLE IN THE DATABASE. EACH CIRCLE HAS A MAXIMUM VALUE OF 150 OBSERVATIONS AND THE ACTUAL AMOUNT OF DATA AVAILABLE FOR EACH SEGMENT IS REPRESENTED AS THE PORTION OF THE CIRCLE THAT IS SHADED.

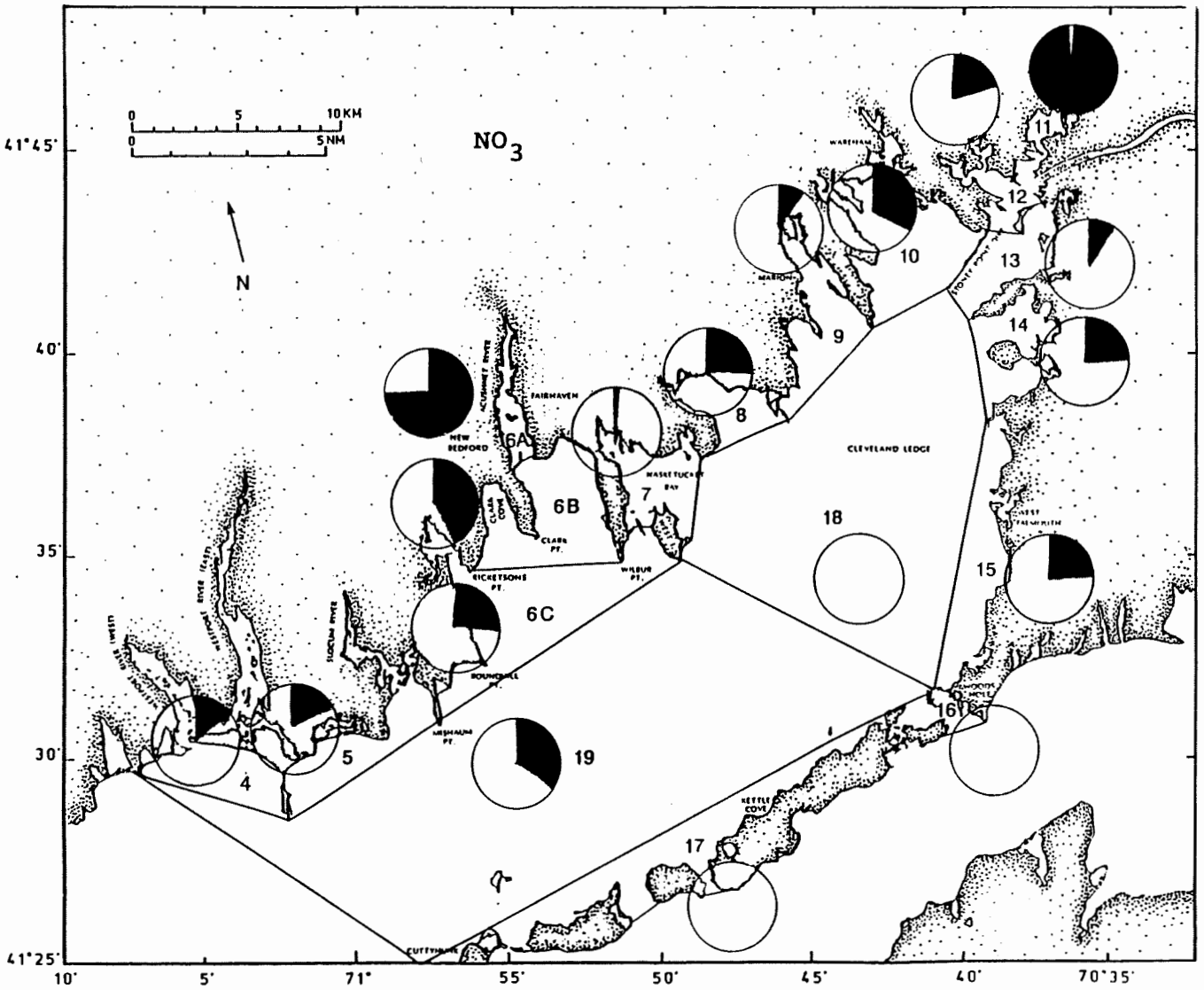

FIGURE 13. SPATIAL COVERAGE OF NITRATE NITROGEN DATA AVAILABLE IN THE DATABASE. EACH CIRCLE HAS A MAXIMUM VALUE OF 150 OBSERVATIONS AND THE ACTUAL AMOUNT OF DATA AVAILABLE FOR EACH SEGMENT IS REPRESENTED AS THE PORTION OF THE CIRCLE THAT IS SHADED.

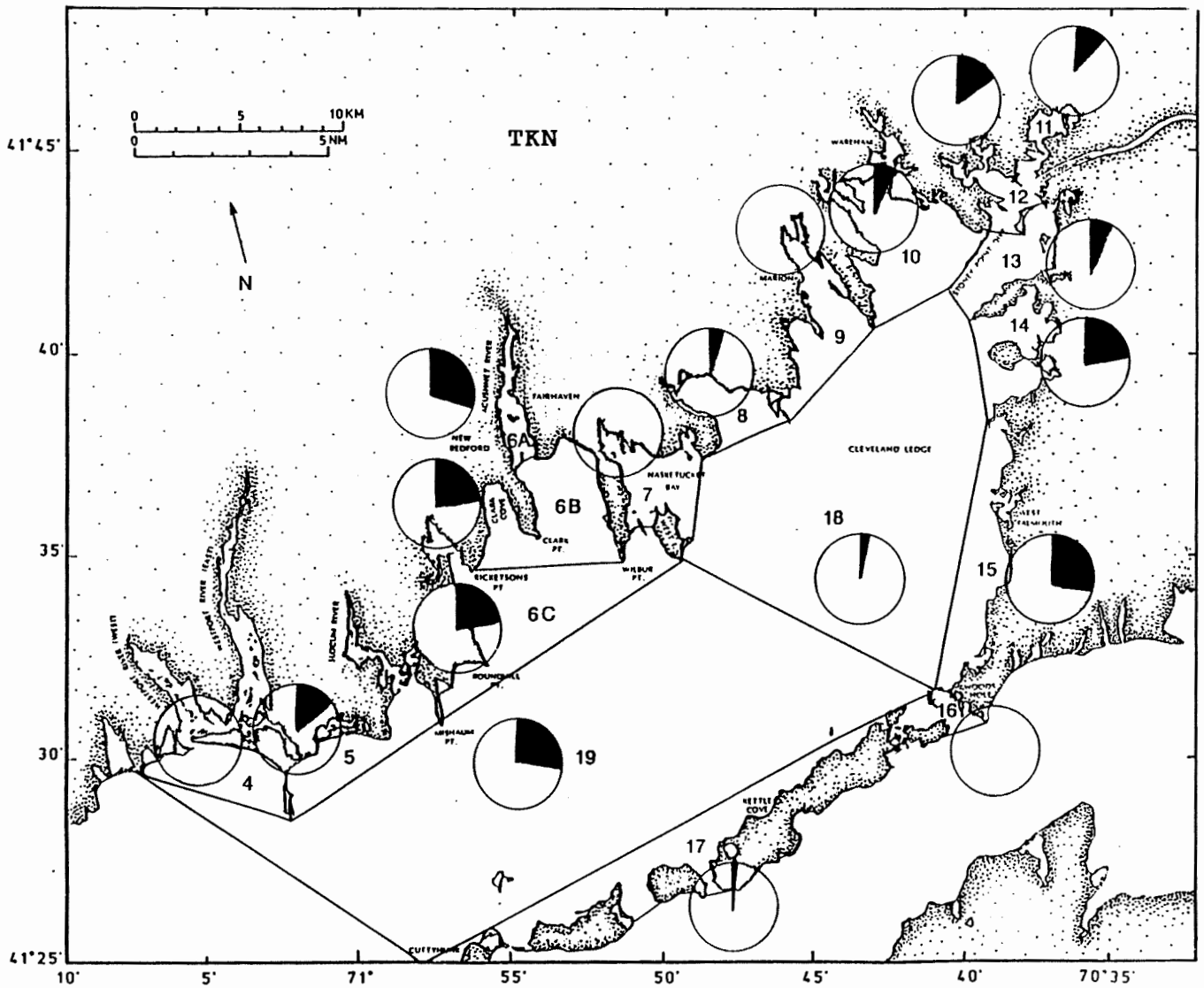

FIGURE 14. SPATIAL COVERAGE OF TOTAL KJELDAHL NITROGEN DATA AVAILABLE IN THE DATABASE. EACH CIRCLE HAS A MAXIMUM VALUE OF 150 OBSERVATIONS AND THE ACTUAL AMOUNT OF DATA AVAILABLE FOR EACH SEGMENT IS REPRESENTED AS THE PORTION OF THE CIRCLE THAT IS SHADED.

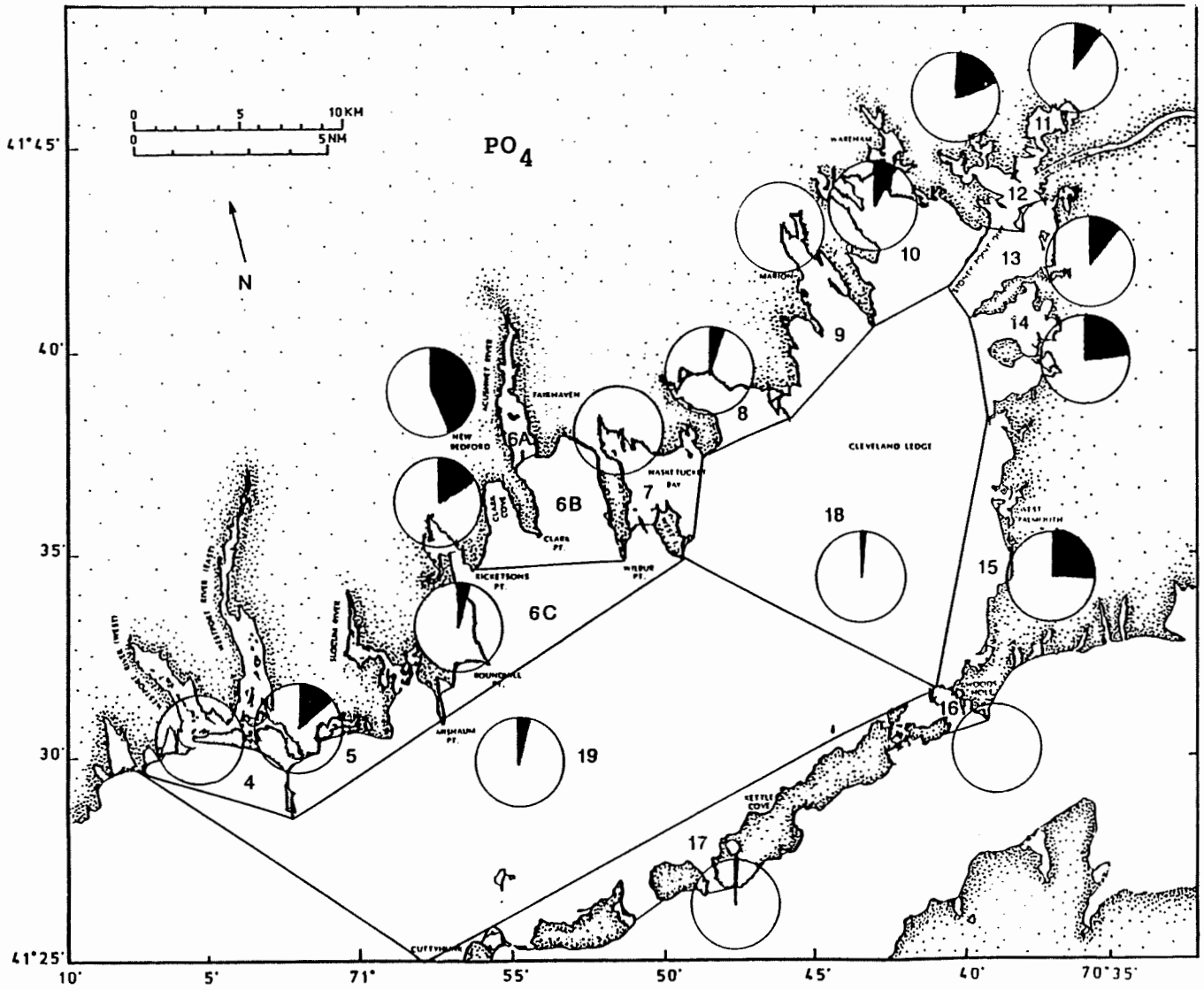

FIGURE 15. SPATIAL COVERAGE OF PHOSPHATE DATA AVAILABLE IN THE DATABASE. EACH CIRCLE HAS A MAXIMUM VALUE OF 150 OBSERVATIONS AND THE ACTUAL AMOUNT OF DATA AVAILABLE FOR EACH SEGMENT IS REPRESENTED AS THE PORTION OF THE CIRCLE THAT IS SHADED.

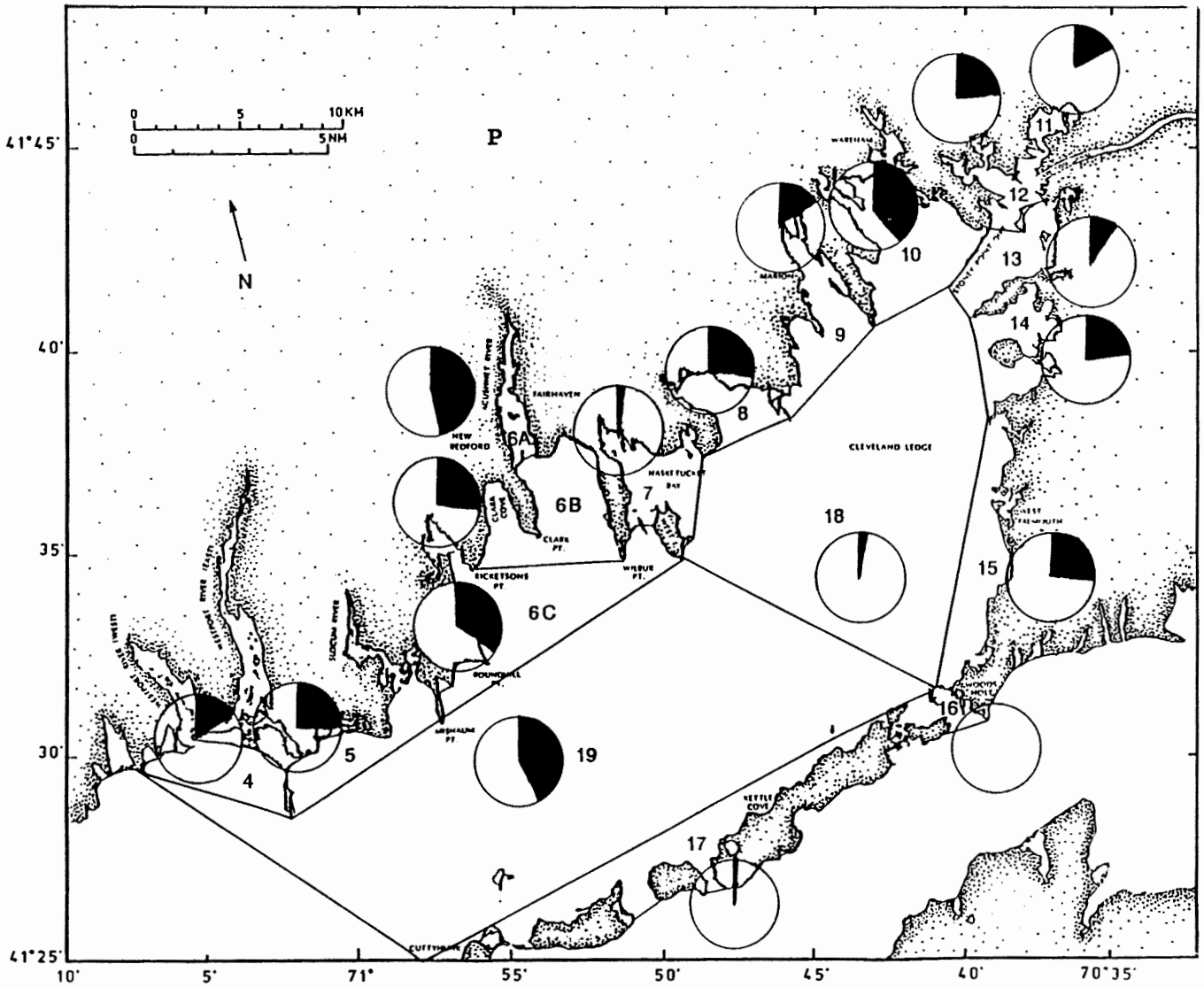

FIGURE 16. SPATIAL COVERAGE OF PHOSPHOROUS DATA AVAILABLE IN THE DATABASE. EACH CIRCLE HAS A MAXIMUM VALUE OF 150 OBSERVATIONS AND THE ACTUAL AMOUNT OF DATA AVAILABLE FOR EACH SEGMENT IS REPRESENTED AS THE PORTION OF THE CIRCLE THAT IS SHADED.

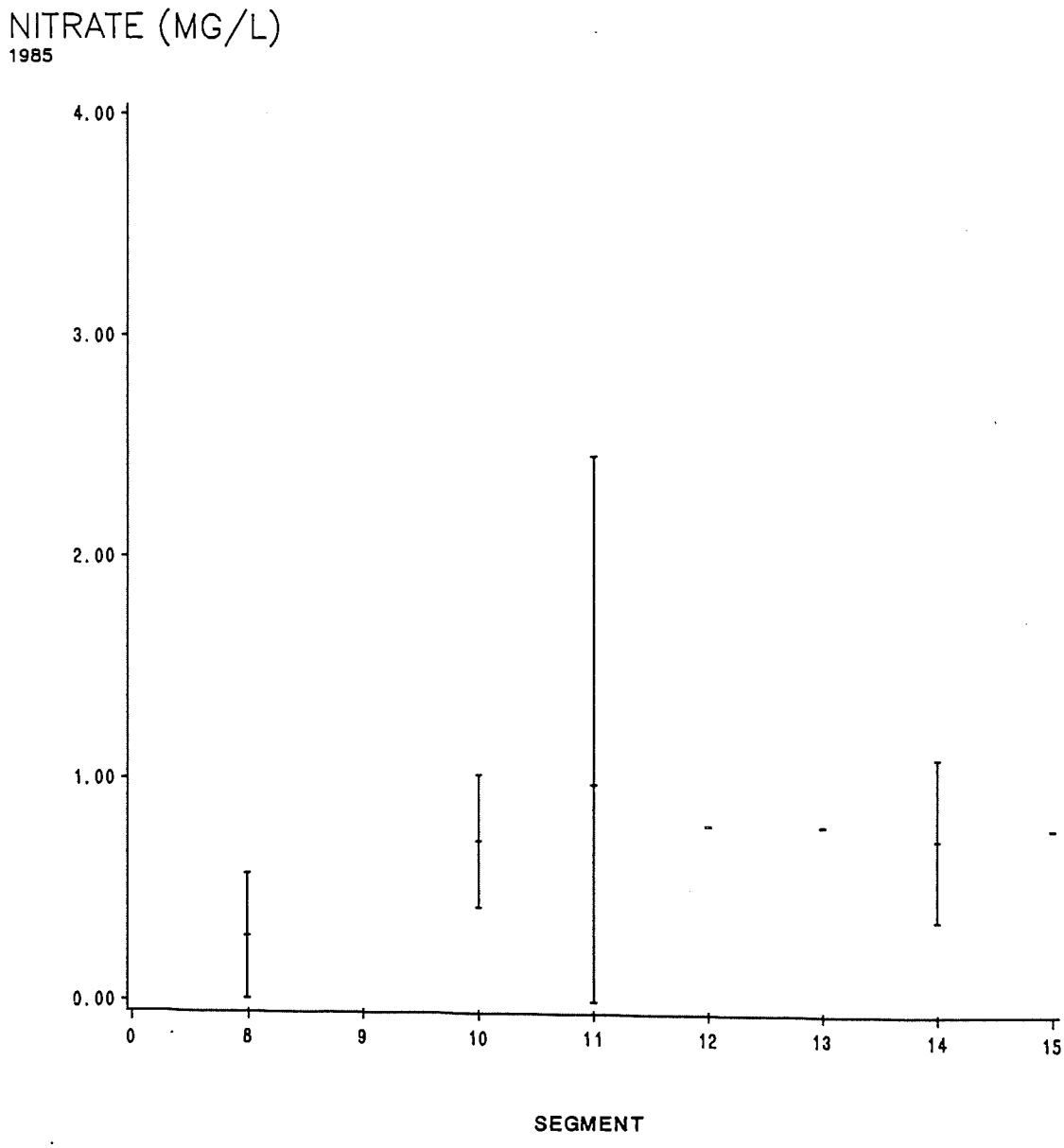

FIGURE 17. MEAN NITRATE LEVELS (MG/L ± 2 SD) FOR EACH SEGMENT DURING 1985.

sampled in 1985. All stations were used as replicates for the segments, following the assumption that station differences would contribute to a representative segment mean. A comparison of the means between segments shows them not to be significantly different from each other at the 95 percent confidence level. As with the coliform data, anthropogenic, analytical, and natural process variabilities could not be factored out of the comparison of means because auxiliary data were insufficient.

Nutrient sampling conditions must be documented when considering the variability due to physical, chemical, and biological processes. Physical transport and mixing cause large fluctuations in nutrient levels. Although it is unreasonable to always collect vertical profiles of density and current, it is possible to integrate nutrient data with other hydrographic information by using a GIS. Upwelling areas can be included as well. Accurate station location data could enable nutrient levels to be related to the general transport characteristics of an area. The potential for nutrient exchange with sediment denitrification is a complex process, but potential exchange can be attributed to areas by relating sediment organic content data, sediment size composition, and depth (Twilley and Kemp, 1986).

Spatial trends can also be investigated by comparing synoptic data for multiple nutrients. The nitrogen to phosphorus (N:P) ratio was calculated by summing nitrate and ammonia concentrations and then dividing the sum by the corresponding phosphate concentration (i.e., $(NO_3+NH_3)/PO_4$). The resultant mean N:P ratios for segments with sufficient data are shown in Figure 18. In general, N:P ratios below 16:1 may indicate a nitrogen-limited condition, and ratios above 16:1 may indicate that phosphorus is the limiting factor. There appear to be interesting similarities between the ratios for the segments on the eastern shore of Buzzards Bay. However, the large standard deviations make it impossible to quantify the trend. As found earlier with the temporal analysis, the variability of values reported within regional segments make it hard to discern spatial trends at this coarse scale.

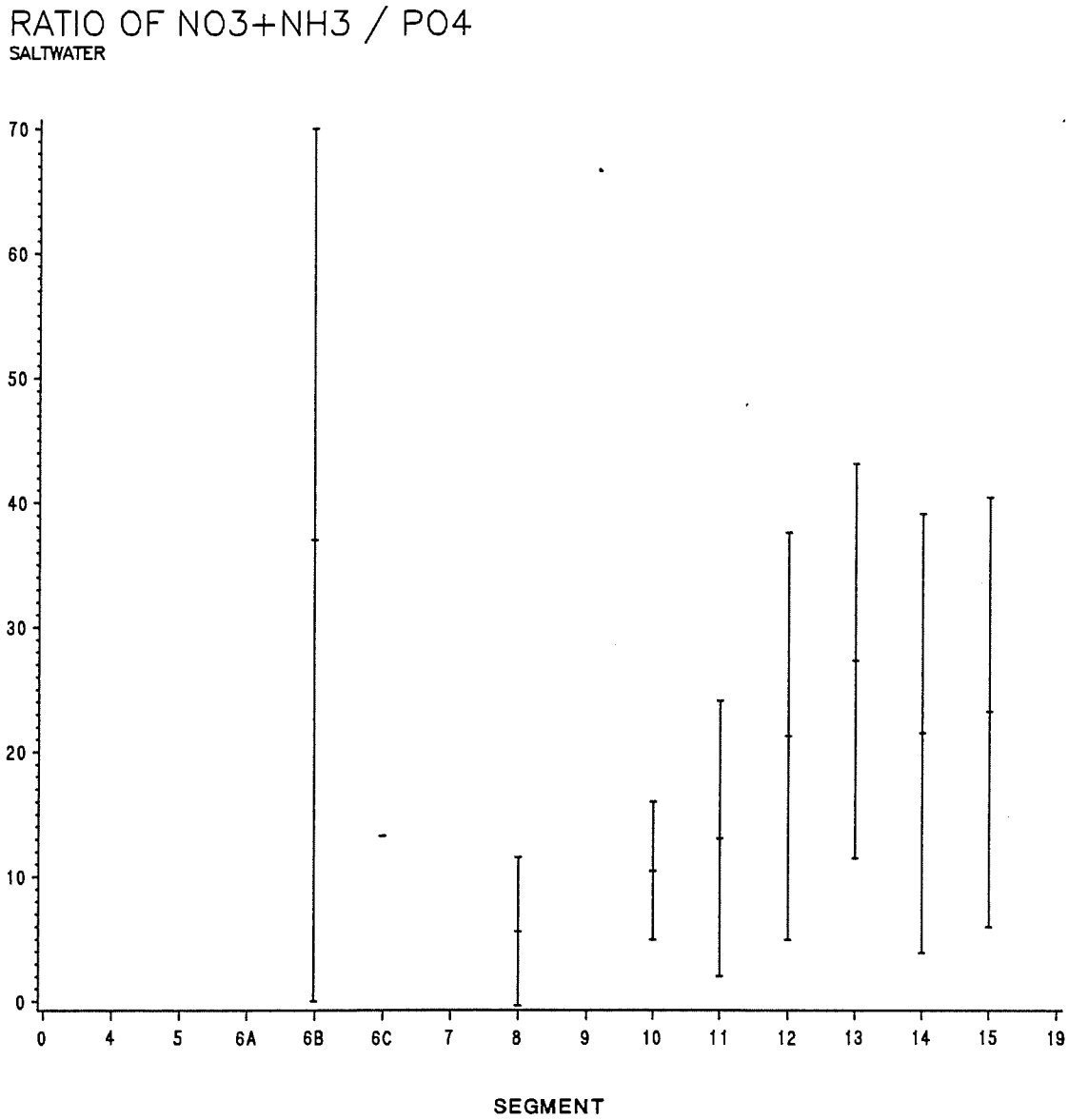

FIGURE 18. MEAN NITROGEN:PHOSPHORUS RATIOS FOR EACH SEGMENT WITH AVAILABLE DATA USING ONLY SALTWATER STATIONS (SALINITY >1 PPT).

4. SUMMARY

4.1 Utility of Coliform and Nutrient Data Sets

To maximize the utility of coliform bacteria and nutrient monitoring, it is important to recognize and address sources of variability. The historical coliform data were useful, as separate data sets, in supporting short-term and localized management decisions. For example, coliform data from a period of successive weeks could be used to help discern use-restriction conditions for particular beaches or shellfish areas adjacent to the sampling station. Minimal use could be made of the historical nutrient data sets in addressing bay-wide differences. Long-term average nutrient levels were successfully assembled to demonstrate variability, but it was impossible to quantify trends.

4.2 Problems With Coliform and Nutrient Data Sets

This data assessment for coliform bacteria and nutrients in Buzzards Bay has pointed out many obstacles to using these historical water quality data to support environmental management decisions. Problems can be categorized according to factors outlined in Table 10. These factors contribute to variability, incomparability, relevancy, and inability to integrate related information. In addition to these natural and anthropogenic factors that cause problems in data usage, there are obstacles that arise due to insufficient data handling capabilities. Data handling obstacles are addressed in the recommendations section below.

TABLE 10. CATEGORIES AND EXAMPLES OF OBSTACLES TO AD HOC ANALYSES OF BUZZARDS BAY HISTORICAL WATER QUALITY DATA SETS.

VARIABILITY

- o Wide range of temporal and spatial scales collected
- o Various sampling scales subject to different processes
- o Each water quality parameter subject to unique processes
- o Data describing sampling conditions often unavailable
- o Proximity to effluents not recorded
- o Discrete sampling depths and/or vertical compositing

INCOMPARABILITY

- o Shift from Total to Fecal coliform measurements not comparable
- o Nutrient species often not comparable
- o Nutrient collection and analysis techniques inconsistent
- o Objectives of samplings incongruent, worse case vs. random
- o Detection limits not reported
- o "Less than" notation used with imprecise analytical values

RELEVANCY

- o Sampling scales mostly relevant to immediate location only
- o Sampling designs not intended for holistic review and integration
- o Sampling frequency mostly relevant in scale of days, weeks
- o Resampling stations for new and short-term conditions, inapplicable to long-term temporal trend analysis

INTEGRATION

- o Hydrographic information not readily available
- o Bathymetry data not readily available
- o Precipitation data not readily available
- o Adjacent land-use and discharge locations data not readily available

4.2.1 Variability

The greatest need, in improving defensible use of Buzzards Bay water quality data, is to address the sources of variability. There are processes contributing to variability at every scale. For example, O'Conner and Flemer (1987) point out the need to

design monitoring programs with consideration for zooplankton behavior. Zooplankton show distinct temporal peaks in biomass variability at scales of days and months, while horizontal variability ranges from meters to kilometers depending on the frequency of sampling.

Interannual variability very often is impossible to assess without integration of broader information such as climatic regime (Peterson et al., 1986). High winds or cumulative effects of a season with abnormal rainfall can lead to variability that could not be assessed based on water quality parameters alone. This problem can be decreased by more complete data recording and interdisciplinary analyses as recommended below.

Spatial variability effects on water quality data are numerous; this summary is not intended to describe all possible factors contributing to spatial variability. Instead, the purpose of the summary is to highlight the problem and suggest means of accounting for some sources and avoiding others. As discussed in Sections 3.1 and 3.2, there is extremely high variability within each of the Buzzards Bay segments. Segments exhibit a range of variability based on their unique sources, sinks, processes, and transport mechanisms. Coliform levels and nutrient concentrations vary, in part as a function of proximity to the source. These spatial differences can affect each water quality parameter differently. Spatial variability can also be compounded by differences in sampling depth; two locations with similar surface conditions can still appear different if one was sampled at mid-depth.

Even with this diversity of causes and consequences, it is possible to better assess spatial patterns and relative scales by improved geographic information processing. A GIS could help to present details of how land use, hydrographics, or drainage areas relate to nutrient levels. River flow and drainage basin size were found to be major factors determining silicate levels in San Francisco Bay and Chesapeake Bay (Peterson et al., 1986).

Nutrient levels were found to vary on the scale of tens of meters in shallow waters close to anthropogenic inputs (Facco et al., 1986). Implementing a GIS-based approach to water quality data analysis, as recommended below, can greatly enhance similar interdisciplinary investigations of water quality in Buzzards Bay.

4.2.2 Incomparability

The largest cause of incomparability between studies was sampling for different parameters. It is necessary to sample for the best indicators of water quality, given the available technology. However, when alternative water quality parameters can be measured, the potential value of being able to compare and integrate the results should be considered. In the studies we examined the shift from measuring total coliform bacteria to measuring fecal coliform bacteria was warranted, but the consequences to the existing continuous data set should have been considered.

Other major sources of incomparability arose from the unavoidable fact that the historical studies each had individual purposes. Each sampling purpose produced certain biases in the the sampling design. Other biases can be avoided, such as the numerical bias that is produced by non-detectable levels being recorded as zeros or detection limits. These differences ought to be documented for use in statistical tests. Reporting of threshold values as "<" or ">" some threshold is another source of bias that leads to lack of comparability between data sets.

4.2.3 Relevancy

The temporal and spatial scales of the historical studies were intended to fulfill their respective purposes. Even the most general grouping of these data, presented above, demonstrated

broad trends of limited utility. Precise environmental management questions need to be outlined prior to sampling to allow proper design of a series of studies that can generate relevant and comparable data.

4.2.4 Inability to Integrate Related Information

Another current obstacle is the inability to selectively retrieve outside data relevant to the time and location being reviewed. It should be possible to integrate these data with related information about that location. The circulation patterns and hydrology of a location are critical to comprehensive interpretation of water quality data. Additional related information that would be valuable to integrate with the water quality data are discussed in the following section as part of the recommendations for improved assessments of spatial variability.

5. RECOMMENDATIONS

Three major actions are recommended in response to the characteristics and obstacles identified in this water quality data assessment (see Table 11). Implementation of these recommendations will improve monitoring study plans, sample recording, and comprehensive data analyses.

TABLE 11. RECOMMENDATIONS FOR IMPROVEMENTS TO COLLECTION, MANAGEMENT, INTEGRATION, AND ANALYSIS OF BUZZARDS BAY HISTORICAL WATER QUALITY DATA.

- o Link management questions to design of data collection
- o Record a complete description of conditions during sampling and analyses to possibly include the following parameters:
  - Temperature, Salinity, pH
  - Tide stage, Depth, Sampling Depth, Current speed and direction
  - Time since rainfall, Amount of rain, Wind speed and direction
  - DO, Secchi Depth,
  - Method code, detection limit, quality review code
- o Utilize a computer system to include functions for
  - Complete Database Management
  - Geographic Information Processing
  - Statistical Analyses

5.1 Link Between Management Questions and Monitoring Design

The most effective collection and analysis of environmental data require that specific questions or hypotheses be stated before initiating any field sampling (Green, 1979). This study has demonstrated that the compilation of scattered data sets into

one review does not necessarily expand the types of questions or hypotheses that can be investigated.

Resampling at pertinent intervals, such as weekly, seasonally, or annually, is required for trend analysis. The intervals necessary to answer a particular question is a function of three parameters. The magnitude of differences that need to be perceived affects the resolution. The required confidence in the perceived differences affects the replication at each interval. Replication is also affected by the variability exhibited by the ecosystem at that particular scale or any smaller scales. There are two major reasons why it is still not possible to recommend appropriate resampling or monitoring intervals.

First, the historical data cannot be used to provide recommended monitoring intervals because relevant scales depend on the scope of the question to be investigated. It would be wrong to continue sampling at episodic intervals and then attempt to re-sort the data for information at different scales. However, the "worse case" sampling programs are appropriate for use-restriction regulatory actions. Therefore, it is recommended that appropriate monitoring scales for baywide sampling be identified based on the priority hypotheses outlined by the Buzzards Bay technical advisory group.

Second, the limited capabilities of the present NCC SAS-based data system make it impossible to use the Buzzards Bay historical water quality data to recommend sampling intervals. The present system was a good way to get data on-line for users who are proficient in SAS programming. This system also served as an effective means to provide summary reports to help Buzzards Bay program managers determine priorities for data set processing and review. It is recommended that the on-line data be transferred to a more complete data management and analysis system, such as EPA's Ocean Data Evaluation System (ODES). (Details of ODES suitability are discussed in Section 5.3). Implementing data management in ODES will allow managers to examine appropriate monitoring intervals using power analysis programs in ODES.

The data should be transferred to ODES as soon as possible, thus creating a more effective link between management needs and monitoring design. ODES can be used by marine scientists to provide input into the ongoing Buzzards Bay program activities, such as the advanced stages of status and trends assessment, and the early planning stages of the comprehensive conservation management plan. Additionally, a DBMS would allow more accurate weighting of recent monitoring results to support use-restriction decisions.

5.2 Complete Record of Sampling Conditions and Methods

As Buzzards Bay program managers and technical advisors plan future monitoring efforts they must address the problems caused by the inconsistencies in historical data types. These planners need to reach a consensus on a standard set of water quality parameters to be sampled (as a minimum) for the network of studies to be integrated. Examples of environmental conditions that could be recorded are described for the Chesapeake Bay program by Mountford and Mackiernan (1987). Other Northeastern estuaries have implemented different standards based on the data needed for a specific estuary and the analytical capabilities available (Phelps et al., 1987).

Consensus should also be reached on collection and analytical methods to be used for each type of the sample. Because methods will vary based on sample type and available resources, there must be provision for recording the method used at time of collection or analysis.

In addition to the sampling data recommended above, there should be provisions for including geographic information in water quality analyses. The knowledge used to manage estuaries is incomplete if it does not include characterization of geographical variability (Nixon and Pilson, 1984). Including geographic information such as areas with extremely high tidal currents or

steep bathymetric features could help to isolate well-mixed regions of the bay. Topographic features have been shown to produce estuarine variability on the scale of hundreds of meters (Dyer and New, 1986) and tens of kilometers (Powell et al., 1986). Such information could also be helpful in categorizing historical stations that may have been in well-mixed areas of Buzzards Bay. As a different example, entering the geographic information for known point sources could help in an assessment of the relative contribution of point and nonpoint sources within river basins (Tippie, 1984).

5.3 Data Management and Analysis System

The data management and analysis system should be designed, built, and maintained by a team includes marine scientists, computer scientists, and statisticians. This team must be able to communicate directly with Buzzards Bay technical leaders and program managers. Implementing data processing with this team approach will ensure that system designs and modifications will be directly relevant and valuable. Including marine scientists on the data management team can also enhance interdisciplinary analysis and presentation of defensible water quality assessments.

It is recommended that the data be transferred to a system that can provide general users with easy access to the data for review, presentations, statistical analyses, and transfer for use on microcomputers. EPA's Ocean Data Evaluation System is the most cost-effective system readily available to meet these needs. The transfer should be carried through the team approach described above. This approach will ensure that the data are organized into a structure that will allow easy combination of comparable data sets. It will also be necessary to include extensive quality assurance reports to inform users of the various levels of documentation available for these data sets.

It is also recommended that the data sets be made available for use with a GIS. Some of the basic presentations and data groupings used in this study could be reworked based on more flexible spatial segmentation and retrievals. For example, some data could be regrouped by station depths, inner-harbor regions, or proximity to shellfish areas. A more powerful review of historical water quality data subsets with related geographic information could lead to limited use in subsequent status and trends analyses.

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APPENDIX A

SUMMARY STATISTICS - TOTAL COLIFORM BACTERIA

APPENDIX A. MEAN CONCENTRATION OF TOTAL COLIFORM BACTERIA (MPN/100 ml), STANDARD DEVIATION, MAXIMUM AND MINIMUM VALUES, AND THE NUMBER OF OBSERVATIONS FOR EACH DATA SET.

Data Set/ Segment	Geometric Mean	Standard Deviation	Minimum Value	Maximum Value	Number of Observations
DEQE-LAKEVILLE					
4	106	7.0	2	11,000	396
5	154	8.3	3	11,000	89
6B	48	15.4	2	460,000	534
6C	74	8.8	2	2,400,000	193
7	37	8.7	2	24,000	120
8	83	9.5	2	4,600,000	272
9	33	12.2	2	210,000	375
10	63	6.7	2	2,400	274
11	80	11.9	2	460,000	173
12	64	8.3	2	46,000	249
13	79	7.5	2	16,000	276
14	28	5.4	2	2,400	148
15	36	5.7	2	2,400	318
16	93	5.2	36	11,000	15
17A	78	3.3	9	1,100	15
FDA 1972					
8	42	11.1	2	5,400	33
10	88	4.7	2	1,300	30
FDA 1981					
14	30	3.7	9	248	25
15	38	3.6	9	248	24
16	20	3.1	9	248	16
FDA 1985					
11	40	13.3	1	920,000	261
DEQE-DWPC 1972					
6A	5,878	18.2	36	4,600,000	50
6B	430	46.7	36	1,200,000	20
DEQE-DWPC 1975					
4	278	5.9	10	5,900	12
5	423	4.8	20	2,000	11
6A	587	9.6	10	40,000	26
6B	131	5.8	10	700	9

APPENDIX A. (Continued).

Data Set/ Segment	Geometric Mean	Standard Deviation	Minimum Value	Maximum Value	Number of Observations
DEQE-DWPC 1975 (cont'd)					
6C	288	8.1	10	2,400	8
7	200	2.7	100	400	2
8	130	8.4	10	12,000	17
9	64	5.1	10	300	10
10	31	5.8	100	2,800	23
11	12	1.6	10	30	5
12	34	9.4	10	4,600	7
DEQE-DWPC 1980					
6B	130	1.2	112	150	2
6C	2	3.1	1	5	2
DEQE-DWPC 1985-86					
5	334	3.3	20	1,000	17
6A	5,998	8.4	250	780,000	29
6B	19,526	2.7	5,000	51,000	4
6C	53	5.9	5	400	7
8	1,503	4.5	20	7,000	13
10	171	6.3	20	5,300	14
11	262	6.2	10	4,000	19
12	134	7.4	5	7,000	22
13	453	6.1	50	8,000	14
14	785	4.6	50	10,000	48
15	352	3.7	20	6,000	37
18	88	3.6	40	600	4

APPENDIX B

SUMMARY STATISTICS - FECAL COLIFORM BACTERIA

APPENDIX B. MEAN CONCENTRATION OF FECAL COLIFORM BACTERIA (MPN/100 ml), STANDARD DEVIATION, MAXIMUM AND MINIMUM VALUES, AND THE NUMBER OF OBSERVATIONS FOR EACH DATA SET.

Data Set/ Segment	Geometric Mean	Standard Deviation	Minimum Value	Maximum Value	Number of Observations
DEQE-LAKEVILLE					
4	55	7.8	2	11,000	363
5	41	6.1	2	11,000	89
6B	27	12.3	2	24,000	492
6C	44	7.1	2	46,000	177
7	15	6.1	2	11,000	119
8	23	6.6	2	91,000	255
9	20	7.7	2	24,000	313
10	15	4.5	2	2,400	427
11	36	7.7	2	11,000	168
12	25	5.5	2	2,400	252
13	24	6.7	2	2,400	278
14	16	4.4	2	2,400	126
15	20	5.5	2	2,400	272
16	76	4.3	36	3,400	13
17	64	---	64	64	1
17A	14	5.2	2	460	39
FDA 1972					
8	13	9.0	1	2,400	33
10	30	4.4	2	490	30
FDA 1981					
14	20	3.3	9	248	25
15	25	3.6	9	248	24
16	14	2.6	9	179	16
FDA 1985					
11	11	8.2	1	240,000	259
FDA 1985-86					
4	28	5.9	2	3,500	103
DEQE-DWPC 1972					
6A	1458	15.1	36	1,100,000	50
6B	339	48.0	36	1,200,000	20

APPENDIX B. (Continued).

Data Set/ Segment	Geometric Mean	Standard Deviation	Minimum Value	Maximum Value	Number of Observations
DEQE-DWPC 1975					
4	267	5.9	10.0	4,200	12
5	121	6.4	10.0	1,900	11
6A	66	5.9	10.0	3,900	25
6B	16	3.9	10.0	600	9
6C	43	4.8	10.0	600	8
7	300	4.7	100.0	900	2
8	26	3.6	10.0	320	16
9	16	2.7	10.0	240	10
10	25	6.5	10.0	3,500	23
11	11	1.4	10.0	20	5
12	13	1.7	10.0	40	7
DEQE-DWPC 1980					
6B	88	1.9	55.0	140	2
6C	1	6.8	0.2	3	2
DEQE-DWPC 1985-86					
4	496	---	496.0	496	1
5	31	2.8	5.0	110	17
6A	683	13.4	20.0	250,000	28
6B	1247	3.9	200.0	5,000	4
6C	12	3.2	5.0	60	7
8	197	5.5	5.0	1,800	13
10	39	3.4	5.0	280	14
11	30	3.1	5.0	440	19
12	12	2.7	5.0	110	22
13	49	6.4	5.0	560	13
14	64	5.5	5.0	4,000	48
15	51	6.3	5.0	5,500	38
18	10	2.2	5.0	20	4
19	5	1.0	5.0	5	4
BARNSTABLE COUNTY HEALTH					
11	9	5.8	1.0	2,400	157

APPENDIX C

SUMMARY STATISTICS - NUTRIENTS

APPENDIX C-1. MEAN CONCENTRATION OF NITRATE NITROGEN (mg/l), STANDARD DEVIATION, MAXIMUM AND MINIMUM VALUES, AND THE NUMBER OF OBSERVATIONS FOR ALL DATA SETS COMBINED.

Data Set/ Segment	Geometric Mean	Standard Deviation	Minimum Value	Maximum Value	Number of Observations
FRESHWATER					
4	0.22	0.20	0.10	0.60	9.00
5	0.49	0.39	0.10	1.50	31.00
6A	0.83	1.82	0.10	11.00	46.00
6C	1.36	0.43	0.60	1.70	5.00
7	0.42	0.05	0.40	0.50	4.00
8	0.97	1.67	0.10	7.00	16.00
9	0.27	0.06	0.20	0.30	3.00
10	0.17	0.10	0.10	0.30	6.00
11	11.39	17.45	0.02	83.30	29.00
12	0.33	0.40	0.10	0.80	3.00
13	0.50	0.14	0.40	0.60	2.00
14	0.24	0.14	0.10	0.50	12.00
15	0.80	0.00	0.80	0.80	2.00
SALTWATER					
4	0.50	--	0.50	0.50	1.00
6A	0.17	0.12	0.10	0.30	3.00
6B	0.19	0.31	0.01	0.80	17.00
6C	0.29	0.45	0.01	1.50	18.00
8	0.30	0.14	0.20	0.40	2.00
10	0.73	0.15	0.50	0.80	4.00
11	1.93	2.52	0.10	16.10	108.00
12	0.69	0.26	0.10	0.80	18.00
13	0.80	0.00	0.80	0.80	11.00
14	0.75	0.18	0.10	0.80	24.00
15	0.80	0.00	0.80	0.80	35.00
19	0.08	0.14	0.01	0.65	22.00

APPENDIX C-2. MEAN CONCENTRATION OF AMMONIA NITROGEN (mg/l), STANDARD DEVIATION, MAXIMUM AND MINIMUM VALUES, AND THE NUMBER OF OBSERVATIONS FOR ALL DATA SETS COMBINED.

Data Set/ Segment	Geometric Mean	Standard Deviation	Minimum Value	Maximum Value	Number of Observations
FRESHWATER					
4	0.06	0.04	0.01	0.13	8.00
5	0.08	0.11	0.01	0.60	31.00
6A	0.98	3.36	0.01	22.00	55.00
6C	0.03	0.02	0.01	0.05	5.00
7	0.04	0.01	0.03	0.06	4.00
8	0.30	0.68	0.02	2.80	19.00
9	0.04	0.01	0.02	0.05	7.00
10	0.03	0.01	0.01	0.05	12.00
11	0.07	0.06	0.01	0.17	8.00
12	0.08	0.09	0.01	0.26	7.00
13	0.32	0.16	0.21	0.44	2.00
14	0.08	0.04	0.03	0.18	12.00
15	0.07	0.04	0.05	0.10	2.00
19	0.02	0.02	0.01	0.04	2.00
SALTWATER					
4	0.08	0.03	0.03	0.13	10.00
5	0.13	0.15	0.02	0.40	8.00
6A	0.23	0.12	0.05	0.80	62.00
6B	0.17	0.19	0.02	1.10	52.00
6C	0.09	0.08	0.01	0.30	32.00
8	0.12	0.06	0.04	0.22	21.00
9	0.14	0.08	0.07	0.30	12.00
10	0.13	0.10	0.02	0.42	43.00
11	0.08	0.04	0.03	0.15	14.00
12	0.07	0.04	0.01	0.15	29.00
13	0.08	0.04	0.03	0.15	11.00
14	0.10	0.06	0.02	0.27	24.00
15	0.11	0.10	0.03	0.52	38.00
17	0.03	0.01	0.02	0.04	2.00
18	0.02	0.02	0.01	0.05	4.00
19	0.12	0.20	0.01	0.69	20.00

APPENDIX C-3. MEAN CONCENTRATION OF ORTHOPHOSPHATE (MG/L), STANDARD DEVIATION, MAXIMUM AND MINIMUM VALUES, AND THE NUMBER OF OBSERVATIONS FOR EACH DATA SET.

Data Set/ Segment	Geometric Mean	Standard Deviation	Minimum Value	Maximum Value	Number of Observations
FRESHWATER					
5	0.07	0.02	0.03	0.10	11.00
6A	1.68	6.21	0.01	30.90	31.00
6C	0.05	--	0.05	0.05	1.00
8	0.07	0.06	0.04	0.17	4.00
10	0.01	0.00	0.01	0.01	3.00
11	0.02	0.02	0.01	0.06	6.00
12	0.07	0.01	0.06	0.08	3.00
13	0.07	0.04	0.05	0.10	2.00
14	0.05	0.03	0.02	0.11	12.00
15	0.07	0.01	0.07	0.08	2.00
SALTWATER					
5	0.09	0.13	0.01	0.39	8.00
6A	0.20	0.08	0.07	0.53	37.00
6B	0.10	0.06	0.02	0.27	23.00
6C	0.13	0.15	0.06	0.48	7.00
8	0.06	0.03	0.03	0.08	3.00
10	0.08	0.03	0.03	0.11	9.00
11	0.06	0.02	0.04	0.11	10.00
12	0.04	0.01	0.02	0.06	18.00
13	0.04	0.01	0.02	0.06	11.00
14	0.04	0.01	0.03	0.07	23.00
15	0.04	0.02	0.02	0.09	38.00
17	0.02	0.01	0.02	0.03	2.00
18	0.02	0.01	0.01	0.03	4.00
19	0.04	0.05	0.01	0.14	6.00

APPENDIX C-4. MEAN CONCENTRATION OF TOTAL PHOSPHORUS (mg/l), STANDARD DEVIATION, MAXIMUM AND MINIMUM VALUES, AND THE NUMBER OF OBSERVATIONS FOR EACH DATA SET.

Data Set/ Segment	Geometric Mean	Standard Deviation	Minimum Value	Maximum Value	Number of Observations
FRESHWATER					
4	0.03	0.01	0.01	0.05	11.00
5	0.06	0.04	0.01	0.14	33.00
6A	0.30	0.58	0.01	3.10	47.00
6C	0.05	0.03	0.01	0.08	5.00
7	0.06	0.03	0.02	0.10	4.00
8	0.24	0.23	0.01	0.78	19.00
9	0.04	0.03	0.01	0.10	7.00
10	0.06	0.06	0.01	0.24	15.00
11	0.07	0.05	0.01	0.14	9.00
12	0.06	0.05	0.01	0.14	7.00
13	0.15	0.12	0.07	0.24	2.00
14	0.10	0.04	0.05	0.18	12.00
15	0.15	0.00	0.15	0.15	2.00
19	0.08	--	0.08	0.08	1.00
SALTWATER					
4	0.04	0.02	0.01	0.07	13.00
5	0.18	0.10	0.11	0.40	8.00
6A	0.06	0.02	0.04	0.10	25.00
6B	0.10	0.12	0.01	0.57	42.00
6C	0.09	0.08	0.01	0.48	38.00
8	0.07	0.07	0.01	0.28	21.00
9	0.03	0.02	0.01	0.06	12.00
10	0.07	0.05	0.01	0.26	43.00
11	0.09	0.05	0.04	0.21	16.00
12	0.10	0.06	0.01	0.26	28.00
13	0.11	0.02	0.08	0.14	11.00
14	0.11	0.02	0.08	0.15	24.00
15	0.11	0.03	0.07	0.19	38.00
17	0.08	0.01	0.08	0.09	2.00
18	0.14	0.08	0.06	0.21	4.00
19	0.07	0.05	0.01	0.24	33.00

APPENDIX C-5. MEAN CONCENTRATION OF TOTAL KJEDAHL NITROGEN (mg/l), STANDARD DEVIATION, MAXIMUM AND MINIMUM VALUES, AND THE NUMBER OF OBSERVATIONS FOR EACH DATA SET.

Data Set/ Segment	Geometric Mean	Standard Deviation	Minimum Value	Maximum Value	Number of Observations
FRESHWATER					
5	1.15	0.44	0.45	1.90	11.00
6A	2.41	4.96	0.33	25.70	26.00
6C	0.77	--	0.77	0.77	1.00
8	1.28	0.80	0.65	2.40	4.00
10	0.77	0.27	0.48	1.00	3.00
11	0.76	0.26	0.47	1.20	6.00
12	0.91	0.17	0.78	1.10	3.00
13	3.05	1.48	2.00	4.10	2.00
14	1.67	0.21	1.40	2.00	12.00
15	1.80	0.14	1.70	1.90	2.00
19	0.60	--	0.60	0.60	1.00
SALTWATER					
5	1.94	0.30	1.40	2.30	8.00
6A	1.22	0.81	0.30	3.10	18.00
6B	0.59	0.57	0.10	2.40	35.00
6C	0.70	0.63	0.10	2.20	32.00
8	1.21	0.50	0.64	1.50	3.00
10	1.30	0.57	0.70	2.20	8.00
11	0.72	0.32	0.30	1.20	10.00
12	0.81	0.42	0.24	2.00	17.00
13	1.47	0.31	1.10	1.90	11.00
14	1.48	0.31	0.99	2.00	24.00
15	1.64	0.39	0.98	2.70	38.00
17	1.45	0.64	1.00	1.90	2.00
18	0.78	0.55	0.23	1.30	4.00
19	0.44	0.33	0.10	1.10	38.00

APPENDIX D

DATA SET OBSERVATIONS - TOTAL COLIFORM BACTERIA

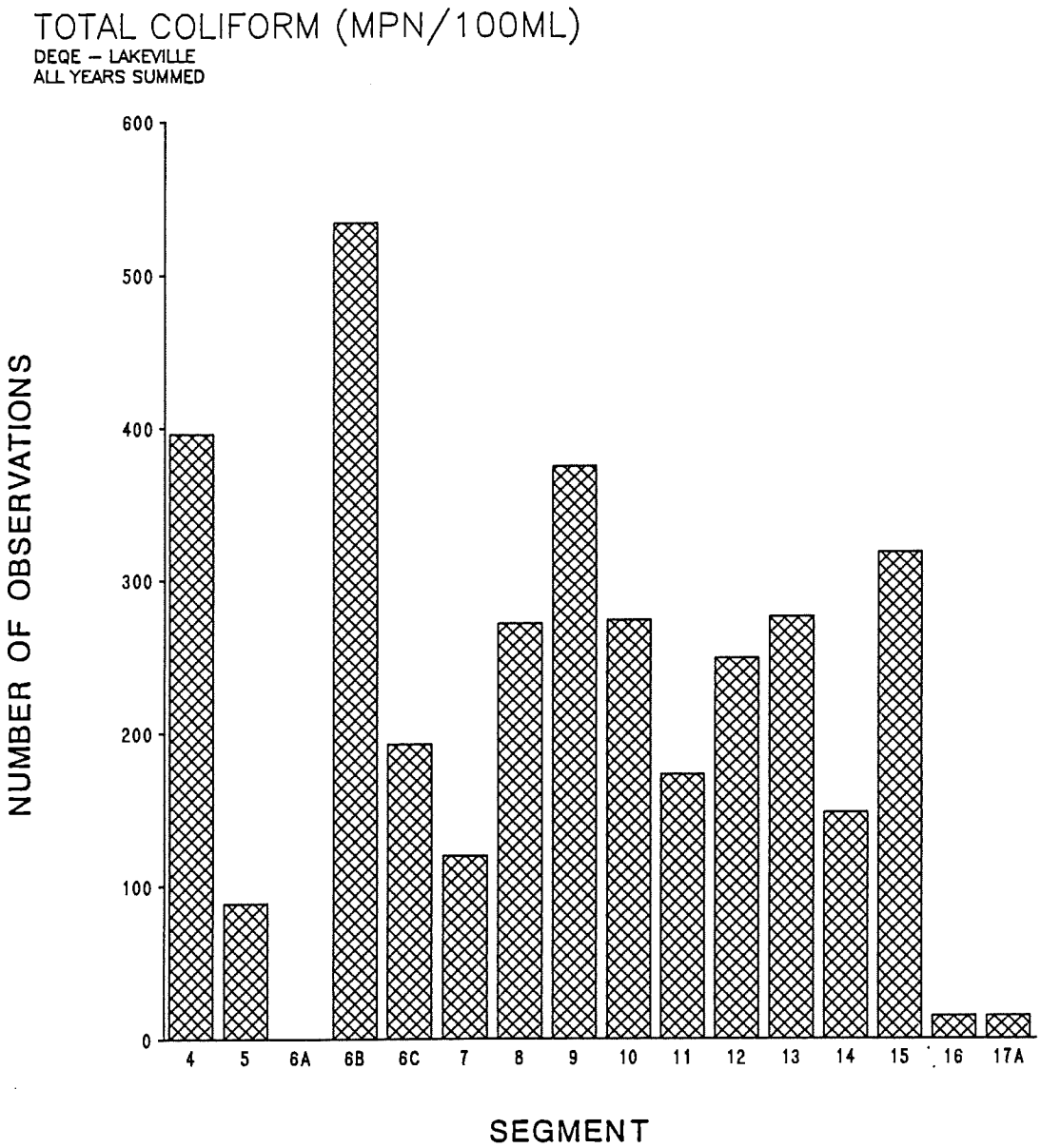

FIGURE D-1. NUMBER OF DATA SET OBSERVATIONS FOR TOTAL COLIFORM BACTERIA COLLECTED BY DEQE-LAKEVILLE FOR EACH SEGMENT FOR ALL YEARS COMBINED.

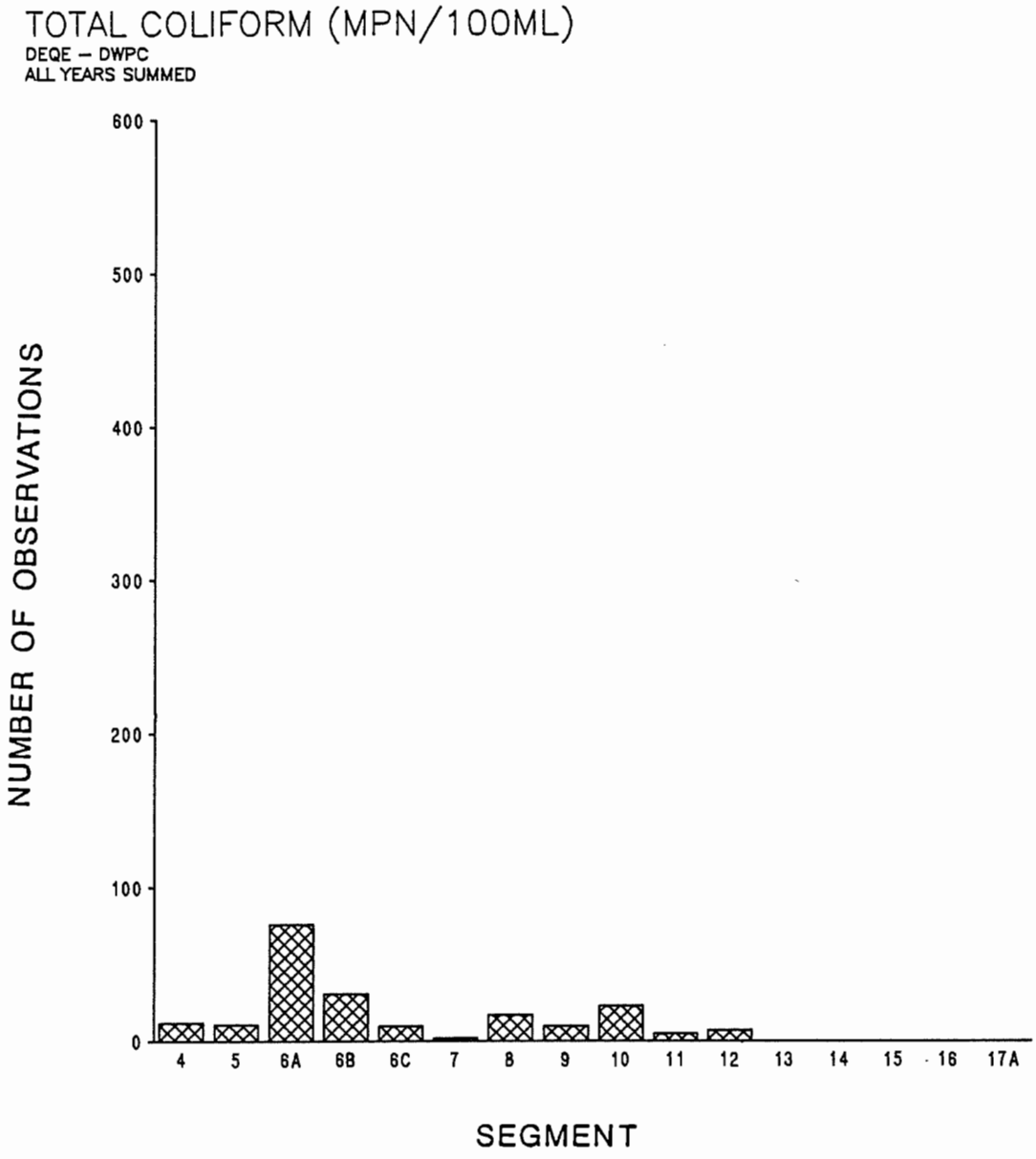

FIGURE D-2. NUMBER OF DATA SET OBSERVATIONS FOR TOTAL COLIFORM BACTERIA COLLECTED BY DEQE-DWPC FOR EACH SEGMENT FOR ALL YEARS COMBINED.

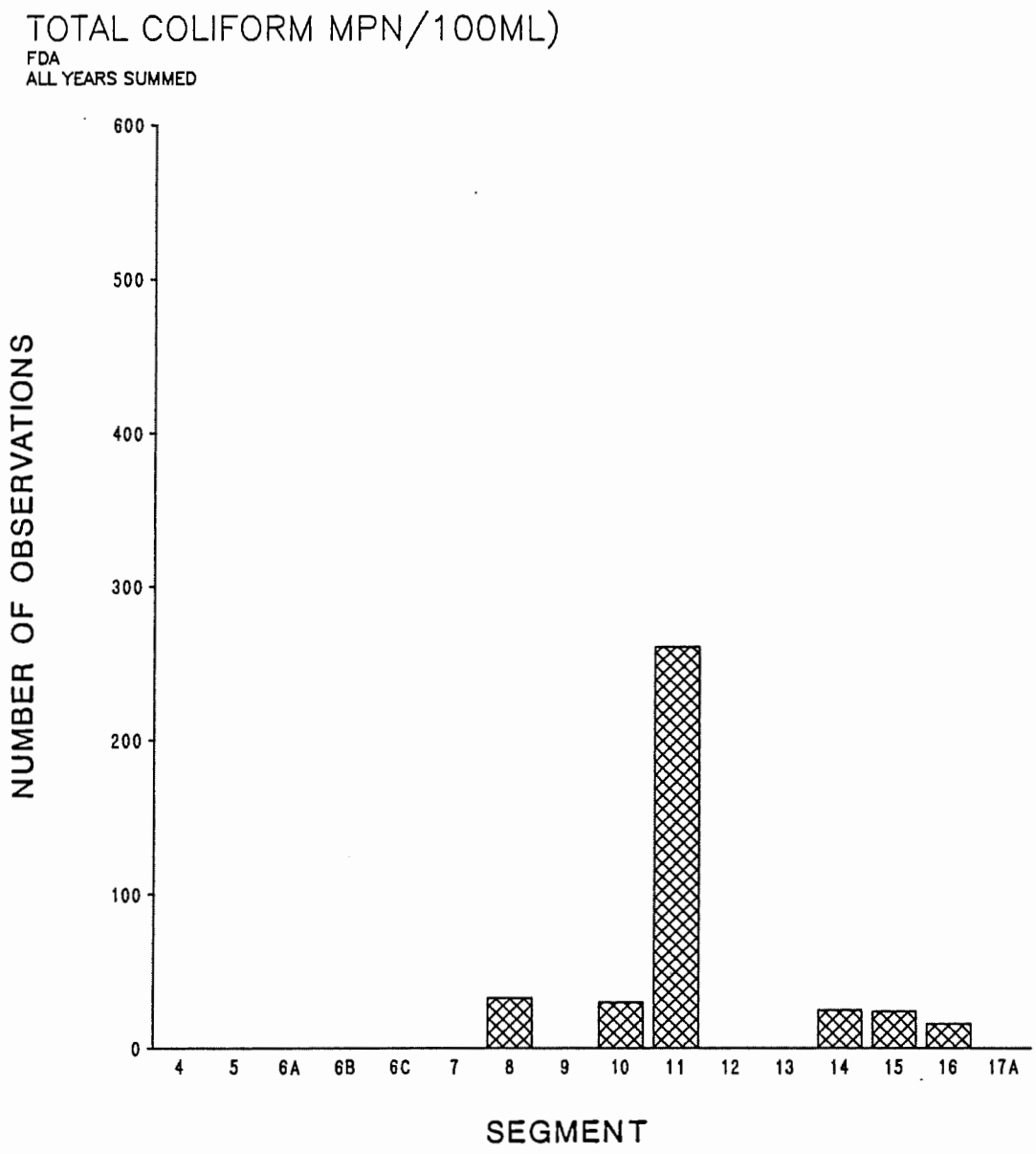

FIGURE D-3. NUMBER OF DATA SET OBSERVATIONS FOR TOTAL COLIFORM BACTERIA COLLECTED BY FDA FOR EACH SEGMENT FOR ALL YEARS COMBINED.

APPENDIX E

DATA SET OBSERVATIONS - TOTAL COLIFORM BACTERIA TEMPORAL COVERAGE

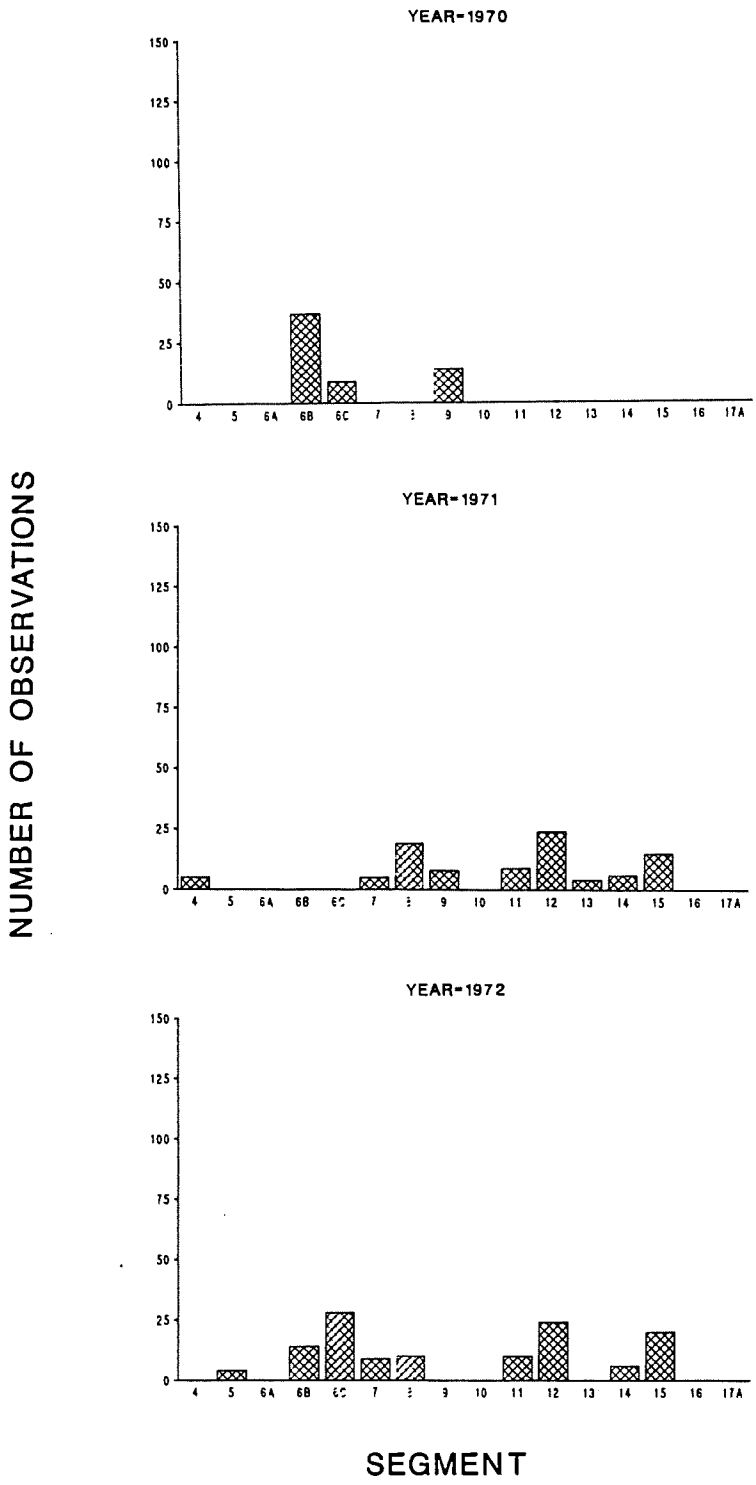

FIGURE E-1. NUMBER OF DATA SET OBSERVATIONS FOR TOTAL COLIFORM BACTERIA (MPN/100 ML) COLLECTED BY DEQE-LAKEVILLE FOR EACH SEGMENT FOR 1970, 1971, AND 1972.

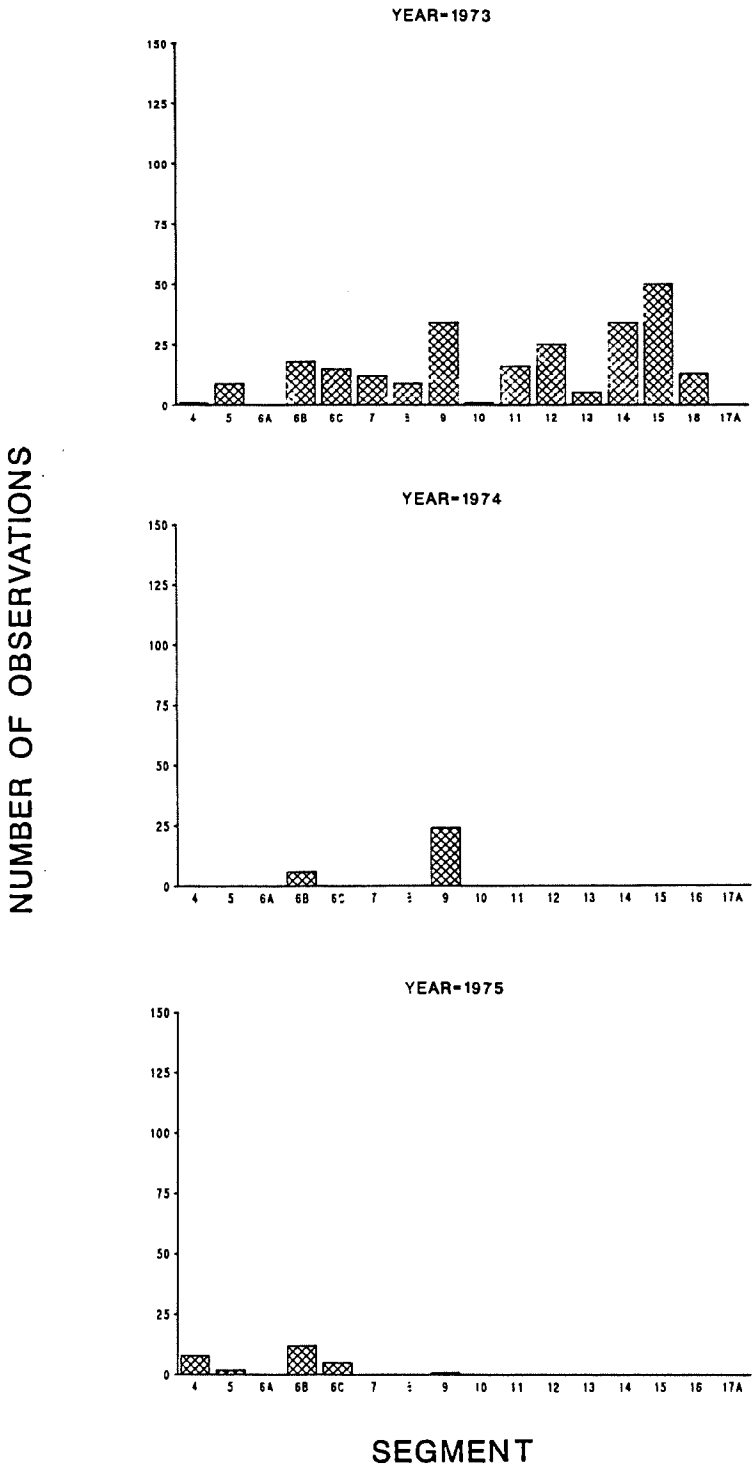

FIGURE E-2. NUMBER OF DATA SET OBSERVATIONS FOR TOTAL COLIFORM BACTERIA (MPN/100 ML) COLLECTED BY DEQE-LAKEVILLE FOR EACH SEGMENT FOR 1973, 1974, AND 1975.

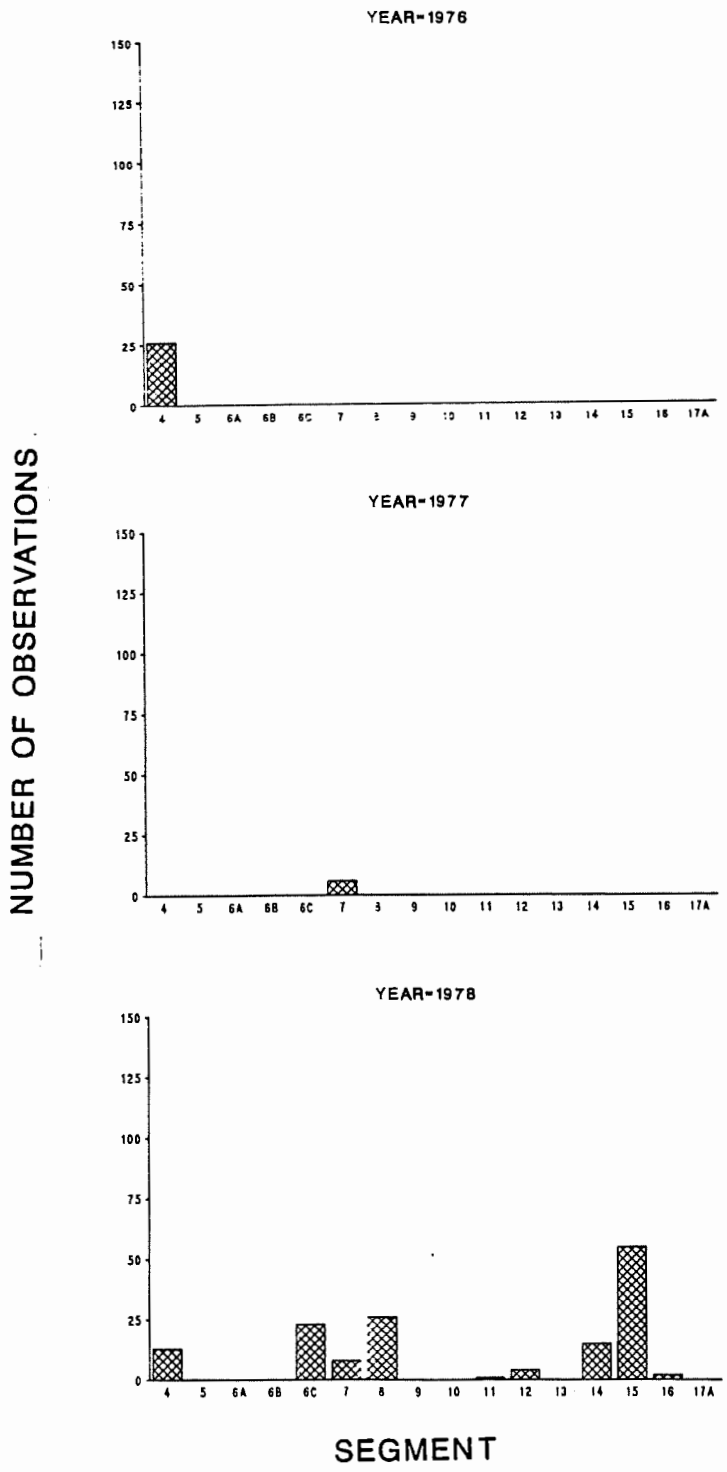

FIGURE E-3. NUMBER OF DATA SET OBSERVATIONS FOR TOTAL COLIFORM BACTERIA (MPN/100 ML) COLLECTED BY DEQE-LAKEVILLE FOR EACH SEGMENT FOR 1976, 1977, AND 1978.

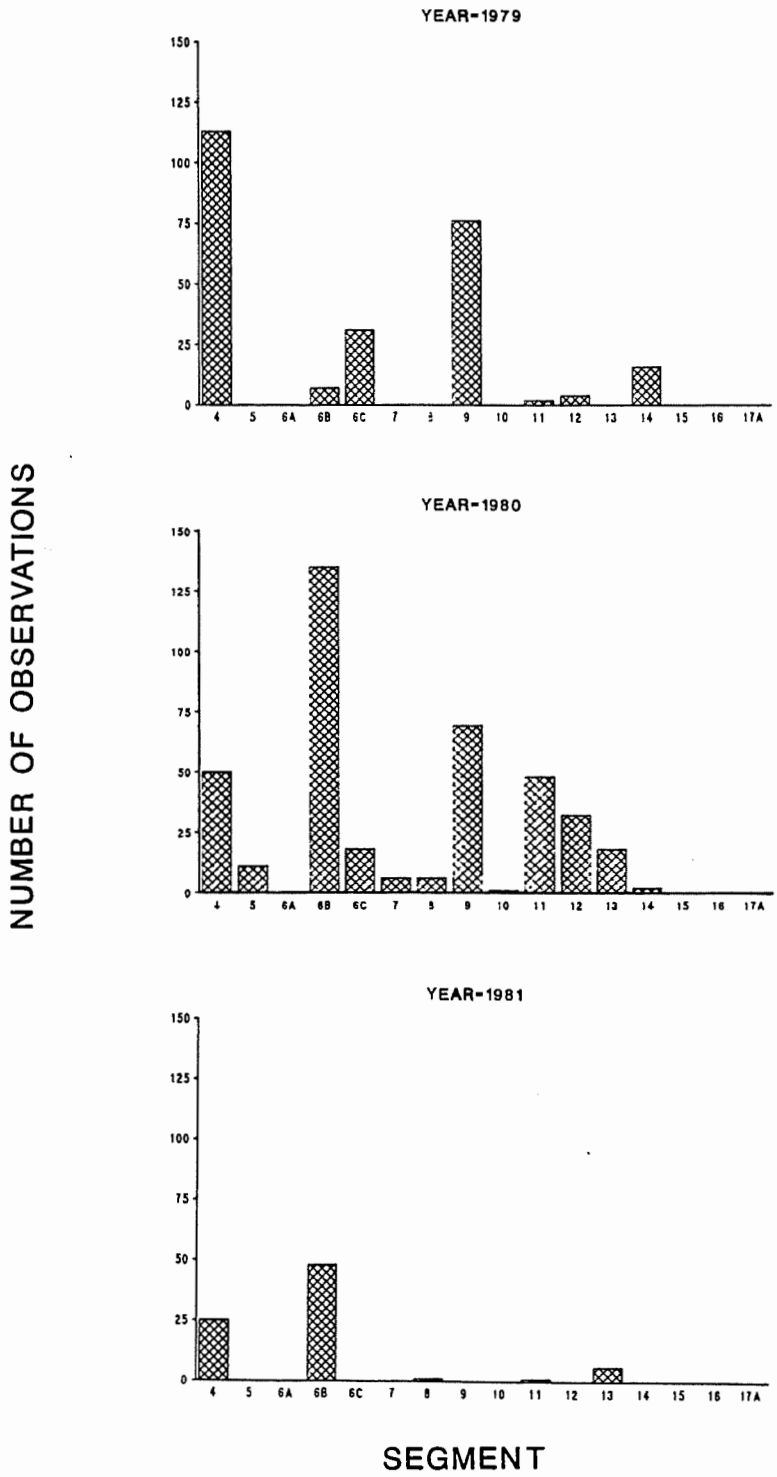

FIGURE E-4. NUMBER OF DATA SET OBSERVATIONS FOR TOTAL COLIFORM BACTERIA (MPN/100 ML) COLLECTED BY DEQE-LAKEVILLE FOR EACH SEGMENT FOR 1979, 1980, AND 1981.

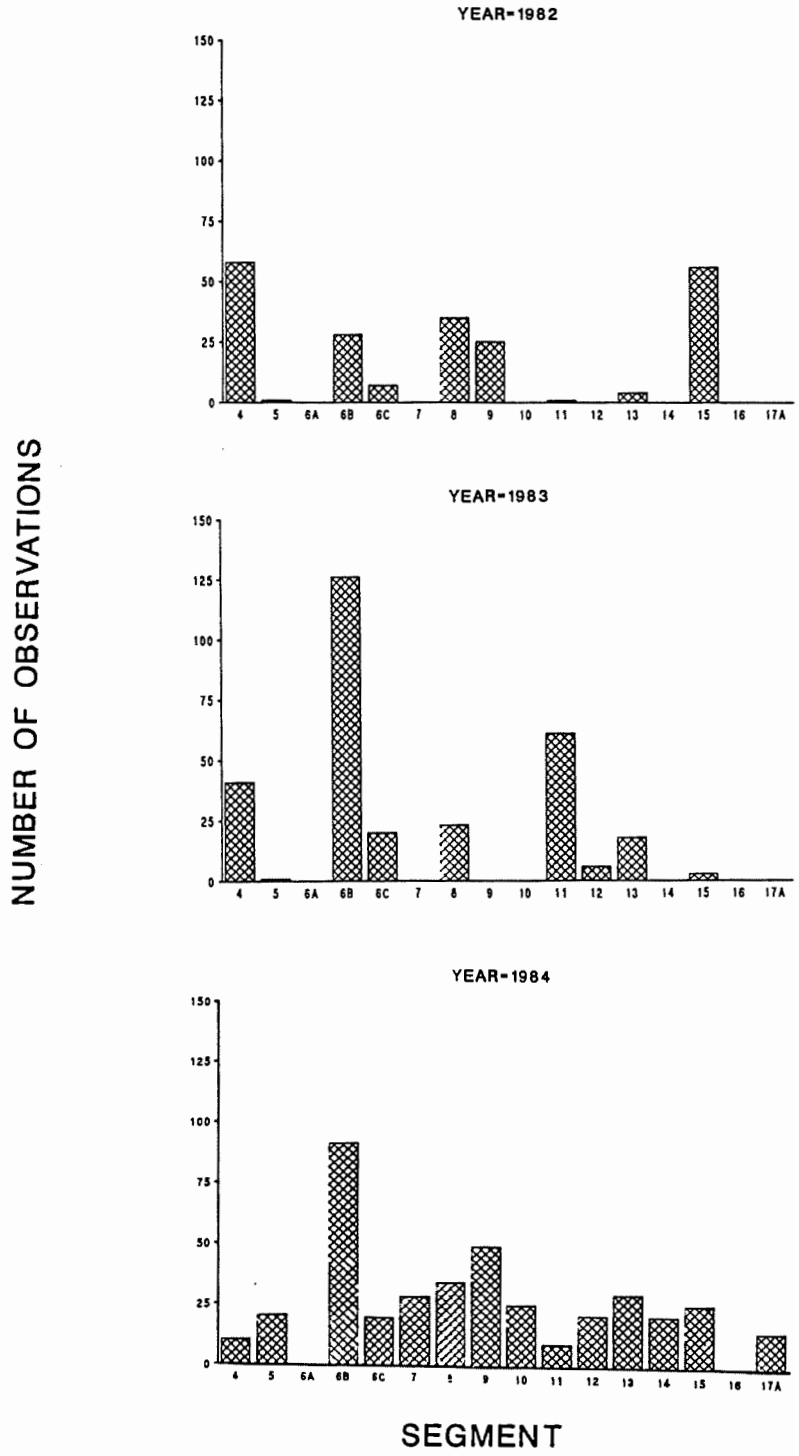

FIGURE E-5. NUMBER OF DATA SET OBSERVATIONS FOR TOTAL COLIFORM BACTERIA (MPN/100 ML) COLLECTED BY DEQE-LAKEVILLE FOR EACH SEGMENT FOR 1982, 1983, AND 1984.

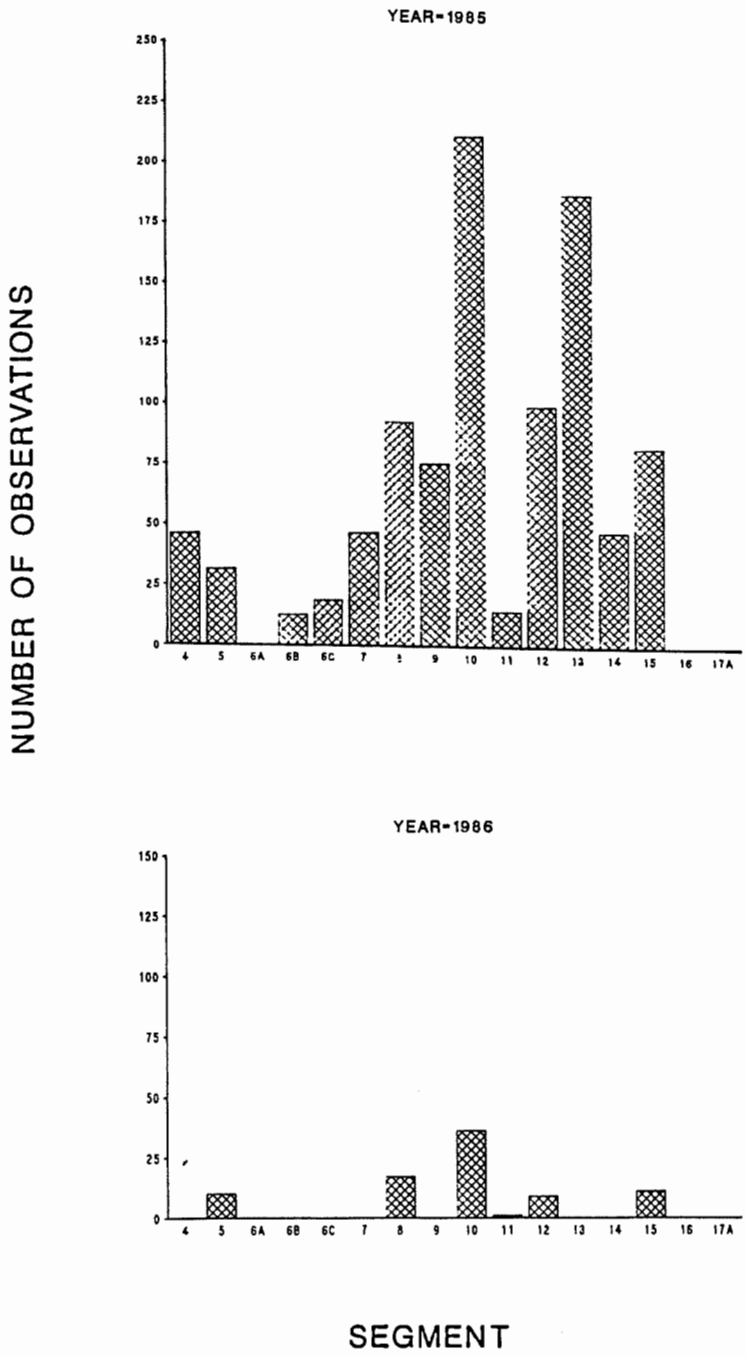

FIGURE E-6. NUMBER OF DATA SET OBSERVATIONS FOR TOTAL COLIFORM BACTERIA (MPN/100 ML) COLLECTED BY DEQE-LAKEVILLE FOR EACH SEGMENT FOR 1985 AND 1986.

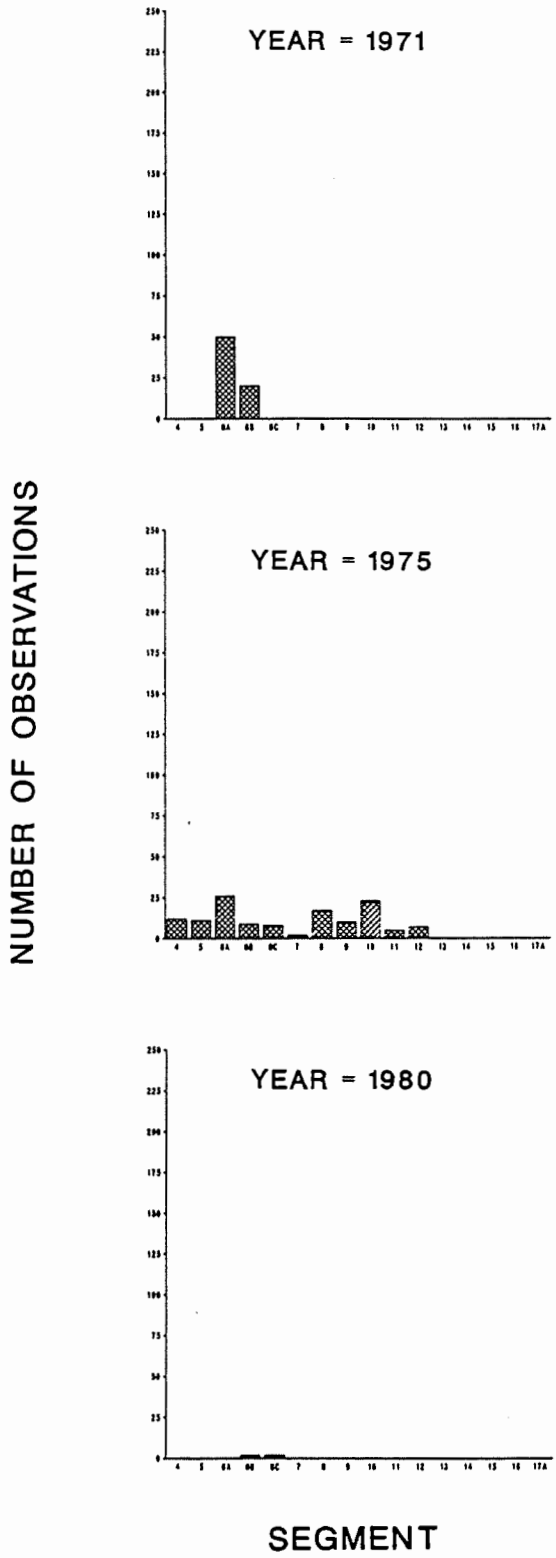

FIGURE E-7. NUMBER OF DATA SET OBSERVATIONS FOR TOTAL COLIFORM BACTERIA (MPN/100 ML) COLLECTED BY DEQE-DWPC FOR EACH SEGMENT FOR 1971, 1975, AND 1980.

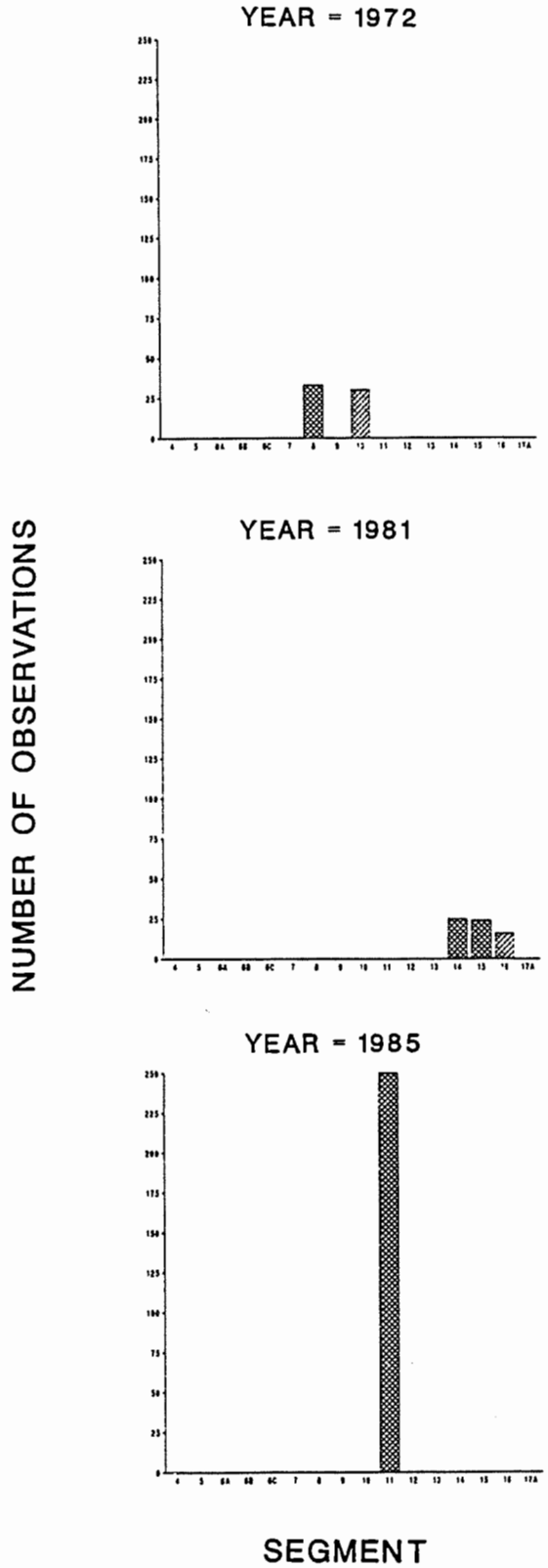

FIGURE E-8. NUMBER OF DATA SET OBSERVATIONS FOR TOTAL COLIFORM BACTERIA (MPN/100 ML) COLLECTED BY FDA FOR EACH SEGMENT FOR 1972, 1981, AND 1985.

APPENDIX F

TOTAL COLIFORM LEVELS FOR SELECTED STATIONS OVER TIME

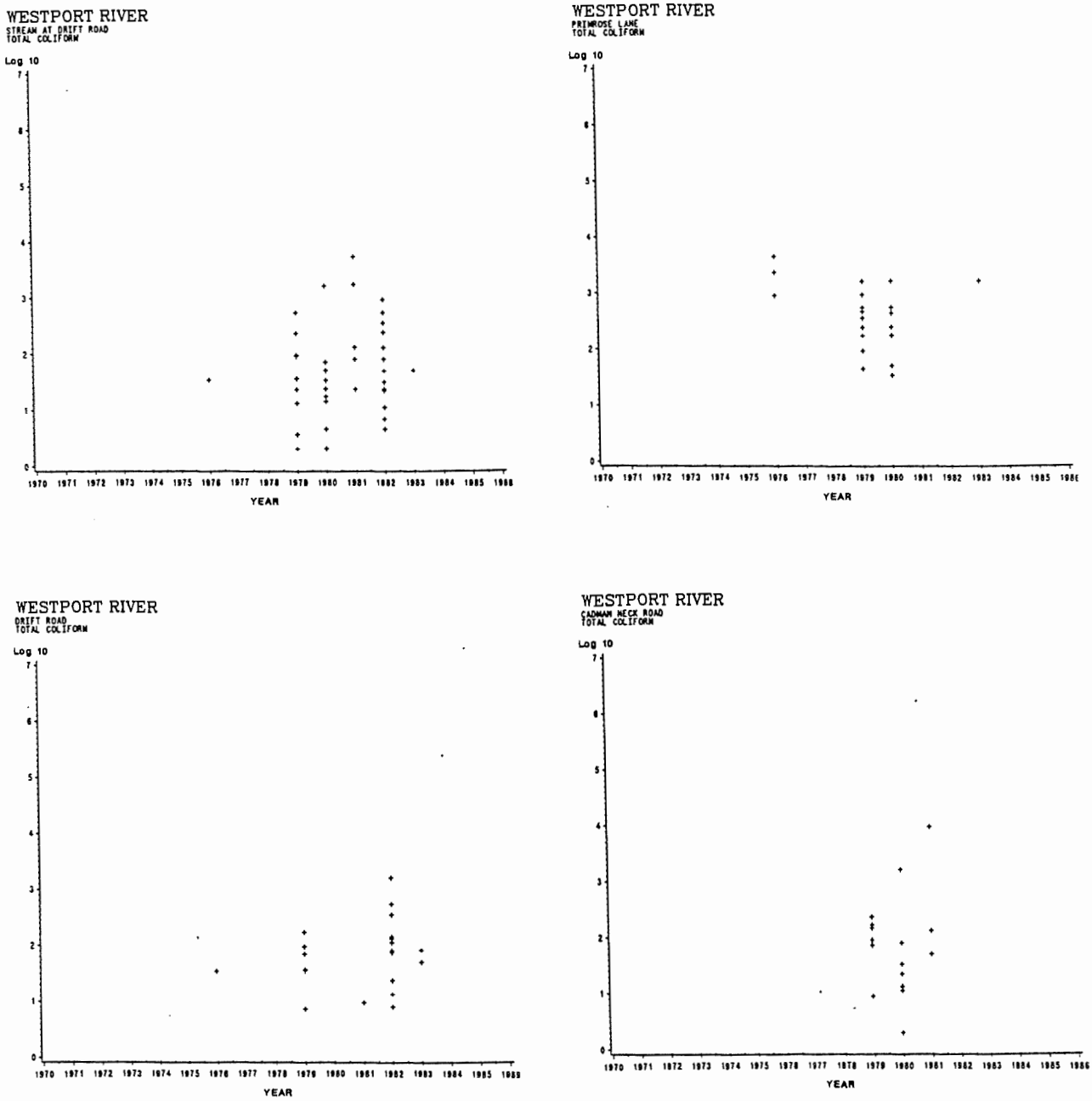

FIGURE F-1. INDIVIDUAL DATA POINTS FOR TOTAL COLIFORM LEVELS (LOG 10) AT STATIONS ALONG THE WESTPORT RIVER OVER TIME.

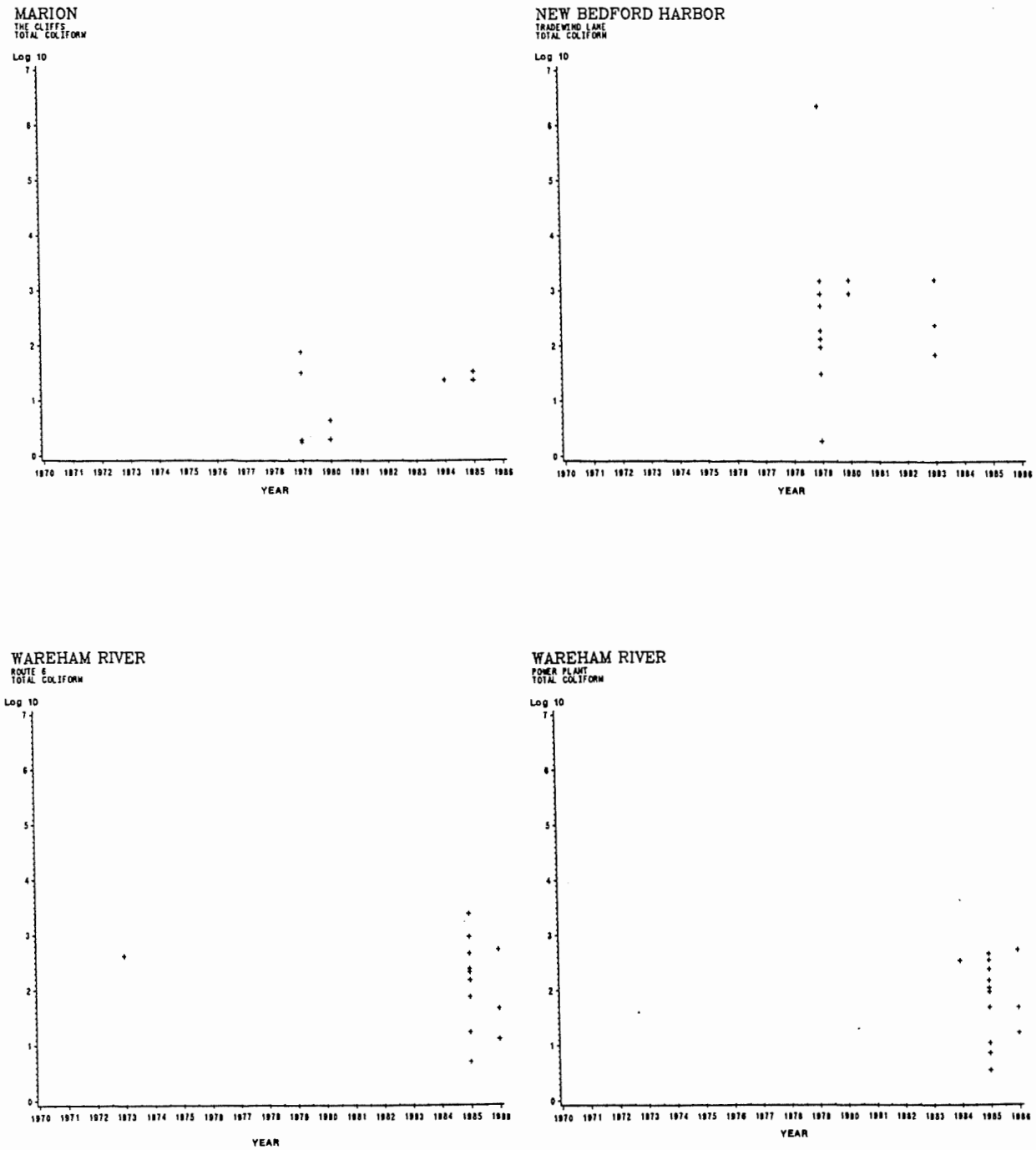

FIGURE F-2. INDIVIDUAL DATA POINTS FOR TOTAL COLIFORM LEVELS (LOG 10) AT STATIONS IN MARION, NEW BEDFORD HARBOR, AND THE WAREHAM RIVER OVER TIME.

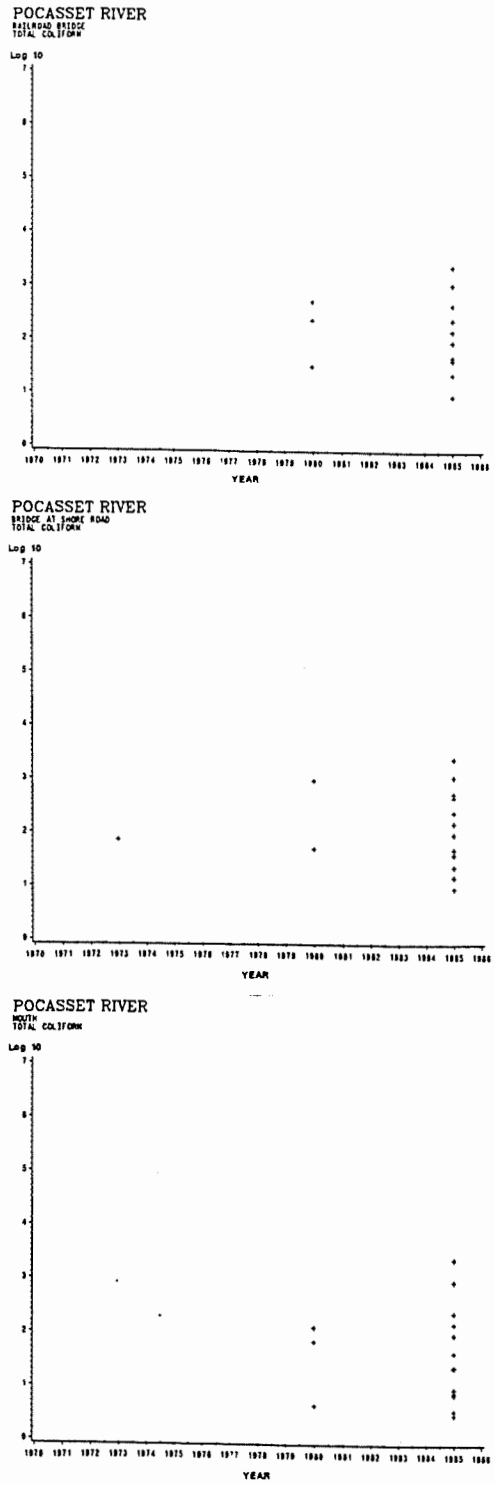

FIGURE F-3. INDIVIDUAL DATA POINTS FOR TOTAL COLIFORM LEVELS (LOG 10) AT STATIONS ALONG THE POCASSET RIVER OVER TIME.