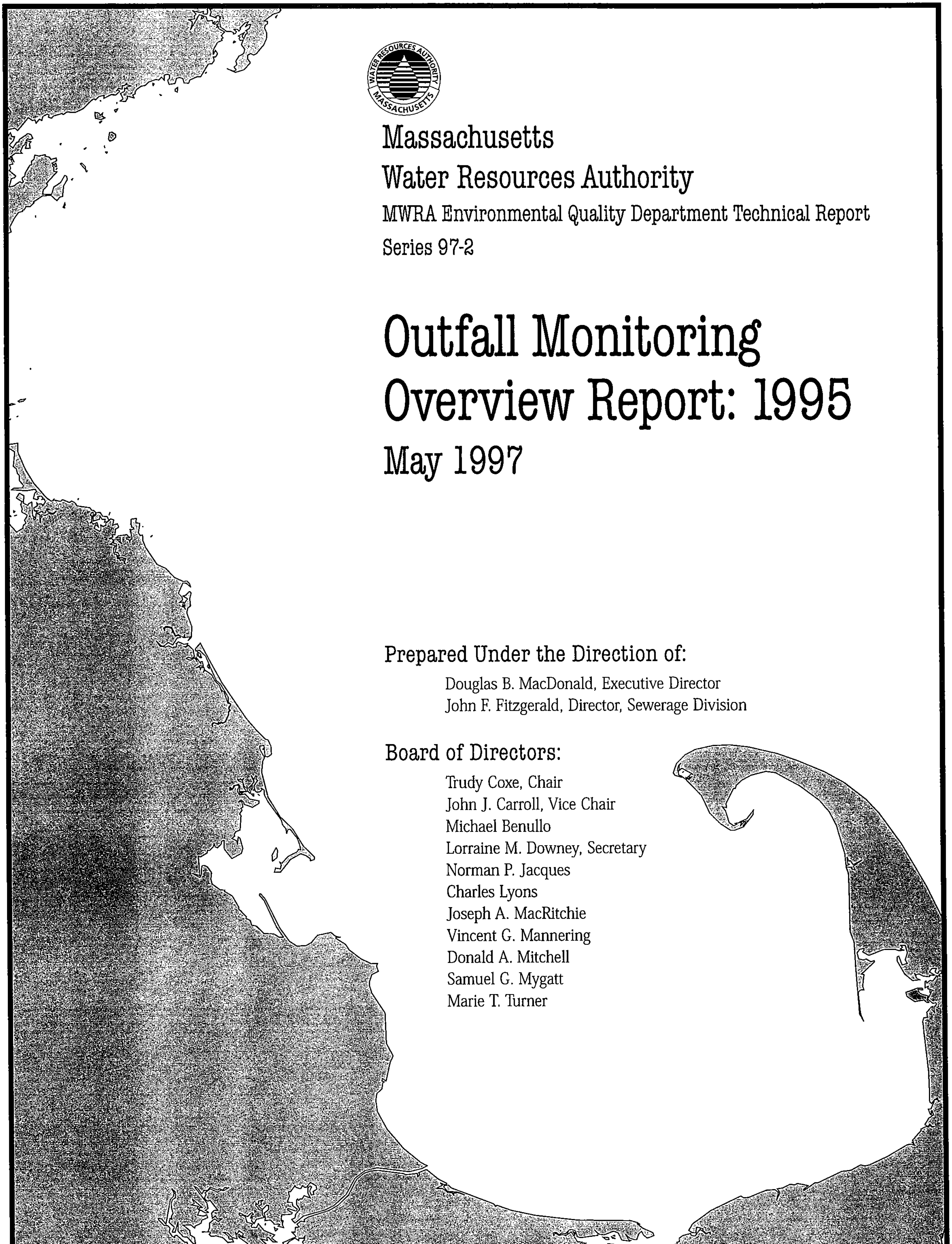

Massachusetts Water Resources Authority

MWRA Environmental Quality Department Technical Report

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Outfall Monitoring Overview Report: 1995

May 1997

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Executive Summary

The people of the metropolitan Boston area, through the MWRA, are in the midst of an ambitious program to upgrade their sewage treatment facilities and improve the quality of Boston Harbor. This program includes the elimination of sludge discharges to the harbor, construction of new primary and secondary sewage treatment plants, and relocation of the current Boston Harbor effluent discharge points to a new location in Massachusetts Bay. Sludge discharge ceased in 1991 and the new Deer Island primary treatment facility went on-line in January 1995. In 1997, the first part of secondary treatment and in 1998 the new effluent discharge outfall to Massachusetts Bay are expected to be operational.

A number of concerns have been raised regarding potential environmental impacts associated with the relocation of the wastewater discharge to Massachusetts Bay. In order to assure that these concerns are addressed, MWRA developed a Contingency Plan and an outfall monitoring program, and documented these in a series of reports. The Contingency Plan (MWRA 1997) develops expectations for environmental quality in Massachusetts Bay and Cape Cod Bay. The expectations are expressed as Caution and Warning Levels that would trigger action if they are exceeded. Those trigger levels are compared to environmental monitoring results in this report, the annual Outfall Monitoring Overview, which will also describe any actions taken in response to an exceedance of a Caution or Warning Level when the outfall is operational. The monitoring results are obtained following the procedures detailed in a report called the Outfall Monitoring Plan (MWRA 1991, 1995).

The outfall monitoring program consists of two main phases. Baseline studies which commenced in 1992 are currently underway to document conditions before outfall relocation. Post-discharge monitoring will commence in 1998; these studies will evaluate conditions after the new outfall is operational. This report describes the baseline monitoring program, summarizes and discusses the program results, and summarizes post-discharge monitoring Caution and Warning Levels.

Both phases of monitoring evaluate six categories of wastewater constituents: nutrients, organic material, toxic contaminants, pathogens, solids, and floatables. These six parameters were evaluated as they apply to four different environmental measurement areas: effluent, water column, benthic environment, and fish and shellfish.

- The MWRA's Baseline Outfall Monitoring Program has gathered considerable information documenting the existing conditions in Boston Harbor, Massachusetts Bay, and Cape Cod Bay. Scientific data collected during the last few years reflect current levels of sewage treatment. As improvements are made to the MWRA sewage treatment process, the extensive economic, aesthetic, and ecological resources of this unique marine system are expected to benefit.

- Wastewater effluent from the treatment plant is routinely evaluated to ensure that discharged effluent meets required standards. Also, the future effectiveness of the secondary treatment plant is being determined through operation of a pilot treatment plant and analysis of pilot plant effluent.

Wastewater Effluent Monitoring

Trigger parameters, thresholds, and 1995 monitoring results for the effluent monitoring program are summarized on Table ES-1.

The baseline effluent program monitors for nutrients, organic material, toxic contaminants, pathogens, solids, and oil and grease. Effluent monitoring has demonstrated that improvements made to the MWRA system during the last few years have generally resulted in improvements in wastewater effluent quality. Pilot treatment plant results indicate that secondary treatment will significantly reduce the effluent levels of organic material, suspended solids, and many toxic parameters. As secondary treatment is implemented and toxic source control measures continue, effluent quality will continue to improve and will result in compliance with federal secondary treatment standards and Massachusetts water quality standards.

TABLE ES-1
Effluent Thresholds Compared to 1995 Monitoring Results

Parameter	Caution Level	Warning Level	1995 Results
Total Nitrogen (nutrients)	Total nitrogen annual loading > 12,500 mtons/year	Total nitrogen annual loading > 14,000 mtons/year.	Not exceeded. Annual loading = 11,460 metric tons
cBOD (organic material)	None.	Weekly or monthly permit levels. Expected levels: 40 mg/L weekly, 30 mg/L monthly.	Always exceeded. Minimum value during year = 50 mg/L. Pilot secondary treatment monthly average = 11 mg/L
Toxics (toxic contaminants)	None.	Toxics concentrations above permit levels (yet to be determined).	Monthly average total PCB concentrations: 7-225 ng/L. (Mitchell et al. (1997) indicate that the range is 1-155ng/L.) None of the effluent concentrations exceed the most stringent WQC modified by their respective dilution factors. Pilot treatment plant concentrations were even lower.
Toxicity (toxic contaminants)	None.	Acute: effluent LC50 for shrimp <50% effluent. Chronic: effluent NOEC for fish growth and sea urchin fertilization <1.5% effluent.	Acute: 7 of 12 tests violated shrimp 20% NOEC limit. Chronic: no violations of minnow 10% NOEC limit; All tests failed red algae 10% NOEC limit.
Bacteria (pathogens)	None.	Daily or monthly permit levels. Expected levels: 400 fecal coliforms/100mL daily, and 200 fecal coliforms/100mL monthly.	7 daily exceedances. No monthly exceedances.
Suspended Solids	None.	Weekly or monthly permit levels. Expected levels: 45 mg/L weekly, 30 mg/L monthly.	Exceeded frequently. Daily range: 23-201 mg/L. Pilot secondary treatment monthly average = 12 mg/L.
Floatables	None.	Floatables less than 5 gal/day.	Not measured until secondary treatment plant is on line.
Oil and Grease (floatables)	None.	Oil and grease permit requirements. Expected level: 15 mg/L weekly.	No exceedances.
Plant Performance	More than 5 violations of permit requirements per year.	Operating in violation of the permit requirements more than 5% of the time over a year.	20 violations. Most from parameters that will be improved by secondary treatment.

The reader is directed to the glossary and acronym summary at the end of the report.

Water Column Monitoring Program

Trigger parameters, thresholds, and 1995 monitoring results for the water column program are summarized on Table ES-2.

A number of different parameters are evaluated in the baseline water column monitoring program. Studies are underway to gather baseline information on nutrient levels, temperature, salinity, algae, and dissolved oxygen in the marine system. As with other water bodies, the Massachusetts and Cape Cod Bays system follows an expected regular seasonal pattern but with considerable spatial and temporal variability of complicated interrelated processes. Starting with the cold well-mixed nutrient-rich waters of winter, the brightening sun of spring provides the light needed for algae (phytoplankton) to grow. Their abundant growth forms a spring algae bloom which begins to deplete the nutrients, especially nitrogen. Spring also brings stratification of the water column due to increased sunshine and freshwater runoff that result in warmer and slightly fresher surface waters. The spring bloom ends as algae deplete the nutrients in surface waters and are blocked from nutrient-rich bottom waters by stratification. During summer, the algal biomass is less overall with the highest biomass located at the boundary between surface and bottom waters (thermocline) where there is a balance between the algal requirement for both light and nutrients. This continues until the fall, when stratification begins to weaken, and storms are able to mix the water column, bringing nutrients to surface waters and resulting in a fall algal bloom.

Monitoring results showed that 1995 was similar to other years with some notable differences. The 1995 annual average phytoplankton density was the lowest yet observed. The spring bloom was normal in magnitude but was followed by intense zooplankton grazing that cleared the water of algae. In the summer, algae were very sparse, although two partial-mixing events occurred that briefly stimulated intense algal growth. Such partial-mixing events are not unique to 1995 but MWRA's methods for observing them have improved. The fall bloom was large, exceeded only by that in 1993. The dissolved oxygen in bottom waters in 1995 declined over the summer and was approaching the low values measured in 1994, but earlier fall mixing resulted in ventilation of bottom waters earlier than in 1994. The minimum dissolved oxygen concentration in 1995 was higher than in 1994, but lower than in 1992 and 1993. Dissolved oxygen concentrations were slightly above the water quality standard, but saturations were slightly below the standard. A total of 19 fin, minke, and unidentified whales were sighted during the summer near field surveys.

■ The Water Column monitoring program is designed to measure water quality in Massachusetts and Cape Cod Bays. Based on extensive predictive modeling studies, changes in water quality due to outfall relocation are expected to be minimal in Massachusetts and Cape Cod Bays. Detectable changes in water quality are expected to occur only in the immediate vicinity of the outfall. The water column monitoring program provides a basis for detecting changes in water quality and plankton resulting from the relocation of the effluent outfall. It also provides a basis for monitoring potential food chain effects on endangered species, such as humpback and right whales.

Benthic Studies

Trigger parameters, thresholds, and 1995 monitoring results for the benthic program are summarized on Table ES-3.

The ongoing baseline benthic monitoring program has provided valuable information on the current status of the benthic environment in the system. Studies are underway to evaluate benthic ecological communities and sediment quality. In the past few years, there has been an increase in Boston Harbor of the abundance of a pollution sensitive amphipod, likely related to sediment quality improvement. Increased amphipod colonization, in turn, appears to be increasing the rate of sediment quality improvement.

■ Benthic Studies are designed to evaluate the sea floor environment in Boston Harbor and Massachusetts and Cape Cod Bays. These studies are designed to assess potential impacts to the Massachusetts and Cape Cod Bays sea floor resulting from relocation of the outfall. Benthic studies also provide a means to document recovery of Boston Harbor following improvements to the MWRA system.

TABLE ES-2
Water Column Thresholds Compared to 1995 Monitoring Results

Parameter	Caution Level	Warning Level	1995 Results
Dissolved oxygen concentration in Nearfield region bottom waters	Monthly mean DO is less than 6.5 ppm or 80% of saturation levels for any one month during stratification (June-Oct.)	Monthly mean DO is less than 6 ppm or 75% of saturation levels for any one month during stratification (June-Oct.)	DO saturation below warning level in September (74.3%). (See Table 3-2)
Dissolved oxygen concentration in Stellwagen Basin bottom waters	Monthly mean DO is less than 6.5 ppm or 80% of saturation levels for any one month during stratification (June-Oct.)	Monthly mean DO is less than 6 ppm or 75% of saturation levels for any one month during stratification (June-Oct.)	DO saturation below warning level in October (71.0%). (See Table 3-2)
Dissolved oxygen depletion rate in Nearfield region bottom waters	DO depletion rate is greater than 1.5 times the baseline rate for any one month during stratification (June-Oct.), -0.041 mg/L/day.	DO depletion rate is greater than 2 times the baseline rate for any one month during stratification (June-Oct.), -0.054 mg/L/day.	1992-95 Average Baseline Rate: -0.027 mg/L/day 1995 Rate: -0.027 mg/L/day
Chlorophyll in Nearfield region	Annual mean concentration greater than 1.5 times the baseline annual mean, 2.93 µg/L.	Annual mean concentration greater than 2 times the baseline annual mean, 3.90 µg/L.	1992-95 Baseline: 1.95 µg/L 1995: 1.39 µg/L
Chlorophyll in Nearfield region	Season mean concentration exceeds 95th percentile of the baseline seasonal distribution. Spring: 2.38 µg/L Summer: 2.37 µg/L Fall: 4.56 µg/L	None.	Spring: 1.02 mµg/L Summer: 0.73 µg/L Fall: 2.58 µg/L
Nuisance algae in Nearfield region	*Alexandrium tamarense* Season mean population densities exceed 95th percentile of the baseline seasonal mean. Spring: 4.56 cells/L Summer: 1100 cells/L Fall: 8.67 cells/L	None.	*Alexandrium tamarense* Spring: 0 cells/L Summer: 0 cells/L Fall: 0 cells/L (See Table 3-3)
PSP extent in Farfield region	New occurrence. PSP has never been observed at 3 of the 18 monitoring stations (see Table 3-4).	None.	No occurrences.
Zooplankton assemblage in Nearfield region	Nearfield assemblage shifts from a transitional community towards an inshore community. Inshore: *Acartia, Eurytemora, Centropages hamatus* Offshore: *Calanus, Pseudcalanus, Centropages typicus, Oithona* Nearfield: *Transitional between two regions.*	None.	Transitional assemblage in nearfield region.
Initial effluent dilution at new outfall location	None.	Effluent dilution less than that set in the NPDES permit.	No data until outfall is online.

TABLE ES-3
Benthic Thresholds Compared to 1995 Monitoring Results

Parameter	Caution Level	Warning Level	1995 Results
Community Structure (Diversity, Species Composition, and Species Abundance) in outfall midfield area	Species diversity, composition, and relative abundance patterns measured in the midfield appreciably depart from those measured during the baseline monitoring period, after factoring out the effect of storms on sediment texture. Specific diversity threshold values are being developed.	None.	Shannon-Wiener Diversity Index Midfield mean = 2.71 (Range 2.18 - 3.13) (See also Table 4-2)
Depth of Oxygenated Sediments [Redox Potential Discontinuity (RPD) Depth] in outfall nearfield area.	RPD depth declines by half. The threshold value is under development.	None.	Nearfield mean = 3.5 cm (Range 1.8 - >6.2 cm)
Toxic Contaminant Concentrations in outfall nearfield area.	Nearfield mean toxic contaminant concentrations greater than 90% of EPA sediment criteria.	Nearfield mean toxic contaminant concentrations greater than EPA sediment criteria or the NOAA Effects Range Median (ER-M) value. Examples: NOAA ER-M values: PCBs = 180 ng/g Mercury = 0.71 µg/g	Example Results: PCBs: Geometric Mean = 4 ng/g Range = 1.1 - 53 ng/g Mercury: Geometric mean = 0.16 µg/g (See also Table 4-3)

In Massachusetts Bay near the site of the future outfall, in an area called the nearfield, the benthic sedimentary environment, or habitat, is highly diverse, with large variability in sediment type over relatively short distances. The benthic biological communities also vary spatially, reflecting a strong influence of sediment type on the benthic community characteristics. In addition, the benthic environment in the nearfield is highly changeable, with dramatic shifts in both sediment type and benthic organisms occurring after storm events. The dominant benthic species in 1995 was also abundant in 1987, but not in 1992 through 1994. Benthic organism densities in Massachusetts Bay are moderately high and the community structure does not reflect stressed conditions. The numbers of species in the benthic community are similar in the nearfield and farfield, but the types of species are different. Sediment metal and organic concentrations in 1995 were similar to previous values and, except for elevated mercury consistently found at one very muddy station, were generally below environmental criteria.

■ The Fish and Shellfish monitoring program focuses on key natural resources in the marine environment. This program evaluates potential risks to human health and the environment from contamination in fish and shellfish. Fish and shellfish studies provide a basis for evaluating recovery of natural systems following MWRA upgrades.

Fish and Shellfish Monitoring Program

Trigger parameters, thresholds, and 1995 monitoring results for fish and shellfish are summarized on Table ES-4.

The baseline fish and shellfish monitoring program focuses on flounder, lobster, and mussels. In 1995, as in previous years, the contaminant concentrations in fish and shellfish at all sites have consistently been well below levels that might cause any concern because of human consumption. Nevertheless, the pattern of contamination provides evidence of the

TABLE ES-4
Fish and Shellfish Thresholds Compared to 1995 Monitoring Results

Parameter	Caution Level	Warning Level	1995 Results
Mercury in fish and shellfish from Outfall site	Annual mean mercury concentration in flounder, lobster, and caged mussel meat greater than 0.5 µg/g wet weight (50% of the US FDA action level).	Annual mean mercury concentration in flounder, lobster, and caged mussel tissue is greater than 0.8 µg/g wet weight (80% of the US FDA action level).	Flounder - 0.06 µg/g Lobster - 0.13 µg/g Mussel - NA[1]
PCBs in fish and shellfish from Outfall site	Annual mean PCB concentration in flounder, lobster, and caged mussel meat greater than 1 µg/g wet weight (50% of the US FDA action level).	Annual mean PCB concentration in flounder, lobster, and caged mussel tissue is greater than 1.6 µg/g wet weight (80% of the US FDA action level).	Flounder - 0.041 µg/g Lobster - 0.015 µg/g Mussel - NA[1]
Lead in mussels at Outfall site	Annual mean lead concentration in caged mussel meat greater than 2 µg/g wet weight.	Annual mean lead concentration in caged mussel tissue is greater than 3 µg/g wet weight.	Mussel - NA[1]
Lipid-normalized toxics in fish and shellfish from Outfall site	Lipid-normalized toxic concentrations in flounder, lobster and caged mussel meat greater than two times the baseline concentrations.	None.	Concentrations in µg toxic per gm lipid Lobster PCBs: 2.9 Lobster DDT: 0.4 Flounder PCBs: 11.1 Flounder DDT: 1.1
Liver disease incidence in fish from Outfall site	Flounder liver disease (CHV) incidence greater than in Boston Harbor. The 1991-95 average is 48%.	None.	Flounder CHV prevalence: 14%

[1] Outfall site mussel cage arrays were lost in 1995.

degree of exposure to the fish. In general, contaminant concentrations in flounder meat decline progressively from Boston Harbor to the future outfall site to Cape Cod Bay. However, the highest 1995 concentrations of several metals in flounder liver were present in flounder from the future outfall site. The 1995 data indicated significantly increased concentrations of DDT and PCBs in flounder liver over values from previous years. Liver lesions have been present in flounder from all sites, and the decline started in 1992 continues in the 1995 results.

Contaminant concentrations in lobster meat generally followed the same spatial pattern as contaminants in flounder meat. In lobster hepatopancreas, the highest organic contaminant concentrations in 1995 were present at the future outfall site. Metal concentrations in lobster hepatopancreas were lower in Cape Cod Bay than other sampling sites. Hepatopancreas metal concentrations were similar at the other sites, except for mercury which was highest at the future outfall site. All levels are below those of concern, and are expected to improve as secondary treatment leads to improved effluent and water quality in Boston Harbor and the Bays.

1.0 INTRODUCTION

1.1 Report Objectives and Content

The Outfall Monitoring Program is an important component of the Massachusetts Water Resources Authority's (MWRA's) overall program to improve the quality of Boston Harbor. The Outfall Monitoring Program provides the means to identify, measure and respond to any impacts associated with the relocated outfall. The Contingency Plan (MWRA, 1997) outlines the MWRA's response program in case any unexpected impacts occur. The Outfall Monitoring Overview Report is intended to serve as an annual companion document to the Contingency Plan.

The objective of the Outfall Monitoring Overview Report is to describe the monitoring program results on an annual basis and compare those results to established environmental benchmarks or threshold levels for trigger parameters (described below). If monitoring data indicate that changes to thresholds or trigger parameters are necessary, the report recommends appropriate modifications. In addition, the report will summarize any actions taken pursuant to the Contingency Plan during the year.

This report presents monitoring program results and threshold comparisons for field data collected through 1995. Since data collection started in 1992 and the future outfall is not yet operational, the data in this report represent the fourth year of the baseline collection period. As such, comparisons of data to thresholds are used to test the validity of the threshold values. Also, the report provides interim threshold values for those parameters for which thresholds will be determined from a full set of baseline data. Finally, since the outfall is not operational, actions pursuant to the Contingency Plan are not addressed in this 1995 report, but will be in future reports.

This report is organized into the following sections: (1) this introduction that discusses the overall background and components of the monitoring program; (2) four sections that discuss the issues, design, comparison to thresholds, and recent results for each area of the monitoring program: Effluent, Water Column, Benthic Studies, and Fish and Shellfish; and (3) a glossary and summary of acronyms.

■ A number of related reports have been produced by MWRA. The Effluent Outfall Monitoring Plan, Phase I: Baseline Studies (November 1991) and Phase II: Post Discharge Monitoring (draft November 1995) describe the goals, strategy, and design of the Outfall Monitoring Program in detail. The Contingency Plan (February 1997) provides a detailed discussion of the development of trigger parameter values and MWRA's planned contingency measures. The State of Boston Harbor reports focus on the Boston Harbor system, rather than on Massachusetts and Cape Cod Bays.

1.2 Background

In 1986 the MWRA initiated a program to end longstanding violations of the Clean Water Act associated with the discharge of sewage sludge and effluent in Boston Harbor. This program includes the relocation of the treated effluent discharge point to a location in Massachusetts Bays (Figure 1-1) approximately 9.5 miles from the present Deer Island outfall. Discharge of effluent through the new outfall is expected to begin in 1998.

The U.S. Environmental Protection Agency (EPA) and the National Marine Fisheries Service (NMFS) assessed the potential impacts associated with the discharge of MWRA's wastewater effluent into Massachusetts Bay. Both the EPA and NMFS determined that there would not be significant water quality or biological impacts associated with the project. This conclusion was documented in the EPA's Supplemental Environmental Impact Statement (SEIS) and Biological Assessment and the NMFS's Biological Opinion.

■ The material presented in this report represents data collected through the 1995 field season, and therefore reflects the current and recent levels of sewage treatment. These data are synthesized in a series of technical reports prepared at least annually for every project area. Synthesis reports for 1996 data are currently in development and are expected to add to the understanding of the Harbor and Bay system. A current listing of the technical reports can be found on the internet at http://www.mwra.com.

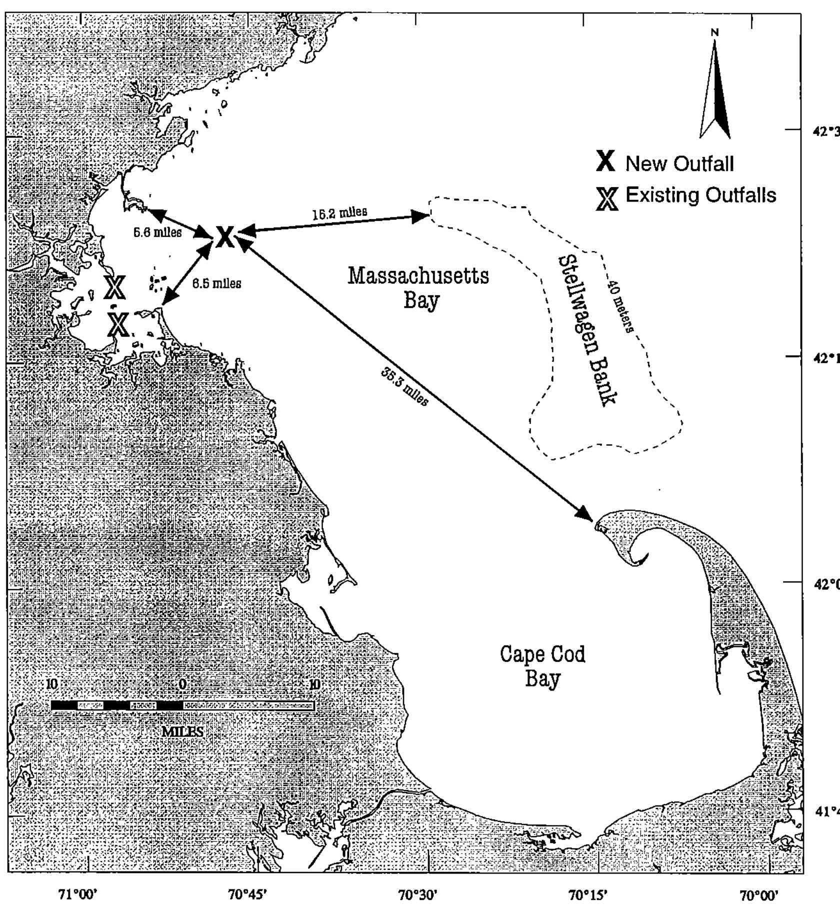
Even though minimal impacts were predicted from the relocated, cleaner discharge, concerns remained with respect to the potential environmental effects associated with the relocation of the wastewater discharge to Massachusetts Bay. General concerns identified with respect to the relocated discharge are potential aquatic life, human health, and aesthetic impacts in Massachusetts and Cape Cod Bays.

In order to assure that discharge from the new outfall does not result in adverse impacts to human health or the environment, the EPA and the Massachusetts Executive Office of Environmental Affairs (EOEA) required the development of an outfall monitoring program. The objective of the monitoring program was to establish baseline conditions of the Massachusetts and Cape Cod Bays ecosystem and measure any future impacts on the system due to outfall relocation. At the direction of the EOEA, an Outfall Monitoring Task Force (OMTF) was formed to provide MWRA with guidance and recommendations on the development of a monitoring plan. The OMTF is composed of academic scientists, as well as representatives from federal and state regulatory agencies and citizens' groups.

Numerous scientific studies performed as part of the outfall siting process in 1986 and 1987 were used as the basis by MWRA and the OMTF for the development of the initial Outfall Monitoring Plan in 1991. Baseline studies, dedicated to determining background conditions in the Bays, began in 1992 (except for flounder studies which began in 1991) and will continue until the new outfall becomes operational in 1998. Then, similar post-discharge studies, dedicated to determining the effects of the discharge, will begin.

The OMTF and MWRA review the monitoring results on an ongoing basis and work to

FIGURE 1-1
Distances of the new outfall from selected sensitive areas in Massachusetts and Cape Cod Bays. The existing outfalls are near Deer Island and the more southerly Nut Island. The new outfall is 9.5 miles from Deer Island.



implement cost-effective modifications that better address public and technical concerns. In May 1996, a technical workshop with MWRA scientists, OMTF members, and nationally recognized scientists was held to evaluate the outfall monitoring program. The workshop included a review of monitoring methods and results, trigger parameters and threshold values, and an evaluation of changes that would improve the effectiveness of the program.

1.3 Trigger Parameters and Thresholds

The Outfall Monitoring Program provides the basis for evaluating potential impacts associated with the relocated outfall and the need for action under the Contingency Plan. MWRA evaluates monitoring program results based on specific measurement indicators of changes from benchmark environmental conditions. These measurement indicators were designated as trigger parameters in the Contingency Plan. A summary of the current trigger parameters is presented in Table 1-1. Each trigger parameter has a quantitative, or in some cases a qualitative, threshold that indicates the potential for impacts. Once discharge begins, the exceedance of trigger parameter threshold values will automatically trigger MWRA action.

- MWRA uses two levels of threshold values to evaluate the need for action under the Contingency Plan:
  - Caution Level exceedances indicate the need for increased study or attention.
  - Warning Level exceedances indicate the need for action to avoid potential environmental impact, triggering the development and implementation of a response plan.

There are two types of thresholds under development that will be used to alert MWRA to different degrees of potential environmental risk. Caution Level exceedances would indicate the need for more intensive study or increased attention. Warning Level exceedances would indicate the need for a response to avoid a potential environmental impact. The trigger parameters and thresholds for each of the measurement areas are discussed in detail in the corresponding report section below.

The definition of a threshold exceedance depends on the trigger parameter. It is desirable for most of the measured parameters (e.g. contaminant concentrations, treatment plant violations, algae and liver disease) to remain *below* the threshold. Other parameters (e.g. dissolved oxygen level, dilution, dissolved oxygen penetration into sediments, percent effluent with specified toxicity level, and diversity) should remain *above* the threshold.

MWRA has used the following sources to establish threshold values for the trigger parameters:

- Limits expected in the forthcoming EPA/MADEP NPDES permit
- State water quality standards
- Predictions made about the impacts of the discharge during the preparation of the EPA's SEIS
- Expert guidance and opinion

Expert guidance has helped MWRA refine the definition of the threshold values. The technical workshops held in May 1996 made the recommendation that MWRA should revise the proposed Caution and Warning Levels. Specifically, it was recommended that MWRA focus on a reduced set of critical trigger parameters, define the trigger parameters more precisely, allow for seasonality

TABLE 1-1
Summary of Trigger Parameters

Monitoring Area	Trigger Parameter
Effluent	Total Suspended Solids
	Biochemical Oxygen Demand
	Pathogenic Indicator Bacteria
	Nitrogen Loading
	Toxic Metals and Organic Chemicals
	Toxicity Testing
	Floatables
	Oil and Grease
	Plant Compliance with Permit Limits
Water Column	Dissolved Oxygen Concentration
	Dissolved Oxygen Respiration Rate
	Chlorophyll
	Nuisance and Noxious Algae
	Zooplankton
	Diffuser Mixing
Benthos	Benthic Community Structure
	Sediment Oxygen
	Sediment Toxic Metal and Organic Chemicals
Fish and Shellfish	Mercury and PCBs in Flounder, Lobster, and Mussels
	Lead in Mussels
	Lipophilic Toxic Contaminants
	Liver Disease in Flounder

■ Environmental data generally demonstrate considerable variability in both space and time due to the inherent behavior of natural systems. In order to accurately measure the characteristics and variability of natural systems, environmental monitoring programs are typically designed to collect large amounts of data. Designs of sampling programs, such as the MWRA Outfall Monitoring Program, consider the appropriate spatial and temporal scales by including a sufficient number of monitoring stations to allow a description of spatial data variability, as well as a sufficient number of sampling times or events to describe the temporal variability.

of the natural baseline in the definition of thresholds, and choose threshold levels which are more protective of the environment. In addition, in the case where the NPDES permit limits serve to define the Warning Levels, MWRA decided that it would not be useful to try to define a corresponding Caution Level. This report, the 1995 Outfall Monitoring Overview Report, reflects the changes resulting from those recommendations and decisions.

Several of the trigger parameters are expressed as change relative to baseline values. Because the baseline period is ongoing, interim thresholds are calculated as an exercise in this report based on the existing four years of monitoring data. The thresholds will be updated each year until just before the outfall begins discharging, when the final threshold values will be calculated.

1.4 Monitoring Program Summary

The Outfall Monitoring Program was developed and has evolved with continuous attention to a number of specific goals and objectives. The Outfall Monitoring Program is intended to:

- Develop baseline data from which future changes can be evaluated
- Test whether the impact of the discharge is within the bounds predicted in the SEIS;
- Evaluate compliance with threshold values for trigger parameters (as defined below); and
- Measure and evaluate potential impacts to Massachusetts and Cape Cod Bays associated with outfall relocation.

The monitoring program has focused on the following six wastewater constituents for determining the environmental impact of coastal discharges of treated sewage, as recommended by the National Research Council:

- Nutrients
- Organic Material
- Toxic Contaminants
- Pathogens
- Suspended solids
- Floatables

The Outfall Monitoring Program was designed to obtain data that would allow an assessment of the water quality and ecological impacts of these constituents. Twenty key measurement parameters were defined within the context of four different environmental monitoring areas: effluent, water column, benthic environment, and fish and shellfish. A summary of the monitoring program is presented in Table 1-2.

TABLE 1-2

Summary of MWRA Monitoring Program

Task	Objective	Sampling Locations and Schedule	Analyses
EFFLUENT MONITORING			
Effluent Sampling	Characterize wastewater discharged from Deer Island Treatment Plant and pilot secondary treatment plant	• Monthly • Daily • Monthly • 3 Times/Day • Daily • Weekly • Weekly	• Nutrients • Organic material (cBOD) • Toxic contaminants • Pathogens • Solids • Oil & Grease • Floatables (starting in 1998)
WATER COLUMN MONITORING			
Nearfield Surveys	Collect water quality data near future outfall location	• 17 surveys/year • 21 locations (See Figure 3-1)	• Temperature • Salinity • Dissolved oxygen • Plankton • Marine mammal/ sea turtle observations • Nutrients • Solids • Chlorophyll • Water clarity • Photosynthesis • Respiration
Farfield Surveys	Collect water quality data throughout Massachusetts and Cape Cod Bays	• 6 surveys/year • 26 locations (See Figure 3-1)	Same as Nearfield Surveys except no mammal/turtle observations
Plume Track Surveys	Track location and characteristics of discharge plume	• 3-4 surveys/year beginning in 1999 (An exploratory survey was performed in 1995).	• Salinity • Temperature • Dissolved oxygen • Chlorophyll • Solids
Mooring	Provides continuous oceanographic data near outfall	• Continuous monitoring • Single station • 3 depths	• Temperature • Salinity • Water clarity • Chlorophyll
Remote Sensing	Evaluate outfall impacts on a regional scale through satellite imagery	• Available daily (cloud cover permitting)	• Surface Temperature • Chlorophyll (not available in 1995)
BENTHIC MONITORING			
Nutrient Flux Surveys	Evaluate nutrient interactions between the sediment and water column	• 5 surveys/year • 8 locations (See Figure 4-1)	• Oxygen demand • Nutrient flux • Porewater nutrients
Soft Bottom Surveys	Evaluate sediment quality in Boston Harbor and Massachusetts Bay	• 60 Boston Harbor stations (See Figure 4-2) • 20 nearfield stations (See Figure 4-3) • 11 farfield stations (See Figure 4-4)	• Sediment chemistry • Benthic community composition • Sediment profile imaging
Hard Bottom Surveys	Characterize marine communities in rock and cobble areas	• 1 survey/year • 6 transects (See Figure 4-5)	• Topography • Substrate • Benthic community composition
FISH AND SHELLFISH MONITORING			
Flounder Studies	Determine contaminant body burden and population health	• 1 survey/year • 5 locations (See Figure 5-1)	• Tissue contaminant concentrations • Physical abnormalities (including histopathology)
Lobster Studies	Determine contaminant body burden	• 1 survey/year • 3 locations (See Figure 5-1)	• Tissue contaminant concentrations • Physical abnormalities
Mussel Studies	Evaluate biological condition and short-term contaminant bioaccumulation	• 1 survey/year • 3 locations (See Figure 5-1)	• Tissue contaminant concentrations • Physical abnormalities

■ For the goals of the program to be met, all of the data must be of known, high quality. Data quality is maintained through the program-wide use of rigorous Quality Assurance/Quality Control procedures. Data from field surveys and laboratory analyses are exhaustively checked and validated to ensure that field equipment was working properly during surveys and that the analyses met the program's Quality Control objectives. Only validated data are loaded onto the centralized database.

The monitoring program is designed to provide data with sufficient temporal and spatial detail to characterize the variability of the Massachusetts and Cape Cod Bays system. Each of the different program areas has different requirements in this regard and the monitoring program design reflects these differences. For example, the water column in Massachusetts and Cape Cod Bays experiences considerable temporal variability and spatial patchiness. The combination of frequent boat-based surveys, continuous monitoring at a mooring, and satellite imagery in the water column program are designed to resolve this variability and provide detailed characterization of the water column system. The benthic environment displays at least as much spatial patchiness as the water column but much less temporal variability. Correspondingly, benthic monitoring is much less frequent than water column monitoring but provides spatial coverage that is similar.

1.5 Data Management

Since the beginning of the Outfall Monitoring Program in 1992, more than 200 million pieces of data have been generated and compiled. As the program continues, the amount of compiled data will grow even larger. In order to meaningfully use this large mass of data, a coupled computerized database system and Geographical Information System (GIS) has been developed. The coupled database/GIS system allows MWRA to store, retrieve, analyze, and display data from the monitoring program. Arc/Info is used as the GIS platform. The database management system consists of an Oracle 7 server networked to PC workstations running MS Access. This system allows monitoring data to be entered, analyzed, and viewed simultaneously by several researchers working at their own computers. The database is the source of the multi-year data analyzed by researchers in the preparation of synthesis reports.

2.0 Effluent Monitoring Program

2.1 Effluent Issues

The National Research Council (1993) has recommended consideration of the following six wastewater constituents in determining the environmental impact of coastal discharges of treated sewage:

- Nutrients
- Organic Material
- Toxic Contaminants
- Pathogens
- Solids
- Floatables

The issues associated with each of these constituents are described below.

Nutrients

Nutrients are essential for the growth of algae and other aquatic plants. However, excessive concentrations of nutrients in the water can be detrimental, and may lead to low dissolved oxygen levels and eutrophication. For marine and coastal environments, such as the Massachusetts and Cape Cod Bays system, nitrogen is the most important nutrient and is the focus of effluent monitoring. However, measurements are made regularly of phosphorous and occasionally silica.

Organic Material

Organic material is a concern because as it decays it consumes dissolved oxygen (DO), which is critical to aquatic life. Low levels of DO may have serious effects on fish and other marine animals. The amount of DO consumed by decomposing organic material in effluent is the biochemical oxygen demand (BOD) which consists of the nitrogenous biochemical demand (nBOD) plus carbonaceous biochemical oxygen demand (cBOD). The standard measurement for BOD is the 5-day BOD test, or BOD5. The BOD5 mainly measures the carbonaceous BOD.

Toxic Contaminants

Toxic contaminants are substances that can cause diseases such as cancer through direct contact with or accumulation in living tissue. Toxic contaminants include trace metals (such as lead, mercury, chromium, and cadmium); volatile organic compounds (such as benzene, toluene, and chlorinated solvents); semi-volatile organic compounds (including polychlorinated biphenyls [PCBs], polyaromatic hydrocarbons [PAHs], and pesticides such as DDT); ammonia; and chlorine. To evaluate levels of trace metals and organic contaminants in the effluent, the MWRA collects and analyzes samples from the effluent from MWRA's treatment plant. In addition, bioassay tests, which measure the response of indicator species to treated effluent, are being used to evaluate toxicity to various life stages of marine organisms such as shrimp, finfish, red macroalgae, and sea urchins.

- Bioassays measure the response of indicator species such as shrimp to toxics in the effluent under specified laboratory conditions. Bioassays designed to assess acute toxicity are expressed in measurement units known as "LC50s." An LC50 is the concentration at which 50% of a shrimp population survives. For example, an LC50 of 60 means that half of the shrimp survived a mixture that was 60% effluent and 40% dilution water. To assess chronic toxicity, the MWRA measures the effluent's "No Observed Effects Concentration (NOEC)." The NOEC is the highest concentration of effluent at which there is no statistical difference in test organism response when compared against a control with no effluent.

Pathogens

Human pathogens are bacteria, viruses, and protozoa from human and animal waste that cause disease in humans. Although human pathogens are not known to harm marine life, they may concentrate in filter feeding shellfish, such as mussels and clams. Human exposure to pathogens may occur primarily from the consumption of contaminated shellfish and from incidental ingestion of water while swimming. Fecal coliform bacteria are often used as an indicator of the presence of human pathogens and to evaluate the effectiveness of chlorine addition at the treatment plant. MWRA regularly measures the levels of fecal and total coliform bacteria. Any health effect of pathogens which escape chlorination and are discharged in marine waters would not extend far from the outfall due to dilution and natural death of the microorganisms.

Suspended Solids

Suspended solids are small particles of matter, such as mud, sand, or organic debris, suspended in the water column. Solids influence the behavior of toxic contaminants and other water quality parameters but the primary concern associated with solids is deposition and the resulting potential for smothering of the bottom habitat and benthic (bottom dwelling) organisms. Another issue of some concern is the aesthetic effect of loss of clarity of waters with high suspended solids levels.

Floatables

Floatables are pollutants that sit on the water surface, as opposed to being in the water column or on the bottom. Typical floatables are plastic tampon applicators, oil, and grease. Floatables are primarily an aesthetic problem, although some floatables, such as oil, can be harmful to marine life.

2.2 Monitoring Program Design

The primary objective of the effluent monitoring program is to characterize waters discharged from the Deer Island treatment plant. Concentrations and variability of chemical and biological constituents in the treatment plant effluent are measured. These data will allow comparison to NPDES permit limitations and evaluation of loadings and potential impacts on Massachusetts Bay.

Under the NPDES program the samples of the Deer Island treatment plant effluent were collected and analyzed as outlined below. Composite samples are taken over a 24-hour period usually at weekly intervals ("weekly composite"). Compositing provides the best estimate of the average concentration of contaminants provided that they do not degrade in the storage unit; those that would degrade have to be collected as a grab sample.

The following samples are collected under the NPDES program:

- ***Nutrients.*** A weekly composite sample is analyzed for total Kjeldahl nitrogen, ammonia, nitrate, nitrite, total phosphorus, and phosphate.
- ***Organic material.*** A daily composite sample is analyzed for 5-day Biochemical Oxygen Demand.
- ***Toxic contaminants.*** A weekly composite sample is analyzed for trace metals of concern: silver, cadmium, copper, chromium, mercury, lead, molybdenum, nickel, and zinc. The analyses incidentally yield data on arsenic, selenium, thallium,

boron, beryllium, iron, and antimony, but these are of little concern for this outfall. Three composite samples per month are analyzed for organic contaminants: petroleum hydrocarbons, pesticides, PAH, PCB, phenols, and phthalates. Volatile organic compounds (VOA) are analyzed in three grab samples per month. Three daily composite samples are used in the monthly bioassay toxicity tests.

- *Pathogens.* Three grab samples per day are analyzed for fecal and total coliform.
- *Suspended solids.* A daily composite sample is analyzed for total suspended solids.
- *Floatables.* A weekly grab sample is analyzed for oil and grease. Once a week the amount of floating material in the final skimmer will be visually estimated to estimate the efficiency of the upstream skimmers (observations will begin in 1998).

In addition to samples collected and analyzed under the NPDES program, other samples may be collected occasionally to provide more sensitive and detailed information about the effluent. Those measurements are called the detailed effluent characterization study (DECS). In 1995 the DECS measurements were made at Deer Island only; every month two samples were taken a few days apart.

- *Nutrients.* Twice-monthly grab samples were analyzed for nitrogen (ammonia, nitrate, nitrite, particulate organic nitrogen, total dissolved nitrogen, and urea), phosphorous (PO4, particulate organic phosphorous, total dissolved phosphorous), silicon (dissolved silicate, and biogenic silica), carbon (particulate organic carbon) and stable isotopes of nitrogen and sulfur.
- *Toxic contaminants.* Twice-monthly composite samples were analyzed for trace metals: silver, cadmium, copper, chromium, mercury, lead, molybdenum, nickel, and zinc. Organic contaminants are analyzed in twice-monthly composite samples: 17 persistent chlorinated pesticides, an extended list of PAHs, 20 PCB congeners, and C10 to C14 linear alkyl benzenes.
- *Sewage tracer.* Twice-monthly composite samples were analyzed for *Clostridium perfringens* spores.
- *Suspended solids.* Twice-monthly grab samples were analyzed for total suspended solids to normalize other measurements.

In conjunction with the relocation of the outfall, MWRA is upgrading the effluent treatment process. In order to assess the effects of the new treatment process on effluent quality before the new treatment facility is operational, MWRA is running a small scale pilot secondary treatment plant. The second objective of the effluent monitoring program is to evaluate the performance of the pilot secondary treatment plant under different operating conditions to explore ways to maximize the removal efficiencies. The effluents from the current treatment process and the pilot secondary treatment plant are being compared in order to assess the removal efficiency of the new process. Therefore, many of the parameters measured in the main effluent treatment plant are also monitored at the pilot secondary treatment plant.

2.3 Threshold Comparison

Thresholds for nine parameters are being established for the effluent. The thresholds for organic material (BOD), toxic contaminants (toxics and toxicity), pathogens (bacteria),

- Priority pollutants are substances that the EPA has determined to be of national concern because of their toxicity at certain concentrations.
- Water quality criteria are maximum pollutant concentration values, or minimum concentrations of desirable parameters (such as DO), that were established to support a specific water body use, such as protection of aquatic life. Acute criteria values were developed to be protective of relatively short-term (less than 96 hours) exposure to pollutants. Chronic criteria are values that provide protection from relatively long-term pollutant exposure.
- Effluent sampling provides the MWRA with the ability to monitor several nutrients, trace metals, and anthropogenic organic compounds prior to discharge. As the level of treatment increases, effluent quality is expected to improve substantially.

TABLE 2-1
Effluent Thresholds Compared to 1995 Monitoring Results

Parameter	Caution Level	Warning Level	1995 Results
Total Nitrogen (nutrients)	Total nitrogen annual loading > 12,500 mtons/year	Total nitrogen annual loading > 14,000 mtons/year.	Not exceeded. Annual loading = 11,460 metric tons
cBOD (organic material)	None.	Weekly or monthly permit levels. Expected levels: 40 mg/L weekly, 30 mg/L monthly.	Always exceeded. Minimum value during year = 50 mg/L. Pilot secondary treatment monthly average = 11 mg/L
Toxics (toxic contaminants)	None.	Toxics concentrations above permit levels (yet to be determined).	Monthly average total PCB concentrations: 7-225 ng/L. (Mitchell et al. (1997) indicate that the range is 1-155ng/L.) None of the effluent concentrations exceed the most stringent WQC modified by their respective dilution factors. Pilot treatment plant concentrations were even lower.
Toxicity (toxic contaminants)	None.	Acute: effluent LC50 for shrimp <50% effluent. Chronic: effluent NOEC for fish growth and sea urchin fertilization <1.5% effluent.	Acute: 7 of 12 tests violated shrimp 20% NOEC limit. Chronic: no violations of minnow 10% NOEC limit; All tests failed red algae 10% NOEC limit.
Bacteria (pathogens)	None.	Daily or monthly permit levels. Expected levels: 400 fecal coliforms/100mL daily, and 200 fecal coliforms/100mL monthly.	7 daily exceedances. No monthly exceedances.
Suspended Solids	None.	Weekly or monthly permit levels. Expected levels: 45 mg/L weekly, 30 mg/L monthly.	Exceeded frequently. Daily range: 23-201 mg/L. Pilot secondary treatment monthly average = 12 mg/L.
Floatables	None.	Floatables less than 5 gal/day.	Not measured until secondary treatment plant is on line.
Oil and Grease (floatables)	None.	Oil and grease permit requirements. Expected level: 15 mg/L weekly.	No exceedances.
Plant Performance	More than 5 violations of permit requirements per year.	Operating in violation of the permit requirements more than 5% of the time over a year.	20 violations. Most from parameters that will be improved by secondary treatment.

The reader is directed to the glossary and acronym summary at the end of the report.

solids (TSS), and oil and grease will be based on the NPDES permit to be issued by the EPA to the MWRA for the Deer Island Treatment Plant and outfall. Three other thresholds, for nutrients (total nitrogen), floatables (other than oil and grease), and plant performance, have already been specified. A summary of the expected effluent thresholds and comparison of 1995 monitoring results to thresholds are given in Table 2-1.

Most of the threshold levels are expressed as a number in relation to a certain interval of time and space. For example, the daily bacteria limit is compared to the pooled measurements in a day. There are three measurements of bacteria in a day, and pooling is calculated in this case as a geometric mean. Likewise, the monthly limit is compared to the pooled measurements taken over a month. The concept of a spatial interval is more relevant to the other monitoring areas and will be introduced in Section 3.3.

Nutrients

Because nitrogen is the most important nutrient to monitor when discharging effluent to marine waters, MWRA tests treatment plant effluent for the concentration of total nitrogen. Assuming certain loadings of nitrogen from the effluent, the SEIS and later modelling studies predicted little or no impact from the outfall discharges. Caution and Warning Levels have been set to verify that the loads assumed in those predictions are not exceeded. Therefore, the Caution and Warning Levels for total nitrogen annual loading have been established as 12,500 and 14,000 metric tons/year, respectively. In 1995, as in previous years, the total nitrogen load has been below these levels. The 1995 annual load of total nitrogen from both Deer Island and Nut Island was estimated at 10,003 metric tons from the DECS data. The 1995 annual load of total nitrogen from NPDES data is 9163 metric tons and the difference is due to composite sampling (NPDES) versus grab sampling (DECS). The pilot secondary treatment plant study showed an average of 10% total nitrogen removal.

Organic Material

Although the NPDES permit has not been issued, the expected Warning Level thresholds for effluent organic materials are 40 mg/L on a weekly average, and 30 mg/L on a monthly average. In 1995, BOD ranged from 50 to 179 mg/L with an average of 102 mg/L. The thresholds being developed apply to the new secondary treatment system, but the 1995 results are from the primary treatment system and experimental pilot plant. BOD levels are expected to drop to below the Warning Level when the new system is fully operational. The monthly average BOD in the effluent of the pilot secondary treatment plant was 11 mg/L, though the pilot plant in 1995 was tested under varying conditions including those more extreme than expected during future plant operation. The highest monthly average for 1995 was 19 mg/L.

Toxic Contaminants

NPDES toxic contaminant limits are based on water quality standards and very conservative assumptions about water conditions within the effluent/sea water mixing zone (i.e. stratified conditions and conservative estimates on available dilution). If limits for toxics are included in the new NPDES permit, they will serve as the Warning Levels for effluent toxic contaminant concentrations. If not, the thresholds will be revised to reflect water quality standards. Presently, the only toxic parameter expected in the permit is PCBs.

In addition to concentration-based tests, the NPDES permit will require the use of laboratory-based bioassays to assess acute and chronic toxicity. The Warning Level for acute toxicity is expected to be an effluent LC50 of less than 50% effluent for shrimp. The Warning Level for chronic toxicity is expected to be effluent NOEC for fish growth and sea urchin fertilization that is less than 1.5% effluent (derived from an assumed dilution of 68). The expected permit limits that form the basis for these thresholds differ from the present toxicity permit limits.

The present acute limit for shrimp of 20% NOEC may change to LC50<50%. The present chronic limit using sheepshead minnow (10% NOEC) will change to one using the more sensitive fish Menidia (1.5% NOEC at edge of mixing zone). The present chronic limit using the red alga *Champia* (10% NOEC) will change to one using a more reliable laboratory test organism, the sea urchin *Arbacia* (1.5% NOEC at edge of mixing zone). Only the results for the present acute toxicity test can be easily compared to the future Warning Levels listed in Table 2-1, and this is reflected in the 1995 results in the table.

Pathogens

Because of the dilution that will be achieved at the new outfall, it is nearly inconceivable that any bacterial water quality standards for fishing, shellfishing, or swimming would be exceeded (except in the immediate vicinity of the outfall, where the Division of Marine Fisheries prohibits fishing and shellfishing) if effluent bacteria concentrations were below the NPDES permit limits.

The Warning Level is based on the expected NPDES permit limits of 400 fecal coliform/100 mL on a daily basis, and 200 fecal coliform/100 mL on a monthly basis. That limit may be revised, however, to reflect the tradeoffs between chlorine toxicity and health risks. Due to dilution and death of the pathogens, health risks are low except in the immediate vicinity of the outfall, where some further degree of protection is provided by the future ban of the Division of Marine Fisheries on fishing and shellfishing at the future outfall. As this report was being prepared, the regulatory authorities were discussing whether a less stringent bacteria limit (14,000 fecal coliform/100 mL) would be appropriate. This is based on a weekly threshold of 200 fecal coliform/100 mL and a dilution of 70.

Solids

The expected NPDES permit limits for total suspended solids (TSS) have been used as the MWRA warning thresholds. These limits are 45 mg/L of TSS weekly, and 30 mg/L of TSS monthly. In 1995, TSS concentrations averaged 63 mg/L with a range between 23 and 201 mg/L. Although the TSS appears to be lower in the new primary plant effluent than in previous years, these values are still substantially higher than the established threshold values. The MWRA anticipates that completion of the new secondary treatment facility will further improve effluent water quality, and that TSS levels will drop substantially once secondary treatment commences. The TSS level for the secondary treatment plant is expected to be approximately 15 mg/L. The pilot secondary treatment plant was tested under varying operating conditions in 1995 and the monthly average TSS in the effluent was 12 mg/L. The highest monthly average for 1995 was 22 mg/L.

Floatables

The Warning Level for oil and grease is the same as the expected NPDES permit limits, 15 mg/L in weekly grab samples. The 1995 results indicate no violations of that threshold (one sample from February of 1995 exceeded 15 mg/L due to a laboratory error). A separate threshold was established for floatables (visible floating debris) which are assessed by a different method from oil and grease. Floatables cause aesthetic problems; oil and grease cause aesthetic as well as toxic problems. The floatables Warning Level was set in relation to the performance of the future secondary treatment plant, which has a series of floatables-removing skimmers. The expectation is that the final skimmer is redundant . If as much as 5 gallons of floating matter accumulates in that final skimmer over the course of a day, that would indicate that it is not redundant and the upstream skimmers may be overloaded or inefficient. The visual inspections will begin in 1998 and be conducted weekly. The design of the present primary plant does not allow for any such quantification of floatables now, and so the 1995 floatables results portion of Table 2-1 is blank.

Plant Performance

The MWRA Caution Level for plant performance is the Association of Metropolitan Sewerage Agencies' (AMSA) standard of 5 violations/year, while the Warning Level is the EPA standard of noncompliance 5% of the time. Monitoring results indicate that 20 violations occurred in 1995, and that most of these violations were due to TSS and BOD exceedances. Once the new treatment system is on line, and TSS and BOD are more effectively removed, the frequency of violations is expected to drop below the threshold.

2.4 Monitoring Results

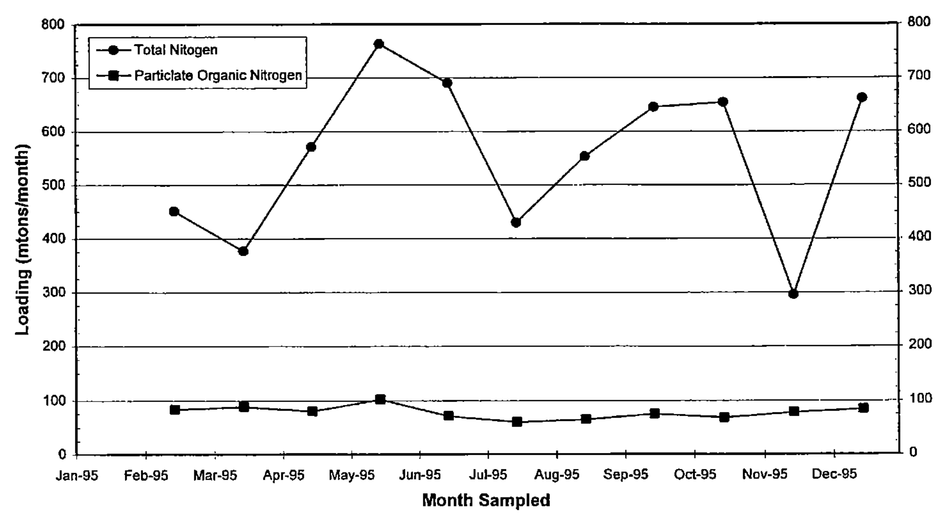
As part of the MWRA Harbor and Outfall Monitoring Project, concentrations of selected nutrients, trace metals, and anthropogenic organic compounds were monitored in the effluent of the MWRA Deer Island Wastewater Treatment Plant as well as in the influent and effluents of the pilot secondary treatment plant. None of the contaminants will exceed water quality criteria after the effluent has been diluted by seawater within a few tens of meters of the outfall. Under typical conditions a 100-fold dilution will occur within that area; it will always exceed 50-fold dilution, ensuring that the chemicals in effluent will pose a minimal risk to aquatic life. A further degree of environmental protection will in the future be provided by the improved removal efficiency of secondary treatment.

2.4.1 Effluent Characterization

Nutrients

In the 1995 DECS sampling program, total nitrogen (the sum of particulate organic and total dissolved nitrogen) in the primary effluent ranged from 516 to 2,250 mM (7.2 to 31.5 ppm) in grab samples. Approximately sixty-nine percent of the nitrogen in the effluent was present as ammonia. Monthly total nitrogen loading ranged from 296 to 763 metric tons/month (Figure 2-1) for Deer Island effluent. The total annual Deer Island discharge, multiplied by 1.5 to include an estimate of Nut Island discharge, was 10,003 metric tons/year. The NPDES program measured total nitrogen load at both treatment plants, at a greater frequency than the DECS study, and as a composite rather than as a grab sample. The variablility was lower in the NPDES data due to the composite sampling, and the annual load was higher (11,460 metric tons/year). The NPDES data are a more reliable estimate of the annual load due to compositing and the greater frequency of measurement whereas the DECS study was nevertheless useful in providing additional information on the forms of nitrogen and other nutrients in effluent.

FIGURE 2-1
Total Nitrogen and Particulate Organic Nitrogen Loading in Deer Island Effluent.



Organic Material

In 1995, monthly BOD levels in Deer Island effluent ranged from 50 to 179 mg/L; seasonally, BOD tended to be lower in the spring and highest in the summer months. The BOD in Deer Island effluent averaged approximately 102 mg/L during 1995.

The start up of the new primary treatment system in January, 1995 did not

- After nearly a decade of planning, design, and construction, the MWRA started-up the new Deer Island primary treatment plant in January, 1995. The primary treatment process involves removing solids from sewage and chlorinating effluent prior to discharge. A new secondary treatment facility is currently under construction. Secondary treatment combines a bacterial process to decompose sewage with a physical settling process. Whereas primary treatment removes 30 to 35% of the organic matter and 20 to 40% of the toxic pollutants, secondary sewage treatment results in removal of more than 75 to 90% of the organic matter and most toxic pollutants prior to effluent discharge..

result in a significant decrease in BOD from 1994 levels. This is to be expected, as much of the organic matter in MWRA's system is dissolved, and not efficiently removed by primary treatment. MWRA anticipates that completion of the secondary treatment facility will further improve the effluent quality, and that BOD levels will drop substantially once this plant is on-line. After startup of the secondary treatment system, it is anticipated that BOD levels will drop to 10-15 mg/L. Results from the 1995 pilot secondary treatment plant study showed a monthly average BOD of 11 mg/L.

Toxic Contaminants

Average effluent analyte concentrations (DECS) for the Deer Island Treatment Plant from January to December 1995 are presented in Table 2-2. None of the mean concentrations of analytes listed in the table exceed the dilution-adjusted water quality criteria (WQC). PCBs are not listed in the table because discussions are underway with EPA to consider updating the WQC for PCBs so they are expressed in terms consistent with the more sensitive analytical techniques in use today (MItchell et al. 1997). The WQC in Table 2-1 were adjusted for the dilution factors adopted by the EPA for this outfall (364 for human health, 68 for chronic, and 52 for acute WQC).

TABLE 2-2

Mean 1995 Effluent Contaminant Concentrations Compared to Adjusted Water Quality Criteria

Parameter	1995 Mean Effluent Concentration[1] (μg/L)	Human Health WQC x 364 (μg/L)	Chronic WQC x 68 (μg/L)	Acute WQC x 52 (μg/L)
Pesticides				
Aldrin	ND	0.027	NA	67.6
4, 4'-DDT	0.007	0.0087	0.068	6.8
Dieldrin	ND	0.026	0.13	36.9
Endrin	ND	364	0.16	1.9
Heptachlor	0.0025	0.102	0.245	2.8
Heptachlor Epoxide	ND	0.036	0.245	2.8
Lindane	0.018	6.8	NA	8.3
PAH				
Acenaphthene	0.093	NA	48,300*	50,400*
Fluoranthene	0.23	15,300	1,090*	2080*
Naphthalene	1.6	NA	NA	122,000*
ΣPAH	16.9	NA	NA	NA
Metals				
Silver	3.95	18,200	NA	120
Cadmium	0.54	3,600	360	2200
Chromium (UI)	15.6	18,200	3,400	57,000
Copper	64.2	NA	197	151
Mercury	0.1	52.4	1.7	109
Nickel	6.3	4,880	560	3900
Lead	11.5	18,200	380	7300
Zinc	74.9	NA	5,800	4900

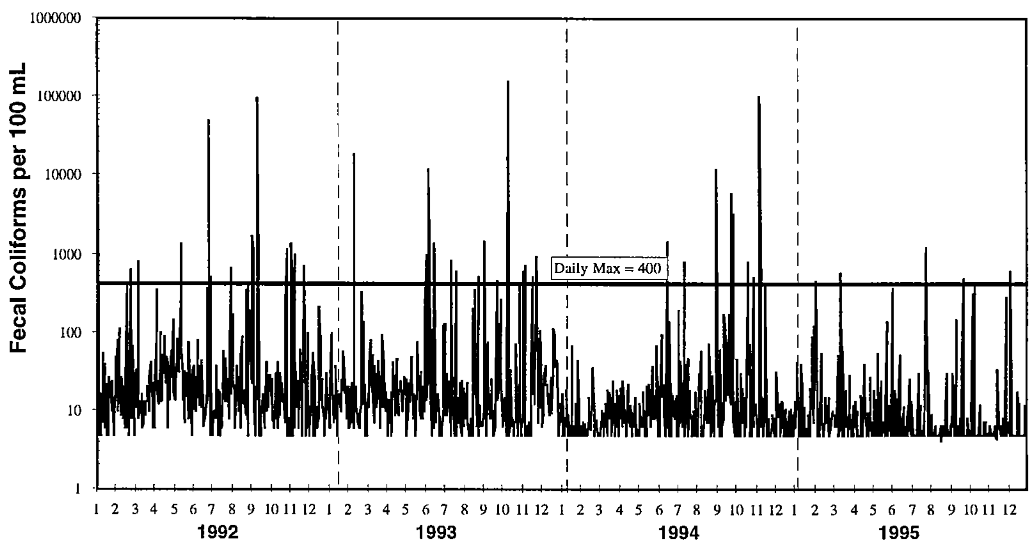
[1]Average concentration in samples in which contaminant was detected.
Source: Butler et al., 1996.
ND = Not detected.
NA = Not Available
* Insufficient information for development of WQC. NOEC used instead.

Toxicity

MWRA performs three different effluent toxicity tests: 1) acute mortality in marine mysid shrimp; 2) chronic survival and growth in sheepshead minnow; and 3) chronic reproduction in red algae. Acute test limits have a NOEC of 20%, while chronic tests have a NOEC of 10%.

In 1995, the results of the acute toxicity tests in shrimp had a range in NOEC of 5 to 20%, with an average of 14%. Seven of the twelve tests violated the 20% acute NOEC limit. The 1995 chronic minnow test results averaged 42% with a range of 20 to 60%. There were no exceedances of the 10% NOEC limit. In contrast, all of the red algae tests failed. The chronic NOEC limit is 10%, while the test results were between 0.7 and 2%, with an average of 2%. These results as well as those from other treatment plants and other practical test considerations have prompted the EPA to revisit the test species, and it is expected that sheepshead minnow and red algae will be replaced in the permit. Exploratory toxicity testing conducted in 1995 include the species *Menidia* and *Arbacia*. The two tests using *Menidia* showed a 20% NOEC. Six tests using *Arbacia* showed a range of 10 to 100% NOEC. These are well above the 1.5% NOEC being considered for permit limits, i.e. the effluent will not violate these toxicity limits.

Figure 2-2
Measurements of Fecal Coliform in Effluent



Pathogens

Fecal coliform levels in Deer Island effluent vary widely (Figure 2-2). While exceedances of the daily maximum threshold occurred in 1995, the number of exceedances was reduced from previous years. No monthly exceedances were observed in 1995 or in previous years. This level of performance is expected to be further improved when the new treatment plant is on-line. The new treatment plant will have a longer chlorine contact time, resulting in increased pathogen destruction.

Solids

Average monthly TSS concentrations in the effluent from the Deer Island Treatment Plant in 1995 ranged from 23 to 201 mg/L. The average TSS concentration was 63 mg/L. Results from the 1995 pilot secondary treatment plant study showed a monthly average TSS of 12 mg/L.

Floatables

Current sewage treatment operation includes regular and efficient removal of floatable materials early in the treatment process. As a result, substantial levels of floatables have not been detected in the effluent. A more comprehensive procedure for assessing visible floatables will be instituted when the secondary plant is on line.

2.4.2 Pilot Secondary Treatment Plant Results

Treatment Plant Effectiveness

Testing at the pilot seocndary treatment plant was conducted throughout 1995. The removal efficiencies of the primary and secondary treatment process continued to be variable; however results are encouraging as they indicate that the concentrations of many contaminants of concern will be substantially reduced through secondary treatment.

The pilot secondary treatment plant was found to have very high removal efficiency in comparison to the primary effluent, averaging approximately 85% removed for total PAHs, total DDTs, and total chlordane. High removal efficiencies (70-85%) were achieved for total LABs, silver, copper, lead, and particulate organic carbon. Intermediate (20-70%) removal efficiencies were indicated for total PCB, zinc, total phosphorus, and dissolved organic carbon. Lindane, cadmium, chromium, mercury, and biogenic silica were also estimated to be in the intermediate removal efficiency range. Inefficiently (<20%) removed contaminants include: molybdenum, nickel, and total nitrogen. The pilot secondary contaminant concentrations were all less than the Deer Island primary effluent contaminant concentrations on the average (some individual samples of pilot secondary effluent may show higher concentration of the inefficiently removed contaminants such as molybdenum, nickel and total nitrogen than the pilot plant influent). Compounds with the highest observed concentrations for individual measurements (note that average concentrations were much lower) were total PAH (3250 ng/L), LAB (2696 ng/L), molybdenum (27.8 µg/L), zinc (58 µg/L) and total nitrogen (2315 µM). The 1995 pilot secondary treatment plant data are consistent with the removal efficiencies used in the EPA SEIS to make impact predictions. As with the primary treatment plant, none of the effluent contaminant concentrations exceed the most stringent water quality criteria modified by their respective dilution factors.

Loading

Contaminant loading reductions approximating the removal efficiencies listed above can be expected. The removal efficiencies estimated from the 1995 pilot secondary treatment plant sample concentrations indicate that the loading of contaminants to Massachusetts Bay will be significantly reduced.

Effluent Quality

The pilot secondary treatment plant data show that the secondary treated effluent will meet all water quality criteria after initial dilution.

3.0 Water Column Monitoring Program

3.1 Water Column Issues

Potential water column issues due to the relocation of the outfall are associated with the effects of the effluent organic material, nutrients, and toxic contaminants. Of these, changes in the nutrient balance in Massachusetts and Cape Cod Bays have the most potential for significant effects on the health of marine life in the Bays.

3.1.1 Organic Material

Organic material occurs naturally in water bodies and may also be introduced by wastewater effluents. Decomposition of organic material consumes dissolved oxygen (DO). DO is oxygen dissolved in water and available to marine mammals for respiration. If DO concentrations are low, a condition known as hypoxia, sensitive animals may suffocate. Hypoxia can occur when the DO demand of decomposition is greater than the natural resupply. The oxygen depletion rate is a measure of this difference between DO supply and demand, and describes how quickly DO concentration decreases.

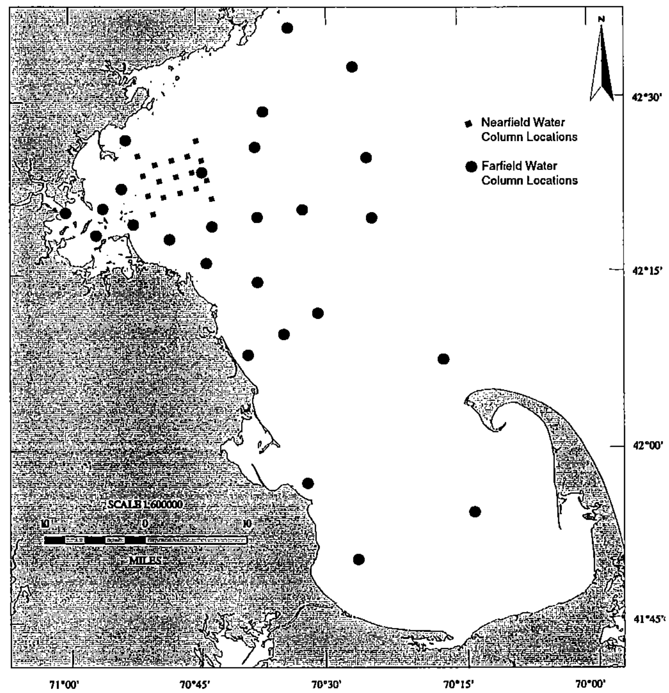


FIGURE 3-1
Nearfield and Farfield water column sampling locations

3.1.2 Nutrients

Nutrients are necessary for the growth of all plants, aquatic and terrestrial. The amount of nutrients in the water, along with several other factors, controls the growth of aquatic plants, including algae. Since algae are the foundation of the aquatic food web, nutrients have a great effect on how much life a marine ecosystem can support. In particular, there are two basic ways in which nutrients from MWRA effluent can have a negative effect on marine environments: through the effects of algae on dissolved oxygen concentration and through changes in algal community structure. Nitrogen is the nutrient of greatest concern.

Low Dissolved Oxygen (Hypoxia)

An algal bloom is a burst of algal growth, which occurs when a variety of conditions come together. A sufficiently high nutrient level is one of the requirements, but other factors such as sunlight and temperature are also important. Algal blooms are the base of the food web, without which fish, whales, and most other marine life would not survive. Algal blooms are necessary, common occurrences in the marine environment, but they can be a cause for concern, depending on the intensity and frequency of the bloom, and the types of algae that bloom.

If a body of water receives too great a nutrient load, it may become subject to eutrophication: over-stimulation of algal growth and excessive algal blooms. When algae grow faster than they are consumed, the excess algae die, sink to the bottom, and decompose. Decomposition of the algae consumes DO, just as with the decomposition of the organic material in discharged effluent as discussed in Section 2.1. This DO consumption can contribute to the creation of hypoxic conditions.

■ **Algae Communities.** The composition of the algal community, or the relative numbers of various algae species, is known as the community assemblage. Approximately 30 to 50 algae species typically are observed in the community assemblage monitored by MWRA. These include species commonly known as diatoms, blue-green algae, and flagellates. Flagellates are planktonic algae that have self-propelled mobility, albeit limited. Red tides are a specific kind of dinoflagellate bloom that may produce toxic chemicals. Some red tides can result in mortality of fish and other marine organisms and toxicity of seafood.

Algal Community Structure (Growth of Undesirable Algae).
Adding effluent to the marine environment may change the relative levels of different nutrients so that undesirable algae dominate or are present along with useful algae. The nutrient composition of effluent is different from that in Massachusetts Bay, and there is public concern that undesirable algae may be better able to take advantage of this difference than desirable algae. Two types of undesirable algae can have direct effects on the marine environment: 1) nuisance algae, such as brown and red tides, which affect the appearance of the water; and 2) noxious algae, such as some red tides, which are toxic to marine mammals, some fish, and, if concentrated in shellfish, to humans. Undesirable algae can also have an indirect effect on the marine environment by out-competing another algal species. If the out-competed species is a primary food source for a marine mammal, that animal may suffer. For instance, it has been suggested that right whales in Cape Cod Bay are linked through the food chain to a kind of algae that might be affected by effluent-induced changes in nutrient concentrations.

3.1.3 Toxic Contaminants

Toxic contaminants are not always toxic. They are harmful at and above certain concentrations, but at lower levels they may be harmless. Some even may be essential to life (e.g. copper and zinc, whereas mercury and lead are not). The timing of exposure is also an important factor: temporary exposures are less harmful than constant ones. This is reflected in higher water quality criteria for acute exposure than for chronic exposure. Animals passing briefly by the outfall would be only temporarily exposed. Because the harmful effect of contaminants decreases with decreasing concentration, the dilution of the effluent is key to minimizing the impact of the outfall.

The potential for increased levels of toxic contaminants in the vicinity of the new outfall is generally low. The new outfall will minimize the environmental impact of effluent by maximizing dilution. Because outfall relocation is unlikely to have a significant effect on the concentrations of toxic contaminants in waters of Massachusetts Bay, toxic contaminant concentrations are monitored in the other three program areas but not in the water column program. Because adequate dilution is central to the expectation of no impact, the effluent dilution achieved by the diffuser will be evaluated using data obtained from the plume tracking surveys (described below).

3.2 Monitoring Program Design

The water column monitoring program is designed to provide measurement of water quality and plankton data in Massachusetts Bay and Cape Cod Bays. The data will help detect changes in the water column of the Bays resulting from the relocation of the effluent outfall.

The monitoring program, which began in 1992, is designed to characterize background water column conditions before completion of the outfall. Once the outfall is on line, water column monitoring data will be compared to background data and any impacts to Massachusetts and Cape Cod Bays will be assessed.

The five major components of the water column monitoring program, nearfield surveys, farfield surveys, plume track surveys, moorings, and remote sensing, are outlined below. These components are designed to provide comprehensive coverage of water quality conditions in Massachusetts and Cape Cod Bays.

Nearfield Surveys

Nearfield water column surveys are designed to collect frequent intensive sets of water quality and plankton data near the outfall location. Impacts are most likely to be measurable near the outfall site, and are likely to be confined to the nearfield area. The nearfield area is defined by a rectangle surrounding the 1.2 mile outfall diffuser line at a distance of 3 miles. The stations are spatially intensive to document the decrease of impacts with distance from the outfall in the region where the decrease is expected to be strongest and most detectable. Data are collected at 17 locations (Figure 3-1) in 17 annual surveys. These surveys provide vertical profiles of physical, chemical, and biological water column characteristics throughout each year, identifying seasonal cycles and events of interest (e.g., algal blooms).

- Chlorophyll is the green pigment in plants that supports photosynthesis. Chlorophyll is used as a measure of the algal biomass, the total amount of algae in the water. The type of chlorophyll most commonly measured is chlorophyll a.

During each nearfield survey, temperature, salinity, dissolved oxygen, chlorophyll fluorescence, light transmission, and photosynthetically available light are electronically measured in situ throughout the depth of the water column. Water samples are collected at selected stations and depths in the water column for laboratory analysis of constituents including nutrients, chlorophyll, suspended solids, dissolved oxygen, phytoplankton, zooplankton, primary productivity, and respiration. The primary productivity (i.e., photosynthesis, the algal growth rate) measurements are performed to evaluate how the algae are responding to ambient nutrients and light. The respiration measurements evaluate the rate of oxygen consumption due to metabolic activity including degradation of algal biomass and other organic matter. Observations of whales, other marine mammals, and sea turtles are also performed during the nearfield surveys.

Farfield Surveys

Farfield water quality surveys are designed to collect intensive sets of water quality, plankton, and primary productivity data over a broad spatial scale, and to cover Massachusetts and Cape Cod Bays. Stations are not spatially intensive as they are in the nearfield, but are spread out over the Bays with adjustments to cover special resource areas and to detect the influence of coastal and offshore sources of nutrients to the Bays. The main purpose of the farfield surveys is to determine differences across the bays and assess seasonal changes over a large area, (e.g., relating trends observed in the nearfield area to the surrounding region).

Six farfield surveys are conducted each year collecting water quality data at 26 stations throughout Massachusetts and Cape Cod Bays (Figure 3-1). Plankton and primary productivity data are collected at selected stations. Farfield and nearfield methods are comparable.

Plume Tracking Surveys.

Plume tracking surveys are performed to determine the location and physical, chemical and biological characteristics of the effluent discharge plume leaving the outfall and mixing with ambient waters. Sampling will include measurement of salinity, temperature, dissolved oxygen, chlorophyll, and suspended solids. The dilution and transformation of components characteristic of the effluent will be tracked using salinity and nutrients as well as other chemical, isotopic, and microbial constituents. Intensive studies will begin when the outfall is on line; some preliminary plume tracking studies of an exploratory nature were performed in 1995.

■ MWRA has conducted extensive water quality modeling studies to evaluate the potential effects of outfall relocation. The results of the modeling studies indicate that outfall relocation will significantly improve conditions in Boston Harbor: i.e. lower nutrient and chlorophyll concentrations and increased dissolved oxygen concentrations. Effects in the Bay would be confined to the immediate vicinity of the future outfall. The modeling study was used to assist in the design of the water column monitoring program, which will be used to verify the modeling study results.

■ Biomass is the total amount of a biological material. Algal biomass is a measure of the total amount of algae present in the water.

Moorings

A mooring is maintained by the US Geological Survey near the future outfall site to measure currents, temperature, salinity, light transmission, chlorophyll, and sediment processes. In addition to a mooring, which physically consists of instruments suspended from a float and anchored by a weight, the USGS also deploys tripods mounted on the sea floor. The purpose of moorings and tripods is to obtain continuous data at a location. The outfall monitoring program uses the data to capture temporal (i.e., time-dependent) variations in water quality between nearfield surveys.

Remote Sensing

Satellites provide remote sensing imagery which the outfall monitoring program uses to capture spatial variations in water quality on a regional scale. The images provide a snapshot of sea surface temperature over the Bays at one time. Sometime after 1995, chlorophyll data will also become available. Remote sensing fills in the information between survey sample locations. Data from remote sensing complements the data from the ship surveys and moorings.

3.3 Threshold Comparison

MWRA is developing thresholds for several water column monitoring parameters in order to assess the potential impacts of the new outfall. The trigger parameters, threshold levels, and 1995 monitoring results for the water column are summarized on Table 3-1. A detailed discussion of the thresholds and current status of compliance with thresholds is provided below.

Most of the threshold levels are expressed as a number in relation to a certain interval of time and space. The relevant data are pooled over those intervals and then compared to the threshold number. The pooling may be done by calculating an average, a geometric mean (e.g. bacteria) or other statistic (e.g. benthic diversity). Pooling yields a number which is less extreme than that of the worst-case individual reading, and so the spatial and temporal intervals have to be chosen carefully – large enough to reflect the ecological response scale of the resource to be protected but small enough to not mask transient problems that occur. The thresholds are designed to be compared to pooled rather than individual data because the latter are dependent on the sampling effort. As an example of how the pooling is done: monthly mean DO in nearfield bottom waters is calculated by averaging the deepest DO measurements from all the nearfield stations during one survey; that result is then averaged over all the surveys (there are up to two) within a calendar month to give the nearfield monthly mean.

Dissolved Oxygen Concentration and Saturation

Aquatic animals are sensitive to the concentration of DO in the water column. Low levels of DO can have negative impacts on marine life. Because of the importance of DO, the state has set a water quality standard that a discharge should not cause DO to fall below 6 mg/L nor below 75% of saturation in Massachusetts Bay.

The DO percent saturation threshold is unique in that it has already been exceeded in the baseline period before the future outfall is operational. The issue of causality implied in the state standard is pivotal in such a case and will be decided on by the OMTF. Water quality modeling studies have indicated that dissolved oxygen levels will improve at the

TABLE 3-1
Water Column Thresholds Compared to 1995 Monitoring Results

Parameter	Caution Level	Warning Level	1995 Results
Dissolved oxygen concentration in Nearfield region bottom waters	Monthly mean DO is less than 6.5 ppm or 80% of saturation levels for any one month during stratification (June-Oct.)	Monthly mean DO is less than 6 ppm or 75% of saturation levels for any one month during stratification (June-Oct.)	DO saturation below warning level in September (74.3%). (See Table 3-2)
Dissolved oxygen concentration in Stellwagen Basin bottom waters	Monthly mean DO is less than 6.5 ppm or 80% of saturation levels for any one month during stratification (June-Oct.)	Monthly mean DO is less than 6 ppm or 75% of saturation levels for any one month during stratification (June-Oct.)	DO saturation below warning level in October (71.0%). (See Table 3-2)
Dissolved oxygen depletion rate in Nearfield region bottom waters	DO depletion rate is greater than 1.5 times the baseline rate for any one month during stratification (June-Oct.), -0.041 mg/L/day.	DO depletion rate is greater than 2 times the baseline rate for any one month during stratification (June-Oct.), -0.054 mg/L/day.	1992-95 Average Baseline Rate: -0.027 mg/L/day 1995 Rate: -0.027 mg/L/day
Chlorophyll in Nearfield region	Annual mean concentration greater than 1.5 times the baseline annual mean, 2.93 µg/L.	Annual mean concentration greater than 2 times the baseline annual mean, 3.90 µg/L.	1992-95 Baseline: 1.95 µg/L 1995: 1.39 µg/L
Chlorophyll in Nearfield region	Season mean concentration exceeds 95th percentile of the baseline seasonal distribution. Spring: 2.38 µg/L Summer: 2.37 µg/L Fall: 4.56 µg/L	None.	Spring: 1.02 mµg/L Summer: 0.73 µg/L Fall: 2.58 µg/L
Nuisance algae in Nearfield region	*Alexandrium tamarense* Season mean population densities exceed 95th percentile of the baseline seasonal mean. Spring: 4.56 cells/L Summer: 1100 cells/L Fall: 8.67 cells/L	None.	*Alexandrium tamarense* Spring: 0 cells/L Summer: 0 cells/L Fall: 0 cells/L (See Table 3-3)
PSP extent in Farfield region	New occurrence. PSP has never been observed at 3 of the 18 monitoring stations (see Table 3-4).	None.	No occurrences.
Zooplankton assemblage in Nearfield region	Nearfield assemblage shifts from a transitional community towards an inshore community. Inshore: *Acartia, Eurytemora, Centropages hamatus* Offshore: *Calanus, Pseudcalanus, Centropages typicus, Oithona* Nearfield: *Transitional between two regions.*	None.	Transitional assemblage in nearfield region.
Initial effluent dilution at new outfall location	None.	Effluent dilution less than that set by the NPDES permit.	No data until outfall is online.

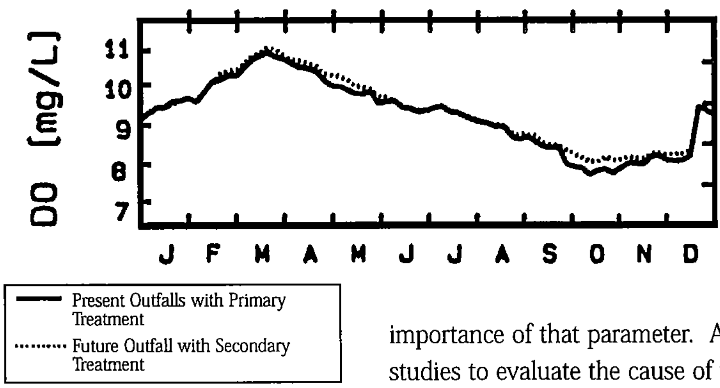


Figure 3-2
Water quality modeling results near future outfall: Existing (1992) conditions and post outfall relocation/secondary treatment (Source: HydroQual. 1995)

future outfall site as a result of outfall relocation and secondary treatment (Figure 3-2). In the post-discharge period, when the Contingency Plan becomes active, action will be taken in response to a violation. The first action to be taken is to notify the OMTF. Even if low DO is determined to be unrelated to the MWRA discharge, it is appropriate to have in place a mechanism for keeping the OMTF immediately informed of episodes of low DO, given the ecological importance of that parameter. Actions could also include further water quality modeling studies to evaluate the cause of the violation.

In 1995 the lowest nearfield monthly mean DO concentration, 6.9 mg/L in September, was above the caution level of 6.5 mg/L (Table 3-2). The lowest individual measurement was 5.7 in September. During the entire baseline period to date (1992-95), the lowest nearfield monthly mean was 6.5 mg/L in September 1994, and the lowest individual measurement was 4.8 mg/L in October 1994.

In Stellwagen Basin in 1995, the lowest nearfield monthly mean DO concentration, 6.7 mg/L in October, was also above the caution level of 6.5 mg/L (Table 3-2). The lowest individual measurement was 6.6 mg/L in October. During the entire baseline period to date (1992-95), the lowest nearfield monthly mean was 6.6 mg/L in October 1994, and the lowest individual measurement was 6.3 mg/L, also in October 1994.

In 1995 the lowest nearfield monthly mean DO percent saturation, 74.8% saturation in September, fell below (i.e., violated) the warning level of 75% saturation (Table 3-2). The lowest individual measurement was 64.2% saturation in September. During the entire baseline period to date (1992-95), the lowest nearfield monthly mean was 74.0% saturation in October 1994, and the lowest individual measurement was 55.6% saturation, also in October 1994.

In Stellwagen Basin in 1995, the lowest nearfield monthly mean DO, 71.0% saturation in October, also violated the warning level (Table 3-2). The lowest individual measurement was 69.3% saturation in October. During the entire baseline period to date (1992-95), the

TABLE 3-2
Minimum DO Concentration and Percent Saturation:
1995 and Baseline Period

Location & Trigger Parameter	1995				Baseline (1992 – 1995)			
	Individual Minimum		Monthly Minimum		Individual Minimum		Monthly Minimum	
Nearfield Concentration	5.7 mg/L	Sept. 95	6.9 mg/L	Sept. 95	4.8 mg/L	Oct. 94	6.5 mg/L	Sept. 94
Stellwagen Concentration	6.6 mg/L	Oct. 95	6.7 mg/L	Oct. 95	6.3 mg/L	Oct. 94	6.6 mg/L	Oct. 94
Nearfield % Saturation	64.2%	Sept. 95	74.8%	Sept. 95	55.6%	Oct. 94	74.0%	Oct. 94
Stellwagen % Saturation	69.3%	Oct. 95	71.0%	Oct. 95	68.2%	Oct. 94	72.6%	Oct. 94

lowest monthly mean was 72.6% saturation in October 1994, and the lowest individual measurement was 68.2% saturation, also in October 1994.

In summary for 1995, both the nearfield and Stellwagen Basin monthly mean DO saturation levels fell below the caution and warning levels. The nearfield region experienced a minimum monthly mean DO saturation of 74.8% in September, while Stellwagen Basin experienced a minimum monthly mean of 71.0% in October.

Dissolved Oxygen Depletion Rate

The DO depletion rate thresholds are based on the calculated average rate from the baseline period. The rates over the four years of baseline to date vary from a low of -0.024 mg/L/day in 1992 to a high of -0.031 mg/L/day in 1994. Both 1994 and 1995, which experienced low DO concentrations and saturation levels, had higher rates of DO decline than 1992 and 1993. Based on the data collected to date, the interim threshold for the average baseline DO depletion rate is -0.027 mg/L/day (Table 3-1). As additional baseline data are collected, this value will be updated. Based on this average value, the DO depletion rate thresholds would be -0.041 mg/L/day for the Caution Level and -0.054 mg/L/day for the Warning Level. The 1995 DO depletion rate was -0.027 mg/L/day, which is by coincidence the same as the average, and below the Caution and Warning Levels.

Chlorophyll and Nuisance Algae

Adding effluent to the marine environment could change the amount of nutrients or the relative levels of different nutrients so that excessive or prolonged algal bloom could occur. As discussed earlier, the settling and decomposition of algal biomass in the bottom water can lead to low DO conditions. Algal biomass is most commonly measured as chlorophyll, a photosynthetic chemical in all green plants. Chlorophyll a is the type of chlorophyll measured in the EPA approved standard test for chlorophyll and adopted by the MWRA, and is the form implied when the "a" is omitted.

As there are no state or federal regulations for chlorophyll, the Warning Level was developed based on expert peer review comments to the OMTF. The commentors agreed with the rule of a thumb that appeared in 1993 in the National Oceanographic and Atmospheric Administration's Estuarine Eutrophication Survey: "normal blooms become problematic when chlorophyll values reach 20 ug/L." The commentors wanted a greater level of protection for Massachusetts Bay, however, because present levels are so much lower (2-3 ug/L), and deleterious changes would be apparent long before the chlorophyll reached the NOAA level of 20 ug/L. Therefore the Warning Level was set at twice the baseline value of the annual mean nearfield chlorophyll concentration, or well before there is a likelihood of biologically significant change.

In addition to the trigger parameter above which focuses on the annual average, another was established which recognizes the inherent seasonality of chlorophyll over the year and is designed to protect against unusually high algal biomass in any one season. By allowing for seasonality the new trigger parameter would be more sensitive to meaningful change. The statistic chosen to reflect the meaning of "unusual" in this case was chosen to be the 95th percentile. A measurement would be deemed to be unusually high if it were to exceed 95 percent of the baseline values. There is a 5 percent chance of a false alarm with this approach but it is appropriate nevertheless to notify the OMTF immediately of such an occurrence.

TABLE 3-3

Plankton Thresholds Comparison

Location	Trigger Paramater	Season	Caution Level	Warning Level	1995 Results
Nearfield	Annual Mean Chlorophyll Concentration	Year	2.93 µg/L	3.90 µg/L	1.39 µg/L
Nearfield	Seasonal Mean Chlorophyll Concentration	Spring	2.38 µg/L	none	1.02 µg/L
		Summer	2.37 µg/L	none	0.73 µg/L
		Fall	4.56 µg/L	none	2.58 µg/L
Nearfield	Seasonal Density of *Alexandrium tamarense*	Spring	4.56 cells/L	none	0 cells/L
		Summer	1,100 cells/L	none	0 cells/L
		Fall	8.67 cells/L	none	0 cells/L
Nearfield	Seasonal Density of *Nitzschia pungens*	Spring	2,670 cells/L	none	2,000 cells/L
		Summer	55,000 cells/L	none	20,000 cells/L
		Fall	5.42×10^6 cells/L	none	16,000 cells/L
Nearfield	Seasonal Density of *Phaeocystis pouchetii*	Spring	2.63×10^6 cells/L	none	0 cells/L
		Summer	0	none	0 cells/L
		Fall	52,000 cells/L	none	0 cells/L

The interim chlorophyll thresholds (shown on Table 3-3) were developed from the existing four years of baseline monitoring data. The chlorophyll concentrations for 1995 were below the existing threshold values.

Nuisance and noxious algae naturally occur in Massachusetts and Cape Cod Bays in small numbers annually. There is public concern that effluent nutrients could stimulate a red tide or similar noxious algae bloom in the vicinity of the new outfall. At the 1996 peer review workshop, it was recommended that the Massachusetts shellfish toxicity monitoring program be used to set red tide Caution Levels. The state program monitors the toxicity of Paralytic Shellfish Poisoning (PSP) at shellfish beds along the edge of Massachusetts and Cape Cod Bays. A list of Department of Marine Fisheries shellfish monitoring stations is provided in Table 3-4.

To date, no shellfish toxicity has been observed at the monitoring stations in Dennis, Barnstable, or Provincetown. Prior to the large *Alexandrium* bloom which occurred in 1993, toxicity had not been observed beyond the Cape Cod Canal. However, toxicity was observed for the first time in Sandwich as a result of the 1993 bloom. Such an occurrence will be viewed as a trigger parameter for contingency planning in order to fully evaluate its origin.

TABLE 3-4

Shellfish Monitoring Stations for PSP

Primary Stations	Secondary Stations
Gloucester-Annisquam Yacht Club	Rockport-Granite Street
Hull-Pt. Allerton	Cohasset-Border Street
Cohasset-Little Harbor	Scituate/Marshfield-South River Humarock
Scituate-Scituate Harbor	Marshfield-Green Harbor
Marshfield-Damon's Point	Duxbury-Eaglenest Creek
Plymouth-Manomet Point	Plymouth-Plymouth Harbor
Sandwich-Cape Cod Canal (east entrance)	Plymouth-Ellisville Harbor
Dennis-Sesuit Harbor	Sandwich-Sandwich Harbor
	Barnstable-Marispan Creek
	Provincetown-The Dike

The nuisance algae thresholds are being developed from the baseline conditions. The Caution Levels will be set as the 95th percentile of seasonal mean concentrations of the three target species of nuisance algae (Table 3-3). In 1995, two of the three species were undetected in the monitoring samples. The potential presence of the third target species was suggested by low concentrations of related indicator species.

Zooplankton

Zooplankton assemblages vary with location in Massachusetts Bay. The species composition of inshore communities is dominated by *Acartia, Eurytemora,* and *Centropages hamatus,* while the species composition of offshore communities is dominated by *Calanus, Pseudocalanus, Centropages typicus,* and *Oithona.* The nearfield region represents a transition between the two communities.

The zooplankton species in inshore communities are known to require the high concentrations of nutrients and algae that are found in Boston Harbor for maximal growth and reproduction. Once the new outfall is online, the nutrient concentrations in both the Boston Harbor and the nearfield region may change. The zooplankton community in Boston Harbor may change beneficially toward that presently in Massachusetts Bay. The Caution Level seeks to protect the zooplankton community in the nearfield of Massachusetts Bay from changing undesirably to one similar to that presently in the Harbor.

Dilution

Since all evaluations of toxic impacts depend on concentrations after initial mixing, the MWRA will measure the actual dilution of effluent by seawater around the new outfall to test predictions of effluent dilution. Testing will focus on measurements of tracers to determine dilution in the immediate discharge mixing zone of the diffuser. The results will be compared with predictions of contaminant concentrations. Because EPA dilution estimates are very conservative, it is extremely unlikely that actual dilution will be less than the EPA predicted dilution. However, if the study showed that real dilutions were less than anticipated and did not reduce toxic contaminant concentrations enough to protect the environment, the EPA and the state could revise MWRA's NPDES permit by lowering the allowable discharge concentrations. Thus, effluent dilution tests provide a Caution Level which would lead to revision of Caution and Warning Levels for toxic contaminants if it were exceeded. As the new outfall is not on-line, no data is available to evaluate this trigger parameter.

3.4 Monitoring Results

The behavior of the Massachusetts Bay system is primarily controlled by the annual weather patterns and cycle, although the individual system components (physical, chemical, and biological) are also largely influenced by complex system interactions (Figure 3-3).

The monitoring program measures the annual behavior of the Bay system and provides data sufficient to quantify the annual variability of each parameter. In 1995 the behavior of the Bay system was similar to that observed in previous years. The following sections present the components of the annual Bay cycle as they were measured in 1995.

Physical Characterization of the Water Column

The annual cycle of the Massachusetts Bay system begins in late winter when the Bay is unstratified. Water temperature and salinity are vertically uniform throughout the water column. As the snow melts in the spring, the runoff increases freshwater input to the Bay from the Merrimack, Charles and other rivers (Figure 3-4). This fresh water runoff enters the Bay at the surface, and because it is less dense than the salty water in the Bay, it stays on the surface. As a result, a vertical salinity gradient develops (Figure 3-5). Simultaneously, as the days get longer, the sun heats the surface water and a vertical tem-

- Water density is a function of water temperature and salinity. Density increases with decreasing temperature and increasing salinity. When the water column is unstratified, the density of the water is similar from top to bottom, and mixing of the entire water column can occur. When the water column is stratified, two distinct layers exist in the water column: the surface layer which is in contact with the atmosphere and the oxygen it contains, and the bottom layer which is isolated from sources of oxygen. These two layers are separated by strong differences in density.

perature gradient begins to develop (Figure 3-6). By the end of the spring (late May) the water column is stratified (Figure 3-7).

During the summer, the water column becomes more stratified due to continued solar heating at the surface. Storms and upwelling events can temporarily break down this stratification and mix the water column. Two upwelling events are evident in the 1995 data shown in Figure 3-6 (early July and mid-August).

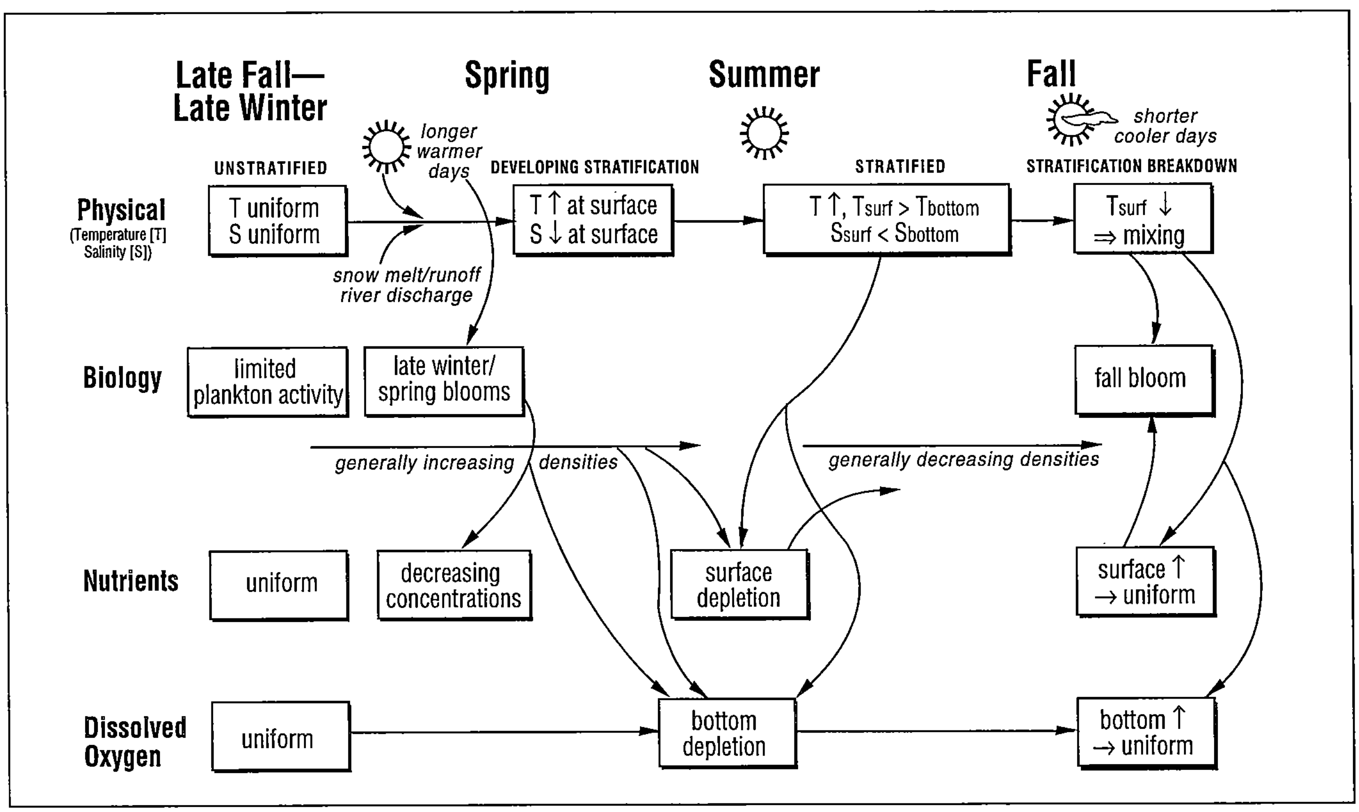
During early-July and mid-August the surface water temperature drops substantially as cooler bottom waters are brought to the surface by upwelling. Bottom water temperatures are unaffected by upwelling.

In the fall, the water column completely re-mixes in a process known as overturn. Overturn occurs because as the days get shorter and cooler, the surface water cools. When the density of the surface water becomes less than that of deeper waters, it sinks. This process generally takes place in October, after which time the water column gradually and uniformly cools throughout the winter. In 1995 a major overturn event occurred in October as seen in Figures 3-6 and 3-7 with overturn complete in November.

Plankton and Chlorophyll

Typically there are two major plankton blooms each year. The increasing sunlight and water temperatures in spring trigger the first phytoplankton bloom, and turnover with its inherent mixing drives another phytoplankton bloom in the fall. An increase in the zooplankton population follows each phytoplankton bloom, as phytoplankton are the main food source for zooplankton. Grazing of phytoplankton by zooplankton controls the measured size of phytoplankton blooms and often ends them. The significance of zooplankton

Figure 3-3
Annual Water Column Cycle of Massachusetts Bay



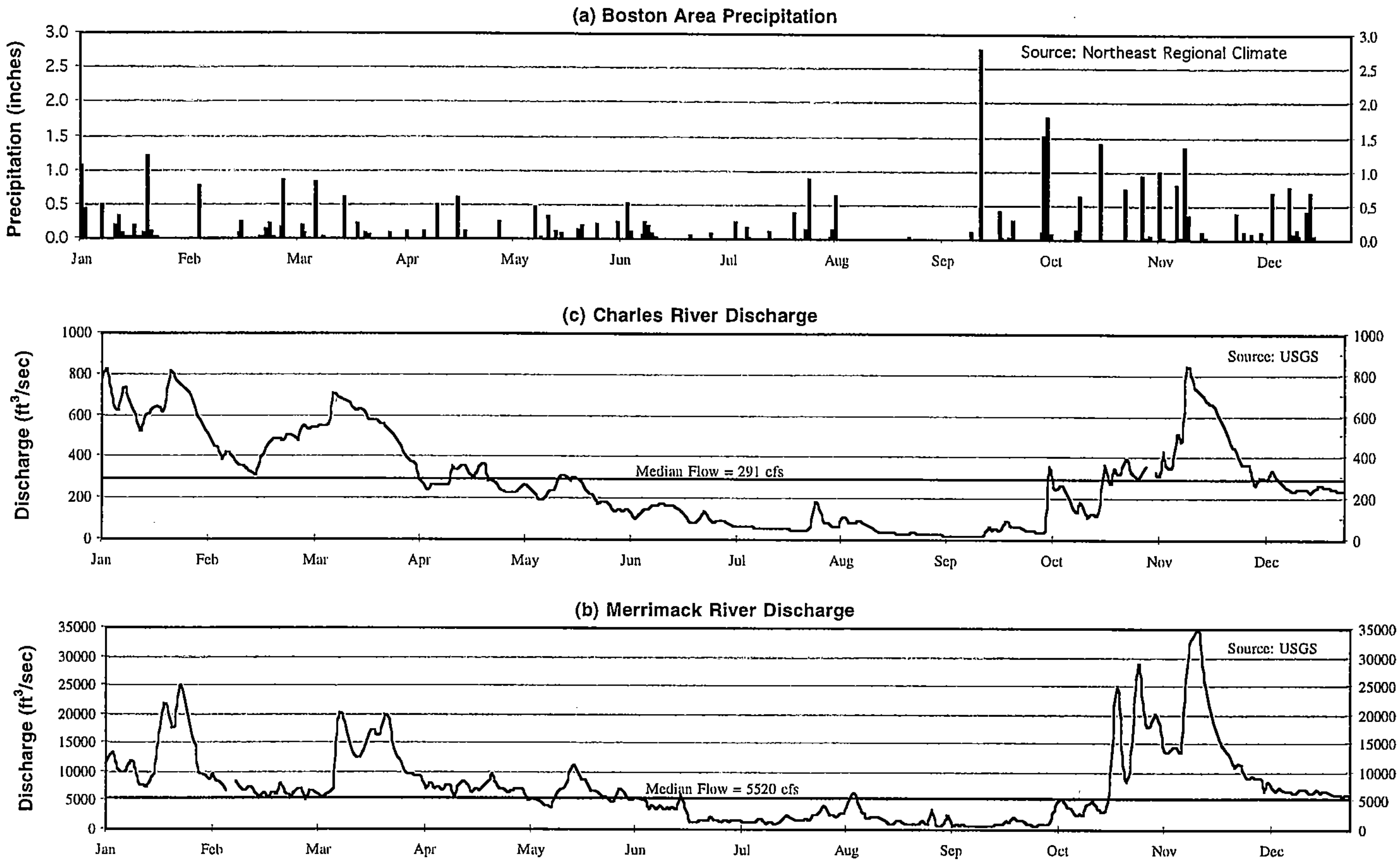


Figure 3-4
1995 Daily Precipitation and River Discharge Data. Merrimack and Charles Rivers

grazing on phytoplankton was demonstrated during the 1995 spring bloom. A fourfold increase in zooplankton abundance coincided with a tenfold decrease in phytoplankton densities in March.

In 1995, as in previous years, spring and fall blooms occurred (Figure 3-8). The size of the 1995 spring bloom was similar to those in previous years. However, algal biomass (as measured by chlorophyll) was lower during the summer, and as an annual average, was lower in 1995 than in previous years. On the other hand, the magnitude of the fall bloom was the second largest recorded in the four-year baseline period. For the most part, the 1995 seasonal phytoplankton blooms (spring and summer peaks) in 1995 were dominated by centric diatoms. The exception was dominance by pennate diatoms during the fall bloom. Zooplankton also showed the typical seasonal changes and peaks in numbers, with copepods (which are the primary food for baleen whales) dominating the zooplankton community.

There was no evidence in 1995 of any significant occurrence of the three toxic or nuisance plankton species monitored by the MWRA monitoring program. There were also no occurrences of shellfish toxicity reported by the Massachusetts Division of Marine Fisheries in 1995.

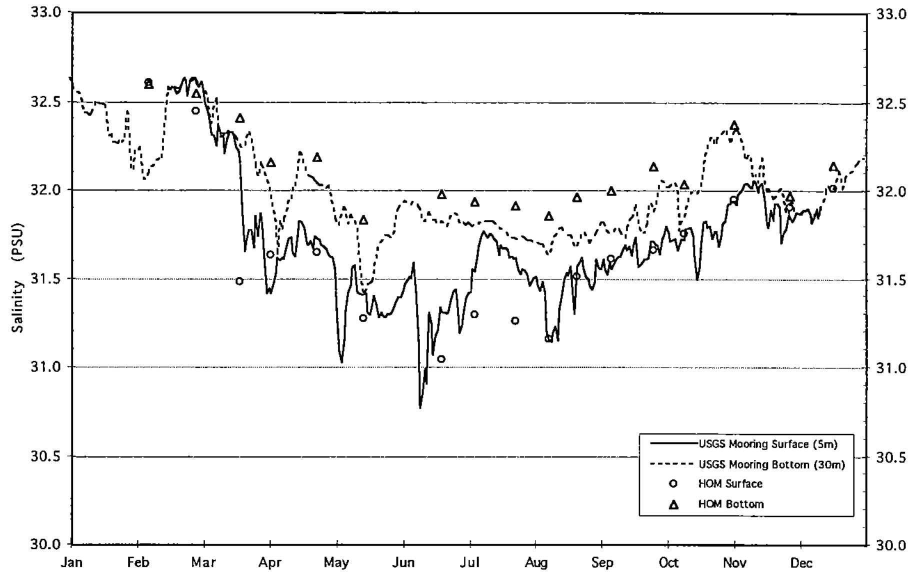


Figure 3-5
1995 Moored Salinity Sensor Data

Nutrient Cycle

The nutrient cycle in Massachusetts Bay is closely linked to the physical and biological changes that take place through the year. Nutrients, like the physical parameters, become vertically mixed during the winter, and begin the year at their highest levels (Figure 3-9). The spring plankton bloom partially depletes the nutrients throughout the water column, as phytoplankton use the nutrients as they grow. As spring and summer progress, continued plankton growth and stratification cause nutrient depletion in the surface water. Lack of algal growth prevents nutrient depletion in the bottom layer. In fact, plankton death and subsequent settling to and decomposition in the bottom layer cause nutrient concentrations to increase somewhat in the bottom waters. Stratification prevents the nutrients in the bottom layer from vertically mixing into the surface layer. Overturn releases the nutrients trapped in the bottom waters to mix throughout the water column (Figure 3-9).

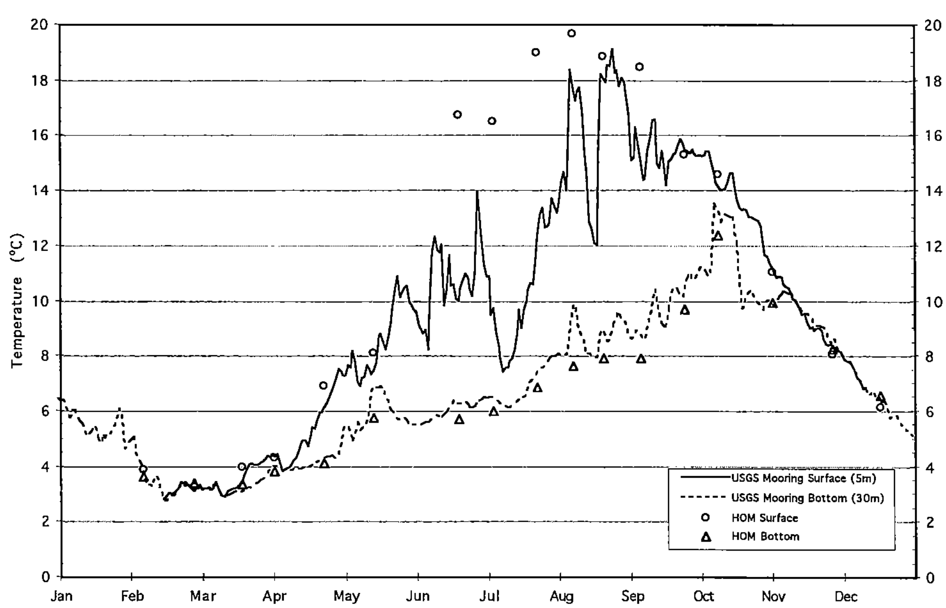
Upwelling events during the summer can release some of the nutrients trapped in the bottom layer into the surface layer. Nutrient releases into the surface layer can result in increased phytoplankton growth. In 1995, the mid-August upwelling event described earlier, resulted in a modest increase in phytoplankton density (as measured by chlorophyll a, Figure 3-8).

Dissolved Oxygen

As with nutrients, dissolved oxygen (DO) is closely linked to the physical and biological changes in the Bay. Water column DO concentrations are the highest during the winter and early spring (Figures 3-10 and 3-11) and are well mixed throughout the water column. The highest DO concentration measured in bottom waters (11.2 ppm) in 1995 occurred in late February, and was lower than that observed in previous years.

Once the water column is stratified, the bottom waters are effectively cut off from the atmosphere (the source of DO). However, consumption of DO via respiration continues. As a result, bottom water DO concentrations decline continuously throughout the stratified period. Mixing or upwelling

FIGURE 3-6
1995 Moored Temperature Sensor Data



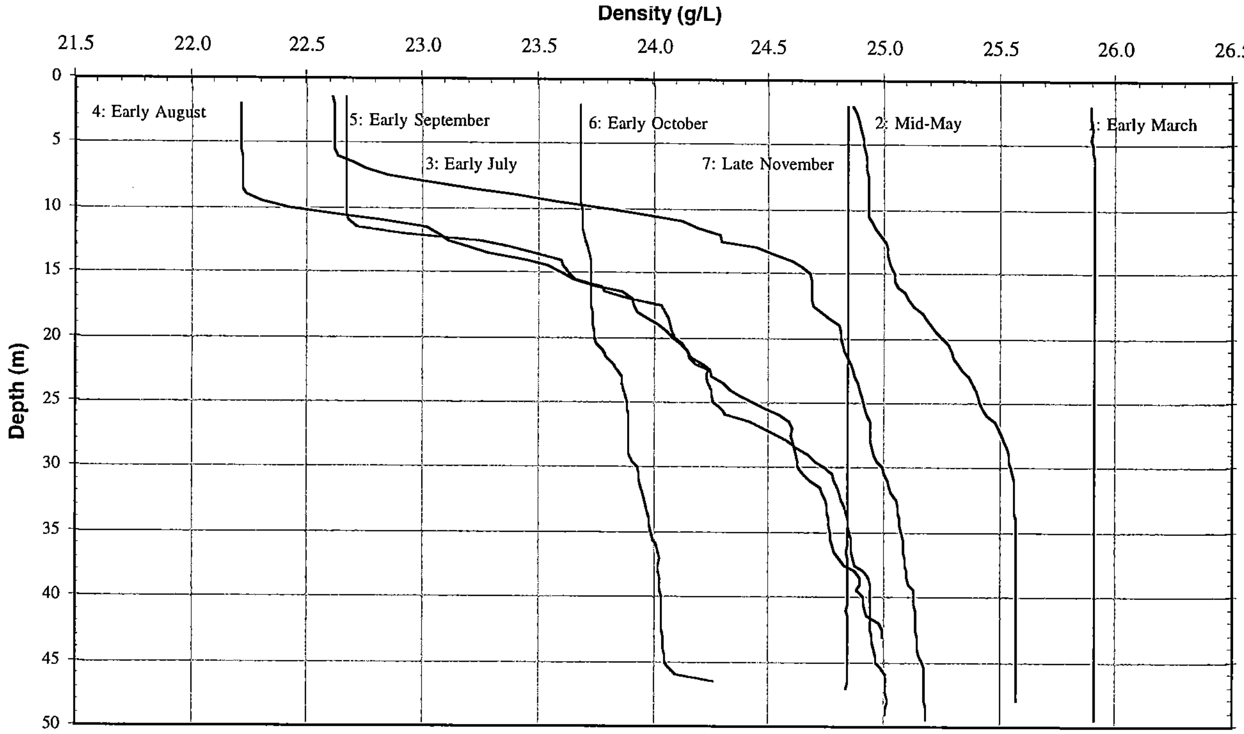
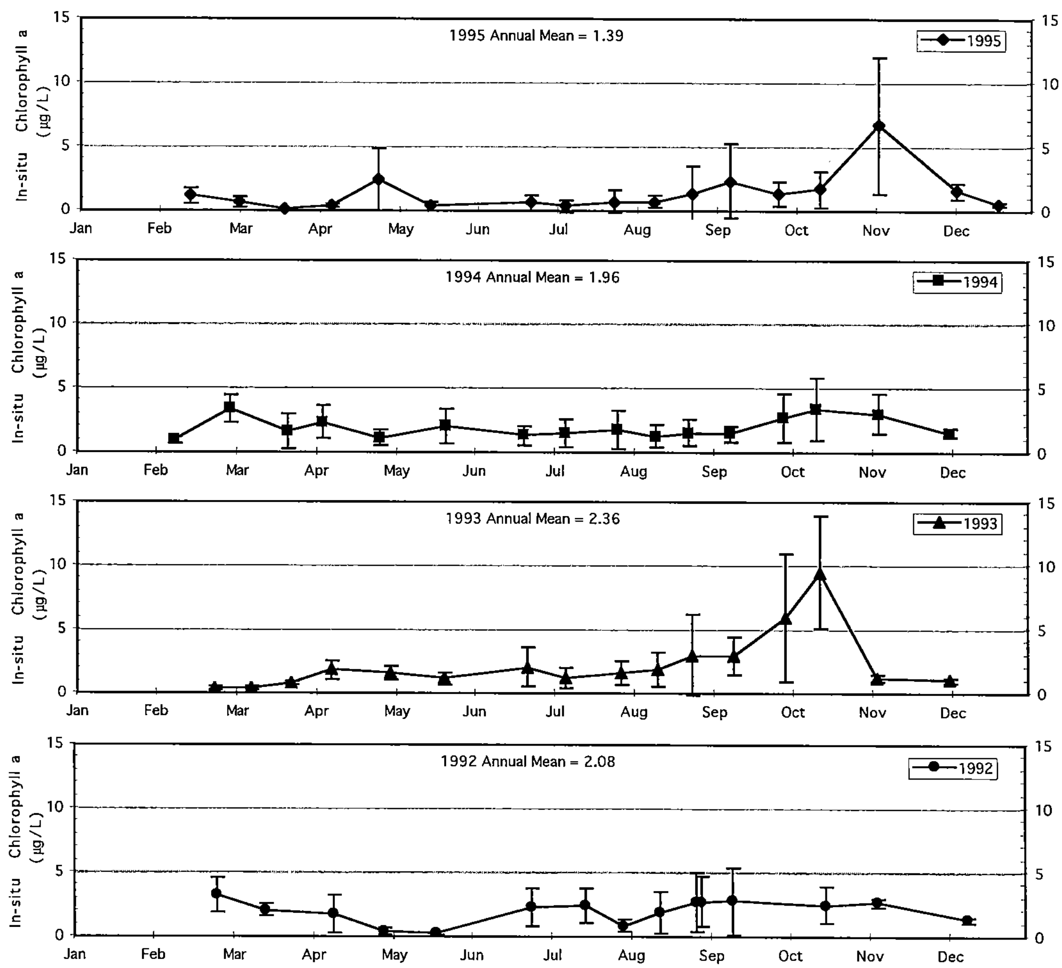


FIGURE 3-7
1995 Seasonal Density Cycle in the Nearfield



- As winds blow from the west and southwest, surface waters are blown away from the coast. Colder bottom waters move in towards shore, and then upwards to replace the warmer outgoing surface waters. This process is known as upwelling, and is experienced by beachgoers as cold water along the shore.

- The saturation level of dissolved oxygen varies with temperature. Cooler water can hold more DO. Therefore, DO concentrations will decrease naturally as the water column warms during the spring and summer.

FIGURE 3-8
1992-1995 Chlorophyll a Averages in the Nearfield
(Error bars represent +/– one standard deviation.)

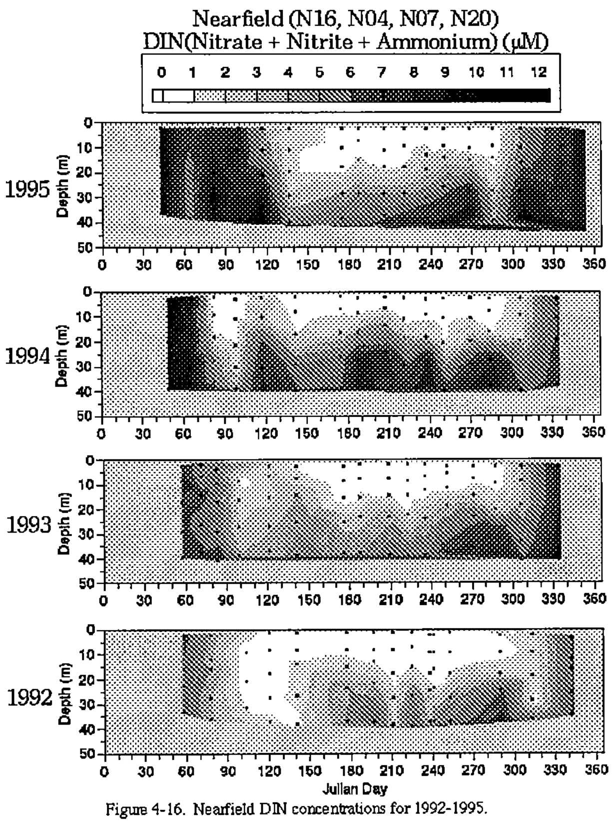


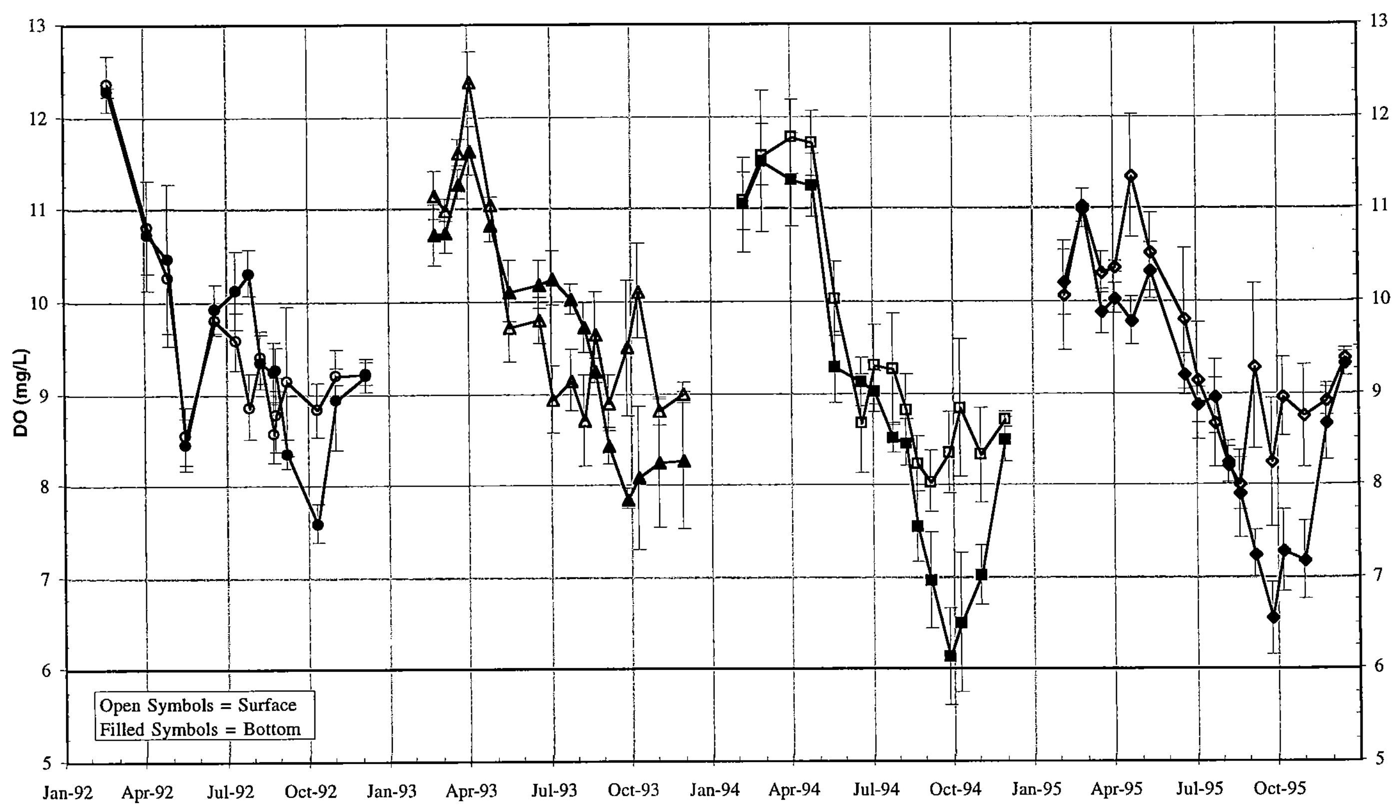
FIGURE 3-9
Nearfield DIN Concentrations for 1992-1995

events can bring DO to the bottom water, as seen in results from the upwelling event observed during July 1995 (Figure 3-10). The fall water column overturn ends the isolation of the bottom layer and results in increased DO concentrations in the bottom waters. Minimum DO concentrations in the bottom water are reached just before overturn, and in 1995: 5.6 mg/L in Cape Cod Bay, 5.7 in the nearfield region and 6.6 mg/L in Stellwagen Basin (Figure 3-11). The survey-average minimum DO concentrations in the nearfield were higher in 1995 than in 1994, although the 1995 concentrations were still significantly lower than in 1992 and 1993. The lower minimum concentrations in 1994 and 1995 were caused by lower pre-stratification DO concentrations in late spring, and faster rates of DO decline during the stratified period (Figure 3-12). The faster rates of DO decline in 1994 and 1995 were driven by warmer bottom water temperatures.

Productivity and Respiration

Both productivity and respiration varied widely over the year. The periods of peak productivity in 1995 occurred before stratification in April, and after overturn in October. These periods correspond to times of a well-mixed, nutrient-rich water column

FIGURE 3-10
1992-1995 Dissolved Oxygen Cycle in Surface and Bottom Waters in the Nearfield
(Error bars represent +/- one standard deviation.)



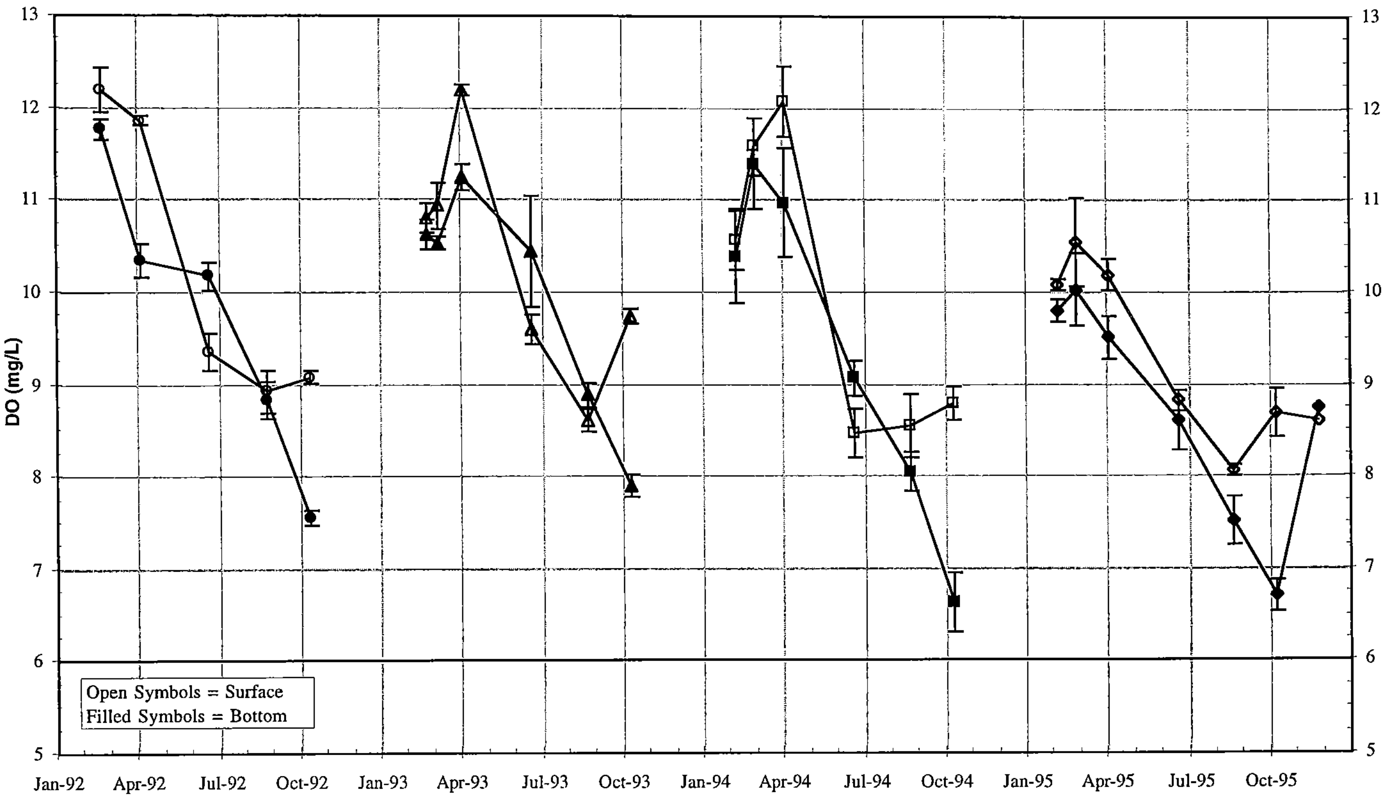
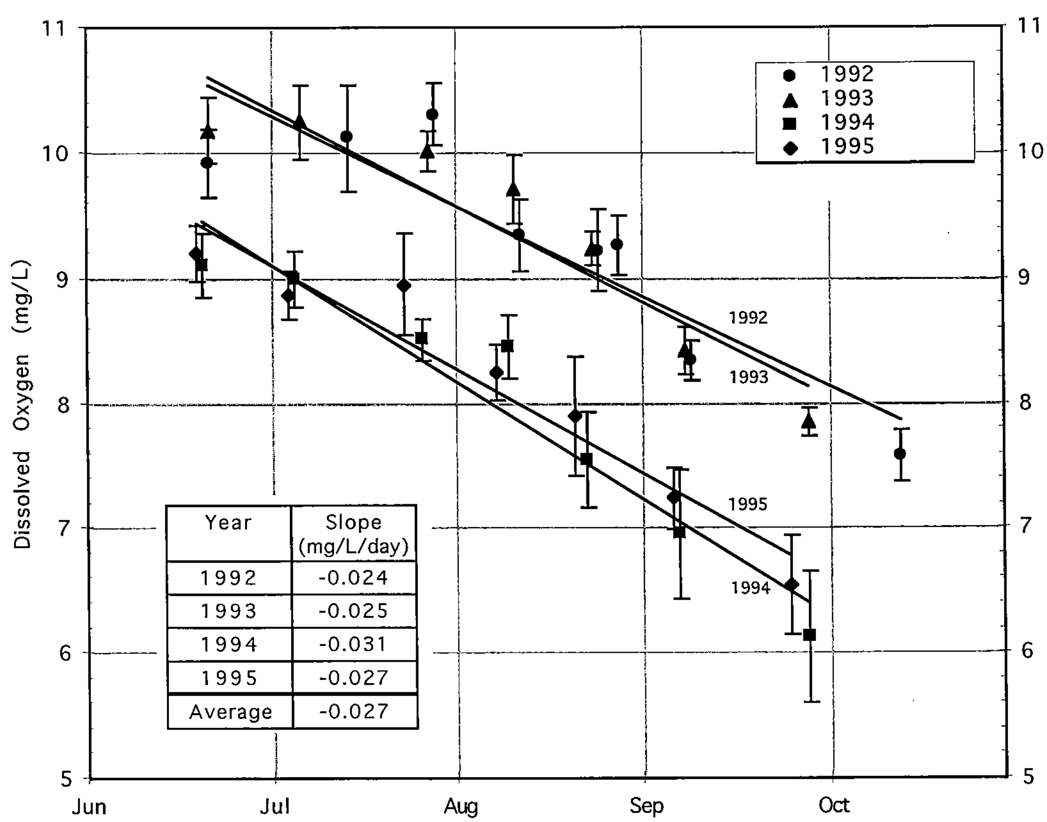


FIGURE 3-11

1992-1995 Dissolved Oxygen Cycle in Surface and Bottom Waters in Stellwagen Basin

(Error bars represent +/– one standard deviation.)



Year	Slope (mg/L/day)
1992	-0.024
1993	-0.025
1994	-0.031
1995	-0.027
Average	-0.027

FIGURE 3-12

Rate of Decline of Dissolved Oxygen Concentrations in Bottom Waters in the Nearfield.

(Error bars represent +/– one standard deviation.)

with plenty of daylight. Algal growth rates were intensely stimulated by the July upwelling event, but too briefly to increase the biomass appreciably. Water column respiration was uniformly distributed during the unstratified period. During stratification, the upper layer experienced higher rates of respiration, while the bottom layer respiration rates were ten times lower. The lower rate of bottom water respiration appears to be related to a reduction in the transfer of organic matter into the colder, bottom layer during the period of stratification.

Marine Mammal/Sea Turtle Observations

A number of whales, dolphins, and harbor seals were sighted during the nearfield surveys. All of the whale sightings occurred during the summer surveys. During the late July survey, three Fin whales, 11 Minke whales, and three unidentified whales were observed. One Fin whale and one unidentified whale were sighted during the early August survey. Two dolphins were observed during the late September survey. One harbor seal was observed during each of the surveys in late March, mid May, early July, and early December. No sea turtles were sighted during any of the surveys.

4.0 Benthic Studies

4.1 Benthic Issues

4.1.1 Nutrients

The concern regarding impact of nutrients on benthic sediments in the area surrounding the outfall, is that eutrophication, as discussed in the Water Column Monitoring section, might lead to hypoxia (low oxygen) in the bottom water overlying the seafloor and, consequently, decreased oxygen within the sediments.

A normal healthy benthic faunal community depends upon well-oxygenated overlying water to deliver the oxygen necessary for benthic respiration and metabolism. The burrowing and other activities of the animals assist the penetration of the oxygenated water down into the sediments. Generally, the healthier the community, with larger and more active animals present, the deeper the penetration of oxygen into the sediment. Thus, the depth of oxygen penetration in soft sediments is monitored by MWRA as a measure of environmental health with respect to sediment oxygen supply and demand.

- The depth of oxygen penetration, or depth to the redox potential discontinuity (RPD), is the location where the sediments change from oxic (having oxygen) to anoxic. The RPD depth can be accurately measured using a microelectrode, but more readily can be estimated (apparent RPD) by visual examination of sediment cores or, more reliably, sediment profile images. The appearance of the oxygenated (aerobic) near-surface layer is light-colored; the deeper anaerobic (having no oxygen) layer is generally full of sulphides and looks dark blue or black.

4.1.2 Toxic Contaminants

Many toxic substances attach to solids, or in the case of metals, may precipitate out of the water column, so are of concern when monitoring the health of the sediments. The solids settle to the bottom, and the contaminants associated with the solids may concentrate, particularly in muddy areas of the bottom where sediments accumulate (sediment deposition areas). Toxic contaminant concentrations in sediments are monitored by MWRA to assess the validity of the prediction that discharge of wastewater from the outfall will not lead to toxic contamination of the sea floor.

4.1.3 Solids and Organic Material

Solids of concern are tiny particles (mud, sand, organic debris) that might be present in the effluent discharged at the outfall. A potential impact of solid particles on the benthic habitat is smothering caused by particulate deposition. Such an impact could occur if the rate of deposition became so great that benthic organisms could not maintain contact with the surface, by burrowing upward, where oxygenated water is available. The problem would be even greater if the settling solids consist of organic material that consumes oxygen.

4.2 Monitoring Program Design

The benthic monitoring program is designed to provide qualitative and quantitative descriptions of the benthic environments of Boston Harbor and Massachusetts and Cape Cod Bays. The goals of the benthic program are twofold. The first objective is to document the recovery of benthic conditions in Boston Harbor following the cessation of sludge discharge and improvements in Combined Sewer Overflow (CSO) treatment and discharge. Comparison of benthic parameters measured before and after termination of sludge disposal into the harbor has provided valuable information on bottom sediment response and benthic ecosystem recovery. Further improvement in sediment quality in Boston Harbor should be seen after the transfer of sewage from the existing Deer Island outfall to the new Massachusetts Bay outfall in 1998.

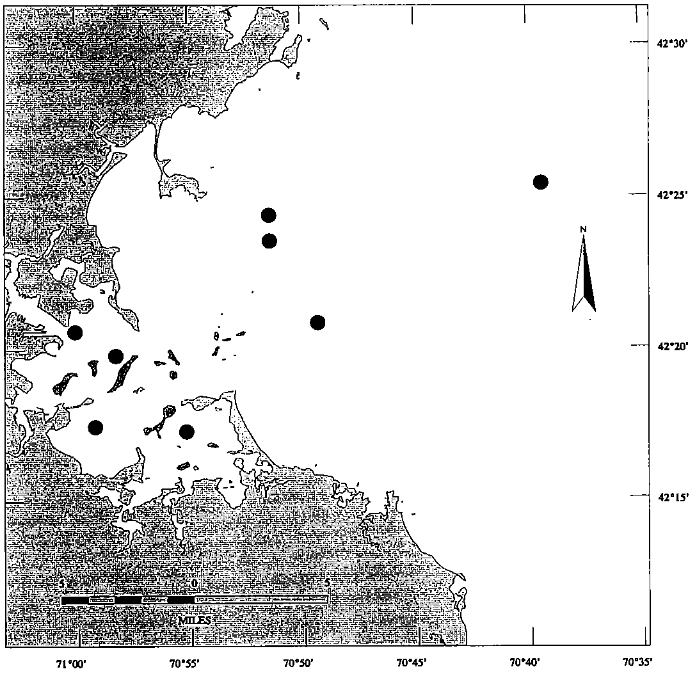
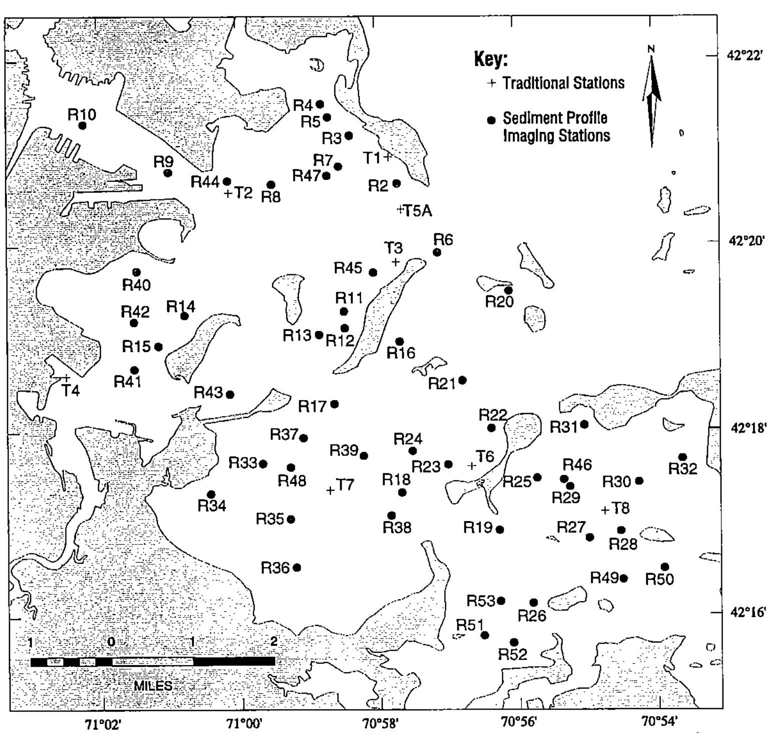


FIGURE 4-1
Benthic Nutrient Flux Sampling Locations

The second objective is to collect background data on physical, chemical, and biological processes in the benthic environment near the outfall location in Massachusetts Bay. These data are essential to assessing potential impacts of the discharged effluent on the surrounding benthic ecosystem.

The benthic monitoring program uses a different definition of nearfield from that used by the water column monitoring program. For the water quality program the nearfield is a rectangle with sides 5 km (3 miles) from the outfall, and farfield stations are those outside that rectangle. The benthic program originally followed a similar convention but with greater sophistication of its spatial analyses now discriminates between three areas of the Bay: the nearfield is 0-2 km from the outfall, the midfield is 2-7 km, and the farfield is greater than 7 km. This convention was not strictly followed in the 1992-1995 surveys, but was included in the 1996 program. The nearfield definition coincides with the area that will be impacted according to the SEIS. The midfield is farther from the outfall and should not show impacts. The station design for the biological program provides the minimum number (12) of samples, necessary for detection of change (Coats, 1995), in each area. There are 8 stations (2 with triplicate samples = 12 samples) in the nearfield, 15 stations (4 with triplicate samples = 23 samples) in the midfield, and 8 stations (all with triplicate samples = 24 samples) in the farfield. Three of the midfield stations, FF10, FF12, and FF13 retain their prior farfield station names to eliminate the necessity of assigning totally new numbers to them; there are already station designations for MF10, MF12, and NF13.

FIGURE 4-2
Boston Harbor Benthic Sampling and Sediment Profile Imaging Stations



Three types of benthic surveys are performed: nutrient flux surveys, soft-bottom surveys, and hard-bottom video surveys. Each of the three survey types is described below.

4.2.1 Nutrient Flux Surveys

Nutrient flux surveys are designed to measure nutrient interactions between sediments and the water column in Boston Harbor and Massachusetts Bay. The nutrient flux surveys take place five times per year at seven sampling locations; in 1995, an eighth station (Quincy Bay), was sampled during the last three surveys (Figure 4-1). Using a sediment coring technique, vertical columns of sediment are removed and brought to the surface intact. For each sediment core, measurements are made of sediment oxygen demand and oxygenation, sediment nutrient flux, and sediment pore water (water contained between sediment particles) nutrients. Analysis of these parameters provides information required to assess nutrient and oxygen exchanges between sediments and the water column, as well as the potential for sediment and water column oxygen impacts.

4.2.2 Soft-Bottom Surveys

Soft-bottom benthic surveys are the core of the benthic monitoring program because they focus on muddy depositional areas which tend to accumulate suspended material. The surveys are designed to assess sediment quality and the status of the benthic communities living in Boston Harbor and Massachusetts and Cape Cod Bays. The soft-bottom surveys use a combination of sediment grab samples and sediment profile images from specified locations to examine the benthic infauna, and physical and chemical sediment parameters, including the apparent redox potential discontinuity (RPD) depth. The four sampling regions are Boston Harbor, the nearfield close to the outfall, the midfield, and the farfield area ranging east to Gloucester and southeast into Cape Cod Bay.

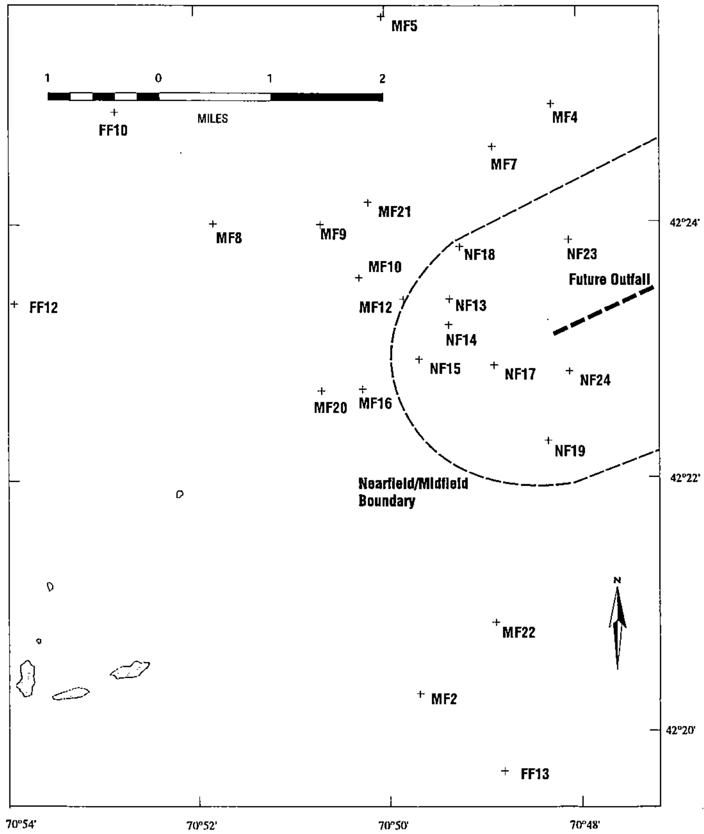
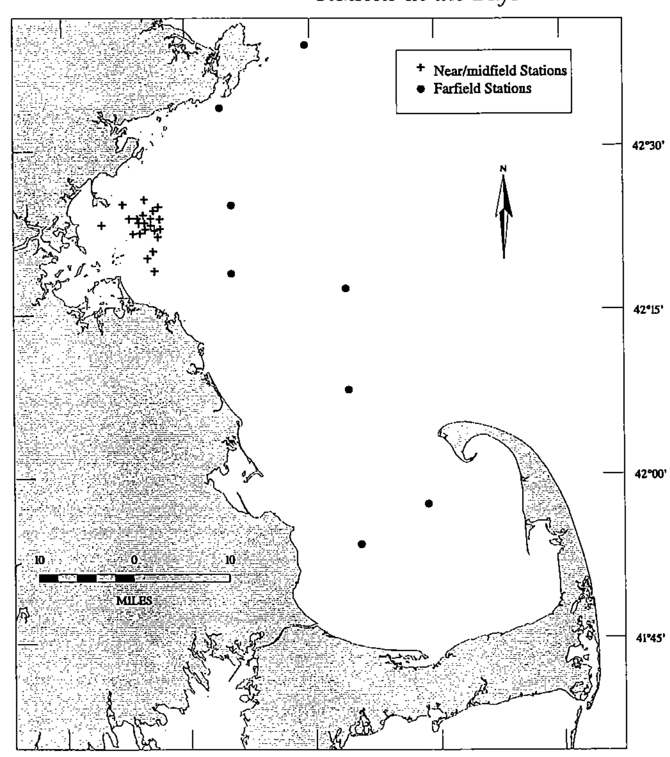


FIGURE 4-3
Nearfield and Midfield Soft Bottom Stations

The Boston Harbor soft-bottom surveys, designed to measure long-term recovery in benthic communities and sedimentary conditions at a variety of locations, are performed twice annually. Grab samples are collected during both surveys at eight stations. Sediment profile images are collected from the same eight stations, as well as an additional 52 stations during the summer survey (Figure 4-2).

FIGURE 4-4
Soft Bottom Benthic Stations in the Bays



Massachusetts Bay soft-bottom surveys in the outfall nearfield and midfield areas provide baseline data on the sedimentary environment, contaminant concentrations, and benthic infaunal communities that can be used as a benchmark to evaluate the effects of sewage disposal from the future outfall when it becomes operational. Surveys of the nearfield and midfield benthos are performed once per year with sampling at eight nearfield (less than 2 km from the diffuser) and fifteen midfield (between 2 km and 7 km from the outfall) stations (Figure 4-3). In 1995, sediment profile images were collected from all eight nearfield and twelve midfield stations.

Farfield soft-bottom sediments are also sampled once per year at eleven locations (Figure 4-4) throughout Massachusetts and Cape Cod Bays. Eight farfield stations are outside of the 7 km midfield boundary; three are in the midfield. The farfield baseline is used as reference for the nearfield and midfield stations and as true monitoring stations in the unlikely event that the effects of the sewage discharge extend farther than expected.

4.2.3 Hard-Bottom Surveys

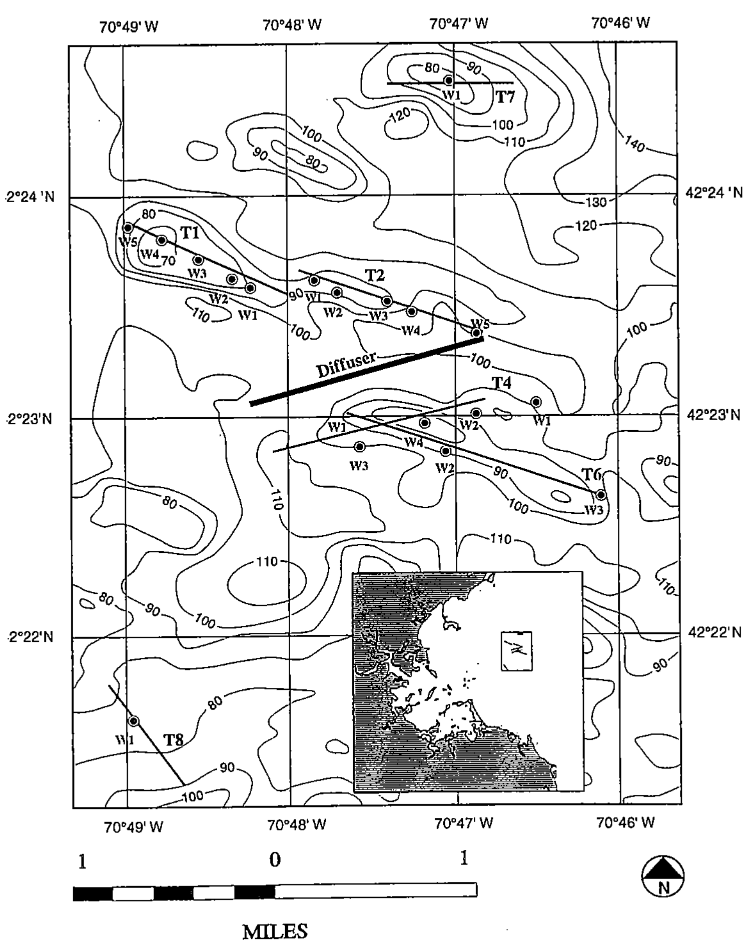
A nearfield hard-bottom video survey is performed annually to supplement the nearfield soft-bottom surveys. The hard-bottom survey provides visual information on the benthic habitat and organisms occupying rock and cobble areas near the future outfall. The concern is that the organisms may be particularly susceptible to the smothering which could occur during the stratified period when low currents may allow particles to accumulate on the rocks. The hard-bottom survey is performed using a remotely operated vehicle (ROV) equipped with a color video camera and a 35-mm camera. These surveys permit assessment of topography and substrata, populations of attached and mobile marine organisms, and other evidence of biological activity. Each survey is performed along pre-specified transects to permit detection of year-to-year changes. In 1995, six hard-bottom transects were surveyed (Figure 4-5).

Both video and still photographs are valuable for establishing baseline data of the drumlin areas near the outfall. The still photographs are used to show finer details of the structure of benthic communities inhabiting hardbottom areas in the vicinity of the new sewage outfall than can be discerned from a review of the video tapes. The two techniques are complementary: the video survey provides greater areal coverage,whereas the still photographs provide more accurate assessments of the benthic communities inhabiting these areas.

4.3 Threshold Comparison

Trigger parameters and their thresholds for the benthic sediments and 1995 monitoring results are summarized in Table 4-1. The basis of the trigger parameters and threshold values, as well as progress in comparing monitoring results to threshold values are discussed below.

FIGURE 4-5
Nearfield Hard-Bottom Benthic Survey Transects



Benthic Community Structure.

Benthic community thresholds are intended to verify the prediction in the SEIS that there will not be appreciable change in the benthos outside the 2 km outfall boundary. The trigger level to describe community change is under development, and MWRA has been considering the utility of various measures of benthic species composition, diversity, and relative abundance. The trigger level developed will involve comparison of a measure of the community in the midfield with its baseline values.

Diversity values using the 1995 data are shown on Table 4-2. Three measures of species diversity, Shannon-Wiener diversity (H'), evenness (J'), and Hurlbert rarefaction are given. These results show that, by most criteria, FF13 (just east of Point Allerton, i.e., Hull) is the least diverse station and FF10 (east of Nahant) is the most diverse of the midfield stations.

TABLE 4-1
Benthic Thresholds Compared to 1995 Monitoring Results

Parameter	Caution Level	Warning Level	1995 Results
Community Structure (Diversity, Species Composition, and Species Abundance) in outfall midfield area	Species diversity, composition, and relative abundance patterns measured in the midfield appreciably depart from those measured during the baseline monitoring period, after factoring out the effect of storms on sediment texture. Specific diversity threshold values are being developed.	None.	Shannon-Wiener Diversity Index Midfield mean = 2.71 (Range 2.18 - 3.13) (See also Table 4-2)
Depth of Oxygenated Sediments [Redox Potential Discontinuity (RPD) Depth] in outfall nearfield area.	RPD depth declines by half. The threshold value is under development.	None.	Nearfield mean = 3.5 cm (Range 1.8 - >6.2 cm)
Toxic Contaminant Concentrations in outfall nearfield area.	Nearfield mean toxic contaminant concentrations greater than 90% of EPA sediment criteria.	Nearfield mean toxic contaminant concentrations greater than EPA sediment criteria or the NOAA Effects Range Median (ER-M) value. Examples: NOAA ER-M values: PCBs = 180 ng/g Mercury = 0.71 µg/g	Example Results: PCBs: Geometric Mean = 4 ng/g Range = 1.1 - 53 ng/g Mercury: Geometric mean = 0.16 µg/g (See also Table 4-3)

TABLE 4-2
1995 Diversity Data for the Midfield Stations (2-7 km from the outfall)

Trigger Parameter	Caution Level	Warning Level	Range and Mean ($\bar{x}$)
Shannon-Wiener H'	Appreciable change	No criteria	2.18 (FF13) - 3.13 (FF10) $\bar{x}$ = 2.71
Evenness J'	Appreciable change	No criteria	0.52 (FF13) - 0.69 (MF4) $\bar{x}$ = 0.64
Hurlbert Rarefaction # spp./50 ind.	Appreciable change	No criteria	12.97 (FF13) - 20.63 (FF10) $\bar{x}$ = 16.48
Hurlbert Rarefaction # spp./100 ind.	Appreciable change	No criteria	18.20 (MF8) - 30.11 (FF10) $\bar{x}$ = 23.12
Hurlbert Rarefaction # spp./500 ind.	Appreciable change	No criteria	34.43 (MF8) - 58.63 (FF10) $\bar{x}$ = 44.07

Establishment of the final threshold values and comparison of threshold values to post-discharge monitoring results will need careful consideration. A decrease in species diversity or a change in species composition is not necessarily a measure of "degradation". While a moderate organic enrichment of the sediment may cause the disappearance of some sensitive species, the overall effect may not necessarily be detrimental if increased biomass is available as a food source for bottom fishes. Also, the existing data from previous years shows that dramatic changes in diversity or other community parameters can occur in the natural system from year to year even without any discharge effect.

Redox Potential Discontinuity

The Redox Potential Discontinuity (RPD) depth is the location where the sediment changes from oxic, or oxygenated, to anoxic, or depleted of oxygen. The RPD depth provides an important measure of the overall health of the benthic infauna habitat. In the absence of a state standard for the RPD depth, a threshold was developed to measure and evaluate significant changes in RPD depth which could provide an indication of adverse impacts from the deposition of discharged organic material. The RPD depth threshold is applicable to the nearfield area.

The 1995 RPD depth results indicate that, in general, sediments appear to be well-oxygenated and are healthy with respect to the depth of oxygenated sediments. The 1995 RPD depth data showed a range of 1.8 cm to greater than 6.2 cm (sediments oxygenated at maximum depth reached), with a mean value of 3.5 cm. Comparison of the results from 1995 and previous years indicates that RPD depth values are similar and have not changed significantly.

Toxic Contaminants

Thresholds for toxic contaminants in sediments are established to be protective of benthic organisms. Monitoring results from the post-discharge operation period will be compared to sediment threshold values to verify predictions of potential toxic contaminant concentration in sediments and to assure that adverse toxic effects to benthic organisms do not occur. Specific threshold values are based on EPA sediment criteria and NOAA ER-M values. Draft EPA sediment criteria exist for five organic contaminants: acenaphthene, fluoranthene, phenanthrene, dieldrin, and endrin. NOAA ER-M values are available for a variety of organic and metal contaminants.

Comparison of 1995 sediment concentration data to relevant thresholds is provided on Table 4-3. The trigger parameter is expressed as a sediment concentration averaged over the nearfield stations (less than 2 km from the future outfall). As in previous years, organic contaminant concentrations were generally low and did not exceed any of the thresholds; even station NF24 with a TOC concentration of 2.77% had organic compound concentrations well under EPA sediment criteria that assumed 1% TOC. Metal concentrations were similar to those measured in previous years. The nearfield mean concentrations for all heavy metals were below the warning level. One individual nearfield station, however, had a mercury concentration of 1.69 µg/g (NF24, Fig 4-3), exceeding the warning level of 0.71 µg/g. Outside the nearfield, station MF21 also had elevated mercury (0.68 µg/g). Elevated mercury was also apparent in the 1994 data and reflects the very highly depositional nature of those sites (data prior to 1995 are unavailable because these stations were added in 1994).

TABLE 4-3
Toxic Contaminant Thresholds and 1995 Data for the Eight Nearfield Stations (0-2 km from the outfall)

Trigger Parameter (units)	Caution Level: 90% EPA criterion[1]	Warning Level: EPA criterion[1] or (NOAA ER-M)[2] level	Range and Mean ($\overline{x}$), and (Geometrical Mean)
Organic Contaminants			
Total PAH (ng/g)	—	(44,792)	78 (NF17) - 10,903 (NF24) $\overline{x}$ = 2,380; (870)
Acenaphthene (ng/g)	1170	1300 (500)	ND (2 stations) - 41(NF24) $\overline{x}$ = 11; (NA)[4]
Fluoranthene (ng/g)	5580	6200 (5100)	8.8 (NF17) - 1050 (NF24) $\overline{x}$ = 245; (96)
Phenanthrene (ng/g)	1620	1800 (1500)	4 (NF17) - 570 (NF24) $\overline{x}$ = 132; (49)
Total PCB (ng/g)	—	(180)	1.1 (NF13, NF17, NF23) - 53 (NF24) $\overline{x}$ = 10; (4)
Total Chlordane (ng/g)	—	(6)[3]	ND (7 stations) - 1.09 (NF24) $\overline{x}$ = 0.136; (NA)[4]
Total Dieldrin (ng/g)	99	110 (8)[3]	ND[5] (8 stations) $\overline{x}$ = 0; (NA)[4]
Endrin (ng/g)	37.8	42	ND[5] (8 stations) $\overline{x}$ = 0; (NA)[4]
Total DDT (ng/g)	—	(46.1)	ND (3 stations) - 11.21 (NF24) $\overline{x}$ = 2.2; (NA)[4]
Trace Metal Contaminants			
Cadmium (µg/g)	—	(9.6)	0.05 (NF13) - 0.46 (NF24) $\overline{x}$ = 0.12; (0.09)
Chromium (µg/g)	—	(370)	23.2 (NF23) - 177.0 (NF24) $\overline{x}$ = 53.5; (41.7)
Copper (µg/g)	—	(270)	3.41 (NF23) - 54.25 (NF24) $\overline{x}$ = 16.60; (11.22)
Lead (µg/g)	—	(218)	25.8 (NF23) - 92.9 (NF24) $\overline{x}$ = 44.9; (41.3)
Mercury (µg/g)	—	(0.71)	0.029 (NF23) - 1.69 (NF24) $\overline{x}$ = 0.36; (0.16)
Nickel (µg/g)	—	(51.6)	7.2 (NF17) - 31.8 (NF24) $\overline{x}$ = 13.8; (12.3)
Silver (µg/g)	—	(3.70)	0.08 (NF17) - 1.1 (NF24) $\overline{x}$ = 0.3; (0.2)
Zinc (µg/g)	—	(410)	25.2 (NF17) - 131.5 (NF24) $\overline{x}$ = 49.5; (42.7)

[1] Values for EPA sediment quality criteria assume 1% organic carbon. Hull and Suter (1995)
[2] NOAA ER-M levels taken from Long *et al.* (1995)
[3] From Long and Morgan (1992)
[4] NA = Not Available. Geometric means cannot be calculated for data sets that include zeroes.
[5] Detection levels: Dieldrin = 0.022 ng/g; Endrin = 0.0061 ng/g.

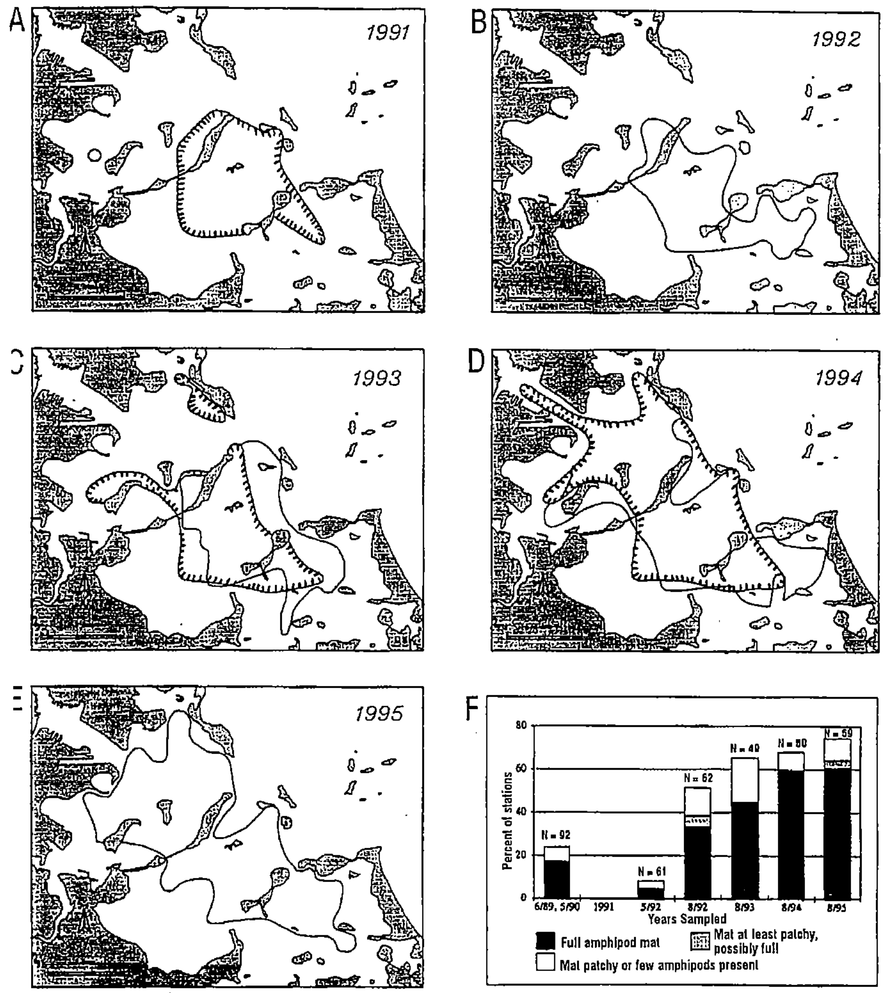


Figure 4-6
Distribution of Amphipod Tube Mats in Boston Harbor from 1991 Through 1995.
Maps courtesy of Brian Howes and Tony Millham, Woods Hole Oceanographic Institution.

- *Ampelisca abdita*, and *A. vadorum* are pollution sensitive, deposit-feeding amphipod crustaceans capable of building tube mats. Tube mats are often several centimeters thick, and may reach densities of over 100,000 individuals per square meter. The widespread colonization of Boston Harbor sediments by this infaunal complex has increased both the degree of sediment oxidation and rates of sediment/water column exchange through bioturbation and burrow ventilation.

4.4 Monitoring Results

Data from the benthic study monitoring program can be broadly categorized as physical, biological and chemical study results. The physical nature of the bottom sediments define the benthic habitat. Benthic organisms that inhabit muddy, sandy, or hard bottom gravel substrates are significantly different.

In Boston Harbor, most surficial sediments consist of mud (silt + clay) rather than sand. In channel and shallow areas near islands, however, fine sediments are washed away by currents and waves, and sandy sediments predominate.

In Massachusetts Bay, there is an overall trend toward finer sediments offshore. However, in western Massachusetts Bay near the outfall, the bottom characteristics are highly variable, ranging from erosional hard bottom (cobbles, gravel, and rock) to soft bottom consisting of sands and muds. These various bottom types are widely interspersed with patch sizes on the order of hundreds of meters. Furthermore, the sediment profile camera has revealed that the sediment spatial pattern between the hard-bottom environment nearest the outfall and the fine sedimentary depositional area further west is temporally dynamic, showing significant movement and redeposition of sediments following major storms. In contrast, the benthic environment in Cape Cod Bay is relatively homogeneous and stable over time.

4.4.1 Biological Study Results

Surveys of benthic biological communities are used by MWRA to evaluate the overall ecological health and environmental quality of the Massachusetts Bay and Cape Cod Bay systems.

4.4.1.1 Boston Harbor

One of the more intriguing findings of the Boston Harbor surveys has been widespread development of dense tube mats of the opportunistic, yet pollution-sensitive amphipod *Ampelisca abdita*. The ampeliscid tube mats have contributed to the appearance of other amphipods as well. Since 1991, there has been a steady increase in the area covered by amphipod tube mats in the harbor (Figure 4-6). Prior to the elimination of sludge discharge, less than 20 percent of stations surveyed showed the presence of amphipod tube mats. By 1995, more than 60 percent of the monitoring stations showed well-developed tube mats. This phenomenon is likely related to improving sediment and water quality following sludge discharge abatement and possibly to the October 1991 storm which dramatically altered the sediment structure in the Harbor. *Ampelisca* colonization has led to increased sediment oxygenation and improved sediment quality.

Although the benthic infaunal communities in the harbor differ from station to station, they have historically fallen into two groups. Northern stations, closest to the outfalls, have been characterized by opportunistic, highly variable assemblages that are able to tolerate high organic sediment loading. Southern stations have generally exhibited more consistent and predictable assemblages dominated by organisms that require better sediment quality (e.g., tube-dwelling amphipods). Sludge abatement has changed the infauna at some northern stations so that they have become progressively more similar to the southern stations.

Infauna species richness increased harborwide since 1991, especially at the northern stations. Several species that were previously rare or absent are increasing significantly in numbers (e.g., the polychaete worm, *Chaetozone vivipara*, and amphipods belonging to the genus *Corophium*). The change in species richness is probably due to habitat modifications caused by *Ampelisca*, which in turn may be related to the sludge abatement.

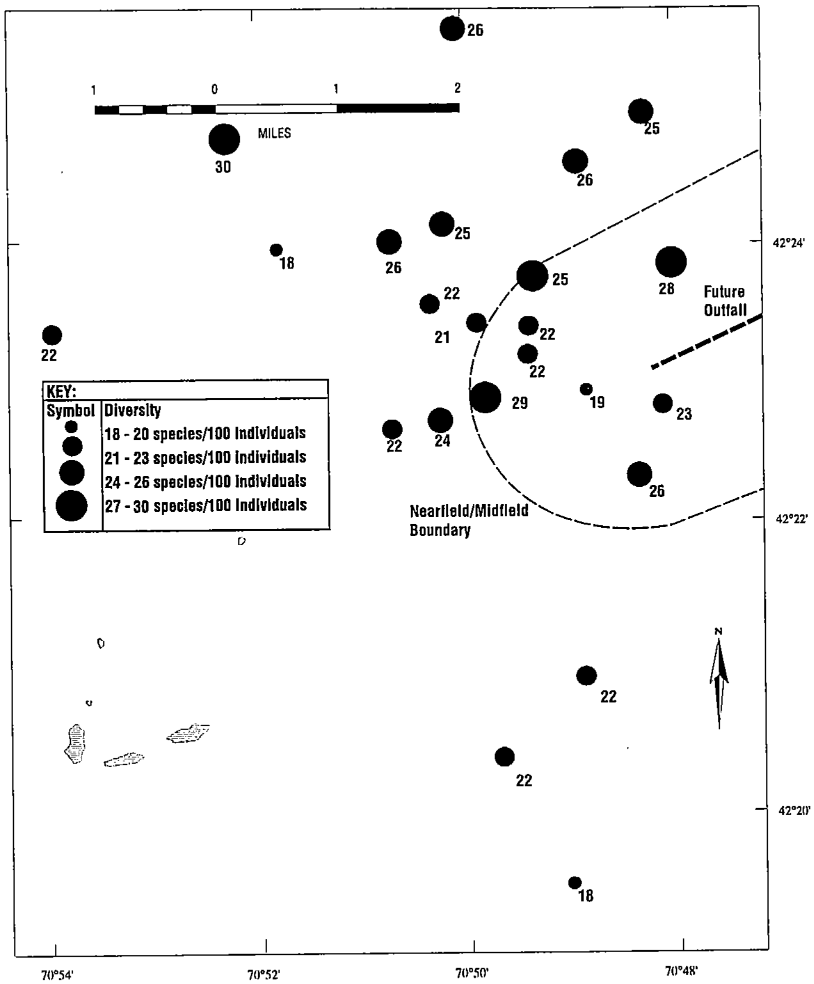


Figure 4-7
Soft-Bottom Benthic Community Diversities at Nearfield and Midfield Stations.

4.4.1.2 Massachusetts Bay

Benthic biology surveys in Massachusetts Bay provide baseline data that can be used as a benchmark to evaluate the potential effects of sewage disposal from the future outfall when it becomes operational.

- **Sediment carbon and nutrient cycling data are sensitive indicators of the changing ecological health of Boston Harbor and are key elements for evaluating the oxygen balance of Massachusetts Bay bottom waters. Results from studies of the sediment-infauna habitat within Boston Harbor provide an example of the complex response of marine systems to changes in organic matter loading rates and the need for direct measurement of benthic processes.**

Nearfield and Midfield Soft-bottom Community

The results of the 1995 Massachusetts and Cape Cod Bays benthic surveys were similar to those seen in the previous year's baseline monitoring data. The structure of the benthic communities in the nearfield and midfield was largely determined by sediment grain-size. In finer-grained sediments, some marine worm species (capitellid and spionid polychaetes) were most abundant, while in sandier sediments, other worm species (syllid and paraonid polychaetes), amphipod crustaceans, and certain oligochaetes predominated. These basic community structures have been observed in the area since inception of this program, with changes at individual stations reflecting the shifting of sediments at individual stations by storm-generated currents.

- Benthic Community Diversity is often used to evaluate environmental change. Examples of changes in community diversity include changes in the relative abundance of various species, or changes in the numbers and kinds of species that live in a particular habitat.

- Diversity of marine organisms is often used as a measure of environmental health; typically, the more diverse the assemblage (i.e., the more species present, taking into account the number of animals collected) the healthier the community. One way to look at diversity is to calculate how many species would have been collected if a sample had only contained a specific number of organisms. This technique, known as rarefaction, allows samples differing in size to be compared.

The results of the soft-bottom surveys suggest that biological variability in the vicinity of the future outfall is greater than expected from pre-baseline monitoring. For example, there was an appreciable change in the dominant spionid polychaete species present in 1995 compared to 1992-1994. In 1992-1994, *Spio limicola* dominated, but in 1995 the dominant species was *Prionospio steenstrupi*, last found to be abundant in the 1987-1988 reconnaissance surveys.

Densities of benthic infauna in Massachusetts Bay are often high, but do not generally reflect stressed environments like those existing in parts of Boston Harbor. The dominant species in the bay are not typically associated with deteriorated benthic habitats but are species that often are found in areas with suspended organically-enriched material in the water column. Certain dominant taxa such as spionid polychaetes are able to clear organic-rich material from the water column, and use it for food and material for tube construction.

In 1995, faunal diversities at the nearfield and midfield stations were similar (Figure 4-7). The number of species in the nearfield ranged from 19 to 29 species per 100 organisms, whereas in the midfield, diversity ranged from 18 to 30 species per 100 organisms (Table 4-2).

Farfield Soft-Bottom Communities.

Benthic community structure in the farfield was mostly influenced by water depth and also by location (Massachusetts Bay versus Cape Cod Bay). The most common species in the farfield were generally similar to those in the nearfield. The two Cape Cod Bay stations differed the most from the Massachusetts Bay stations, probably because of a different sedimentary environment. The spionid polychaete *Prionospio steenstrupi* ranked first at all Massachusetts Bay stations, but was not among the most dominant species at the Cape Cod Bay stations where cossurid polychaetes dominated.

Diversity was basically similar to that of the nearfield and midfield, ranging from 16 to 26 species per 100 organisms. Species diversity, species composition, and infaunal density all exhibit large swings from year to year, as they do in the nearfield. These variations probably reflect changes in area-wide environmental conditions that in turn influence the timing and success of larval settlement of benthic organisms. However, faunal assemblage patterns in the farfield are more consistent than in the nearfield so that sampling in the farfield will help distinguish changes due to natural processes from those caused by anthropogenic ones related to the operation of the outfall. Similarities between the benthic community at midfield stations and a farfield station near Gloucester Harbor indicate that the Gloucester station can serve as a good qualitative reference site for benthic communities in the vicinity of the future outfall.

Nearfield and Midfield Hard-Bottom Communities

The complex topography in the hard-bottom areas in western Massachusetts Bay has a substantial influence on epibenthic communities. These communities are primarily determined by depth, with red algae dominating the shallower drumlin tops (about 70 feet deep) and macroinvertebrates dominating the deeper bottoms. Location on the drumlins, depth, bottom type, and habitat relief all appear to play a role in determining the structure of benthic communities inhabiting hard-bottom areas. Some species show strong preferences for specific habitats, while others are broadly distributed. Some areas are homogeneous in terms of bottom type and the fauna inhabiting them, while others exhibit more patchiness.

4.4.2 Sediment Chemistry Results

The MWRA benthic surveys have obtained data necessary to evaluate the sediment quality and related habitat quality conditions and factors in Boston Harbor and Massachusetts and Cape Cod Bays.

4.4.2.1 Boston Harbor

The 1995 study results indicate that sediment quality in Boston Harbor is improving due to the breakdown of the organic matter that had settled on the harbor bottom during sludge discharge, which ended in December 1991. While sludge was being discharged, the benthic community was apparently overwhelmed by the amount of settling organic material. When this practice stopped, the benthic community began to degrade the material that had accumulated over the years. Rates of the organic matter breakdown process, or remineralization, were more than twice as high in 1995 than reported in any previous monitoring period. The remineralization rate increase is likely due to the expansion of *Ampelisca* populations, as discussed above.

The increased remineralization rate has important implications for sediment and water quality in Boston Harbor. Remineralization of organic matter containing nitrogen has resulted in an increased flux of nutrients from sediments into the water column. The remineralization process involves respiration, a DO consumption process. As a result, sediment respiration has an important influence on sediment and water column DO in Boston Harbor. Even though the increased rate of remineralization is improving Boston Harbor sediment quality, organic carbon concentrations remain relatively high and it will likely take several years for natural levels to return.

4.4.2.2 Massachusetts Bay

Dissolved Oxygen/Nutrients

In 1995, rates of sediment oxygen uptake and nutrient remineralization in Massachusetts Bay were comparable to those measured in previous years, in contrast to the changes that have occurred in the Harbor. The sediments at all stations were relatively well oxidized with relatively high RPD values and undetectable dissolved sulfide within the sediment porewaters. Rates of oxygen uptake were low, consistent with measured low rates of nutrient release and porewater nutrient pools. The stability of these measures indicates that they will be sensitive tools for detecting relatively small changes in carbon enrichment.

The Massachusetts Bay benthic environment plays less of a role in contributing to nutrient flux and DO depletion than it does in Boston Harbor. The greater water depth in Massachusetts Bay allows more remineralization to take place within the water column before particles reach the benthos, and stratification tends to isolate the benthos from the upper water column. Bottom waters may be affected by the benthos during periods of stratification.

Toxic Contaminants

Organic constituents in the sediments collected in 1995 (Table 4-3) are similar qualitatively and quantitatively to those from prior years. Concentrations of organic constituents are generally low and in no case exceed any relevant environmental standard.

- Sediment quality guidelines are useful screening tools to evaluate potential impacts to sediment-dwelling organisms. The National Oceanographic and Atmospheric Administration (NOAA) has developed effects-based guidelines based on a weight of evidence from many studies. Chemical concentrations below the NOAA "Effects Range-Low" (ER-L) values are rarely associated with toxic effects, whereas chemical concentrations above the NOAA "Effects Range Median" (ER-M) values often are associated with toxic effects.

Sediment metal concentrations in Massachusetts and Cape Cod Bays in 1995 (Table 4-3) were also similar to those measured in previous years. These metal concentrations are generally below NOAA ER-M values. The existing effluent metal data, and ambient sediment and water quality data, indicate that metal ER-Ms are unlikely to be exceeded after outfall relocation, even with the effluent at the existing primary treatment level. Possible exceptions to this may occur in localized areas if a large accumulation of organic matter results in anoxic conditions near the sediment-water interface. Under those conditions, precipitation of insoluble metal sulfides could enhance sediment metal concentrations. However, since sulfide-bound metals have been demonstrated to be nontoxic, there would not be an increase in sediment toxicity even if such metal precipitation were to occur. Also, the impending treatment plant upgrade from primary to secondary treatment is expected to result in a decrease in effluent metal concentrations, making an adverse increase in sediment metal concentrations even less likely.

5.0 Fish and Shellfish

5.1 Fish and Shellfish Issues

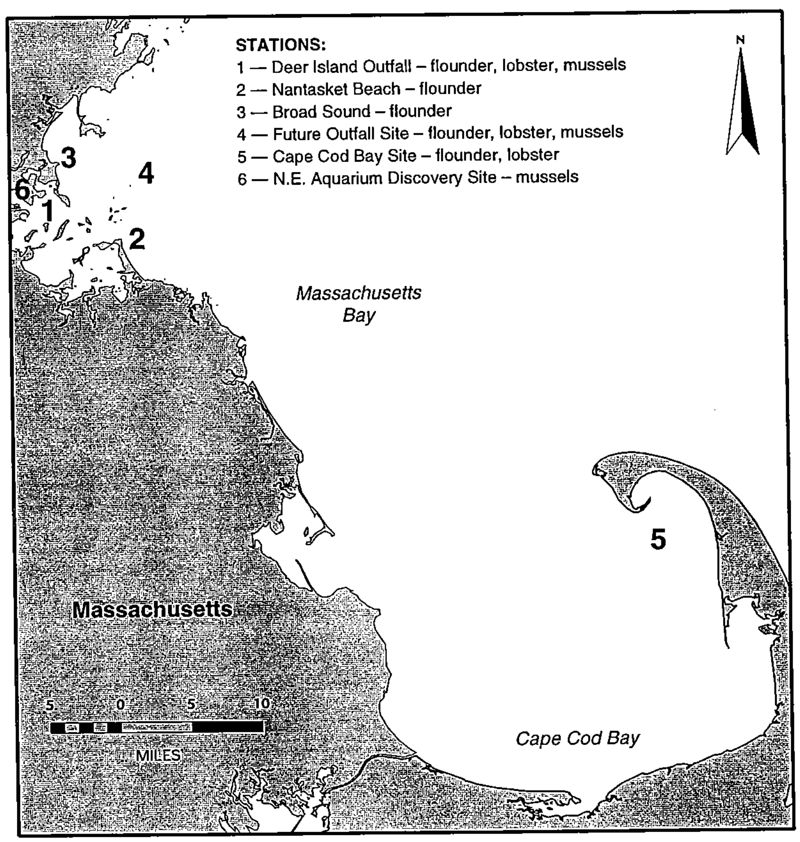
The impending relocation of the outfall has raised questions concerning the effects of the effluent on water quality and marine life. Toxic contaminants in the effluent have the potential to cause a variety of problems throughout the food chain. Because many toxic contaminants adhere to particles, toxic impacts on marine animals are likely to primarily affect bottom-dwelling organisms and the animals that feed on them, such as flounder and lobster. Shellfish, such as mussels and clams, that feed by filtering suspended matter from large quantities of water are also potentially vulnerable to toxic contaminants. Exposure of flounder to toxic contaminants may result in fin rot and other diseases. Consumption of contaminated organisms results in exposure of predators through the food chain including ultimately human consumers of fish and shellfish.

■ Fish and Shellfish Action Levels. The U.S. Food and Drug Administration (FDA) has established action levels for toxic or deleterious substances inhuman food and animal feed. Action levels represent limits at or above which FDA may take action to remove products form the market. For example, the FDA legal limit for contaminants in fish and shellfish is 2.0 ppm for total PCBs and 1.0 ppm for mercury.

5.2 Monitoring Program Design

The fish and shellfish monitoring program addresses potential risks to human health and the environment arising from contamination of ecologically significant and economically important fish and shellfish stocks. The primary goals of this monitoring program are (1) to evaluate the health of these marine resources in terms of disease, and (2) to evaluate organic and inorganic contaminant concentrations in the organs and edible tissues of these organisms. Bioaccumulation data are collected from flounder, lobster, and mussel populations in Boston Harbor, Massachusetts Bay, and Cape Cod Bay. Comparison of the data between stations and between pre- and post-discharge periods will allow evaluation of spatial and temporal trends in the fisheries. In addition, the biomonitoring programs will provide baseline data that may be used to assess the potential environmental impact of the effluent discharge on Massachusetts Bay, and to evaluate the facility's compliance with the NPDES effluent discharge permit requirements. The three biomonitoring surveys are outlined below.

FIGURE 5-1
Sampling Stations for Winter Flounder, Lobster and Mussels during 1995.



The flounder survey is designed to collect sufficient mature winter flounder to perform general and histopathological examinations and determine bioaccumulation of priority pollutant organics, metals, and other constituents. Flounder surveys began in 1991 and are performed annually at five locations: the Deer Island outfall, future outfall site, Cape Cod Bay site, Broad Sound and Nantasket Beach (Figure 5-1). Fish are collected using a bottom trawl deployed by a commercial dragger.

Similarly, the lobster survey is designed to collect sufficient mature lobster specimens to provide data on gross abnormalities and provide sufficient tissue samples for determination of physiological condition and body burden of contaminants. Once each year since 1992, lobsters have been collected in 25 to 30 commercial lobster traps deployed at each of three locations: the Deer Island outfall, future outfall site, and Cape Cod Bay site (Figure 5-1).

In the mussel bioaccumulation survey, blue mussels are obtained from a clean location, deployed, and recovered for determination of biological condition and short-term accumulation of contaminants in tissues. Mussels are used as test organisms because of the extensive database available on the rate at which they bioaccumulate contaminants and because they provide good spatial and temporal experimental control. Each year since 1987, mussels have been deployed in replicate arrays consisting of moored cages in waters near Deer Island and in Massachusetts Bay near the outfall location (Figure 5-1). Mussel arrays are deployed using a subsurface and surface buoy system.

- The presence of physical abnormalities in fish and shellfish can be a sensitive indicator of contaminant exposure. Tumors, lesions, finrot, and gross deformities are physical abnormalities that may be attributable to pollution. Certain physical abnormalities such as liver lesions may only be detected through histopathology, the study of adverse changes in tissue structures.

5.3 Threshold Comparison

To track the chronic environmental impact of the toxic contaminants, the MWRA measures the concentrations of a variety of toxic contaminants in flounder, lobster, and mussels from various locations in Boston Harbor and Massachusetts and Cape Cod Bays. Thresholds for fish and shellfish, summarized in Table 5-1, are designed to identify any effects on marine life and potential effects on human consumers of fish and shellfish. The thresholds apply to the new outfall site.

Of the five monitoring thresholds, three are associated with the potential for edible tissue (flounder, lobster, mussel) to exceed Warning Levels for mercury, lead, or PCBs. Except for lead, the Caution Levels are 50% of the U.S. Food and Drug Administration (FDA) Action Limits; the Warning Levels are 80% of the FDA Action Limits. Lead thresholds are based on an EPA risk assessment that determined the amount of lead that can be consumed without adverse health effects. The mussel arrays set out at the future outfall site in 1995 were lost. The flounder and lobster data show that current tissue concentrations are generally an order of magnitude or more below the Warning and Action Levels (Table 5-1). Values approaching the Warning or Action Levels should be readily detectable.

Because some toxics tend to concentrate in lipid-rich (fatty) tissues, a lipid-normalized threshold was established to protect against increases in these contaminants. This threshold is exceeded if bioaccumulative lipophilic contaminants double and remain at that level for three consecutive years. The three-year specification was chosen to smooth the highly variable nature of these measurements. The concentrations for 1995 are shown in Table 5-1. The interim Caution Level was not available for this report but will be included in the 1996 report. One finding was that the contaminants in flounder liver and lobster hepatopancreas, which are not considered edible tissue for any of the thresholds, was relatively high in 1995. The validity of the analytical tests was checked and confirmed.

In order to monitor and assess the potential impacts of toxic contaminants on flounder, a threshold concerning the prevalence of flounder liver CHV was developed which compares the postdischarge prevalence of CHV with the baseline average prevalence in the Harbor. The 1995 CHV prevalence at the future outfall site (14%) is below the interim threshold value (Fig 5-2). The monitoring design will be able to detect changes approaching the Caution Level.

5.4 Monitoring Results

5.4.1 Flounder

The results of the fish and shellfish program have revealed temporal and areal patterns, and illustrated the variability of the ecosystem. In general, levels of contaminants and the number of physical abnormalities in the fish and shellfish studied, have decreased over the study period. Boston Harbor organisms are the most affected by toxic contaminants, while those in Cape Cod Bay are least affected. The following sections present the 1995 fish and shellfish monitoring results, along with comparisons to previous data.

■ Replicates are multiple samples that are used to increase the reliability and accuracy of experimental data. Multiple arrays of mussels are used to increase the sample population and thereby reduce the uncertainty in the results.

In 1995, fifty winter flounder were collected at each of the five monitoring program sites: Deer Island Flats, the future outfall site, Nantasket Beach, Broad Sound, and eastern Cape Cod Bay (Figure 5-1). All flounder were examined for physical abnormalities, and histopathological liver lesions. In addition, the tissue from fifteen of the fifty flounder from three locations (Deer Island Flats, future outfall site, eastern Cape Cod Bay) was analyzed for concentrations of organic and inorganic contaminants.

Physical Condition and Histology

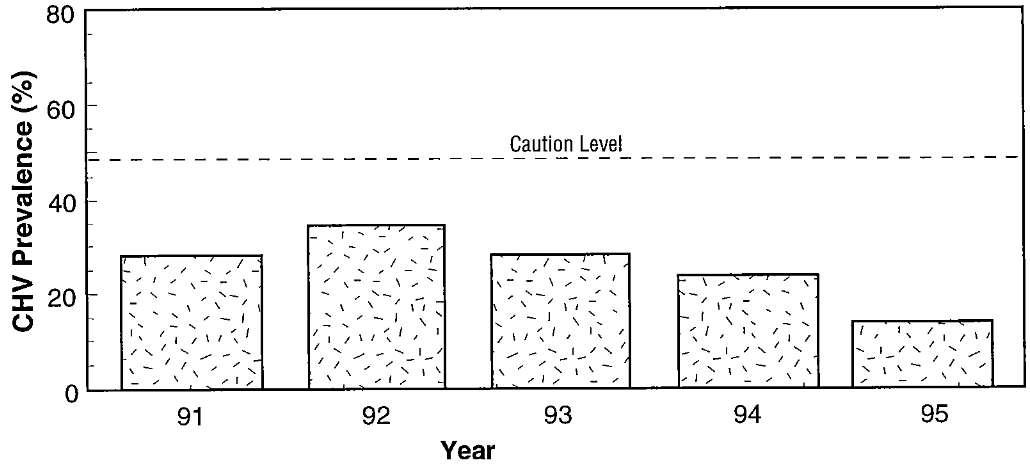
The external condition of the collected fish indicated few abnormalities, although fin erosion was seen in fish from all stations. The flounder from the future outfall site and Cape Cod Bay showed significantly lower levels of fin rot than other stations. The amount of

TABLE 5-1
Fish and Shellfish Thresholds Compared to 1995 Monitoring Results

Parameter	Caution Level	Warning Level	1995 Results
Mercury in fish and shellfish from Outfall site	Annual mean mercury concentration in flounder, lobster, and caged mussel meat greater than 0.5 µg/g wet weight (50% of the US FDA action level).	Annual mean mercury concentration in flounder, lobster, and caged mussel tissue is greater than 0.8 µg/g wet weight (80% of the US FDA action level).	Flounder - 0.06 µg/g Lobster - 0.13 µg/g Mussel - NA[1]
PCBs in fish and shellfish from Outfall site	Annual mean PCB concentration in flounder, lobster, and caged mussel meat greater than 1 µg/g wet weight (50% of the US FDA action level).	Annual mean PCB concentration in flounder, lobster, and caged mussel tissue is greater than 1.6 µg/g wet weight (80% of the US FDA action level).	Flounder - 0.041 µg/g Lobster - 0.015 µg/g Mussel - NA[1]
Lead in mussels at Outfall site	Annual mean lead concentration in caged mussel meat greater than 2 µg/g wet weight.	Annual mean lead concentration in caged mussel tissue is greater than 3 µg/g wet weight.	Mussel - NA[1]
Lipid-normalized toxics in fish and shellfish from Outfall site	Lipid-normalized toxic concentrations in flounder, lobster and caged mussel meat greater than two times the baseline concentrations.	None.	Concentrations in µg toxic per gm lipid Lobster PCBs: 2.9 Lobster DDT: 0.4 Flounder PCBs: 11.1 Flounder DDT: 1.1
Liver disease incidence in fish from Outfall site	Flounder liver disease (CHV) incidence greater than in Boston Harbor. The 1991-95 average is 48%.	None.	Flounder CHV prevalence: 14%

[1] Outfall site mussel cage arrays were lost in 1995.

FIGURE 5-2
Prevalence of CHV near the Future Outfall Site, 1991-1995.



fin erosion observed throughout is considered low, and is well below that observed in the late 1980s.

The flounder liver histology results indicated that flounder from all sampling locations experienced liver lesions. The flounder from Deer Island Flats and Broad Sound exhibited the greatest prevalence of lesions. The prevalence of one type of liver lesion, centrotubular hydropic vacuolation (CHV), has been used by MWRA since 1991 as a sensitive indicator of contaminant exposure in flounder from Boston Harbor and the bays.

Although there is significant regional variability, sampling results indicate that the incidence of CHV in winter flounder has been decreasing since 1991. The presence of CHV in fish from the future outfall site has dropped steadily from about 30% of the population in 1992, to 14% in 1995. Meanwhile, the prevalence of CHV in flounder from Broad Sound has dropped from more than 75% to about 30% over the same period. In other areas, such as Cape Cod Bay and Nantasket Beach, the prevalence of CHV has been relatively constant.

Bioaccumulation

In 1995, contaminant concentrations were measured in 15 flounder meat samples, and 15 flounder liver samples from the Deer Island Flats, future outfall site, and East Cape Cod Bay sampling locations. All samples were analyzed for PCBs, chlorinated pesticides, and mercury. The liver samples were also analyzed for a number of other organic and inorganic contaminants.

The monitoring results (Figure 5-3) indicate that contaminant concentrations in flounder meat and liver are generally higher in Boston Harbor near the Deer Island outfall and at the future outfall site than at the Cape Cod Bay site. Contaminant concentrations at the future outfall site are generally intermediate between values at Deer Island and the Cape Cod Bay site. However, several metals in flounder liver (copper, lead, silver, and zinc) were higher at the future outfall site than at Deer Island in 1995. Two notable features of the 1995 flounder liver data when compared to previous years are 1) elevated concentrations of DDT and PCBs, and 2) reduced chlordane levels. These variations are likely due to a number of complex factors, including the transport and mobility of contaminated sediments and the effects of exposure of fish to contaminants in sediments and resuspended sediments.

5.4.2 Lobster

Fifteen northern lobsters were collected from each of three sites (Deer Island Flats, future outfall site, East Cape Cod Bay; Figure 5-1) for the 1995 monitoring program. Muscle and hepatopancreas samples were taken from each lobster and analyzed for PCBs, chlorinated pesticides, and mercury. The hepatopancreas samples were also analyzed for a number of other organic and inorganic contaminants.

With the exception of one incidence of shell erosion at the future outfall site, no deleterious external conditions were noted.

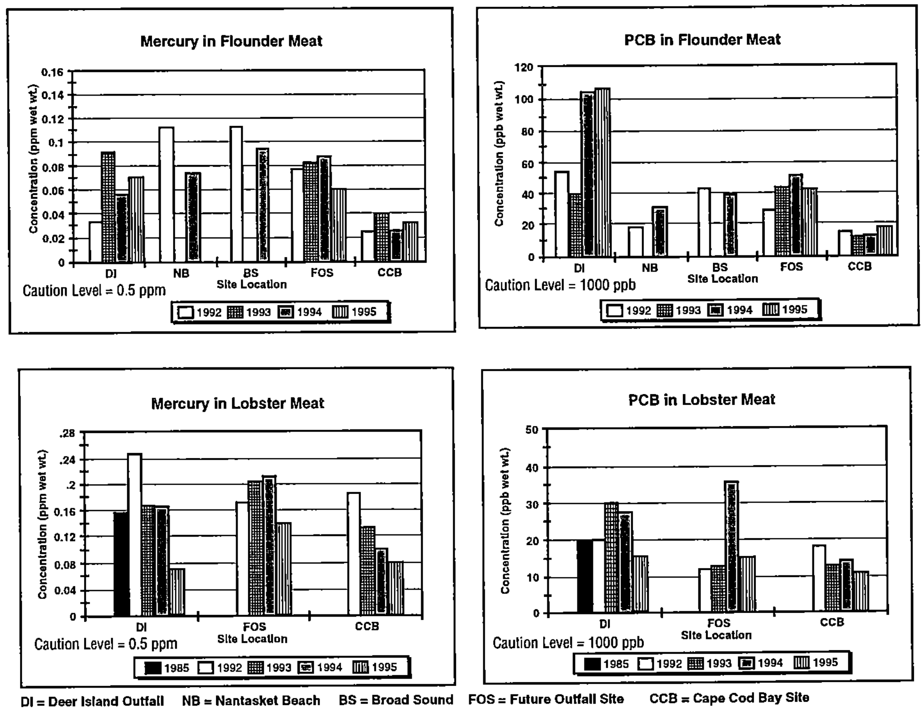


FIGURE 5-3
PCB and Mercury Concentrations in Flounder and Lobster Meat, 1992-1995.

As in previous years, the 1995 mean concentrations of organic compounds in edible tail meat tissue were generally highest at Deer Island Flats and lowest in East Cape Cod Bay. However, PCB concentration levels were similar at Deer Island and the future outfall site (Figure 5-3). In a departure from previous years, the 1995 mean concentrations of organic compounds in the hepatopancreas were generally higher at the future outfall site than at either of the other two sampling locations. The major changes in organic contaminant levels in 1995 were: 1) a decrease in chlordane in tail meat, and 2) an increase in PCBs and pesticides in the hepatopancreas.

Mean mercury concentrations in tail meat were highest at the future outfall site (Figure 5-3), while mercury concentrations in the hepatopancreas were similar among stations. The concentrations of other metals in the hepatopancreas were similar at all sampling locations, although typically a bit lower in East Cape Cod Bay. Silver concentrations in 1995 were markedly higher than in previous years at all sampling locations. For example, the silver concentration doubled at the future outfall site between 1994 and 1995. Otherwise, 1995 metal concentrations in the hepatopancreas were generally lower than those measured previously.

5.4.3 Blue Mussel

A series of mussel bioaccumulation studies has been conducted since 1987 to determine whether selected contaminants (PCBs, pesticides, PAHs, and metals) bioaccumulate in shellfish. Mussels were collected from two relatively clean locations: Gloucester and Sandwich, MA and deployed in cages in three locations (Figure 5-1): near the present outfall location at Deer Island Flats; at the future outfall site; and in the inner Harbor (hanging from the New England Aquarium's barge, the Discovery). After 60 days, mussels were harvested for biological and chemical analyses. In 1995, the arrays were successfully retrieved at the Deer Island Flats and Discovery sites, but not at the future outfall site. The loss of the future outfall site array was apparently due to entanglement with fishing gear.

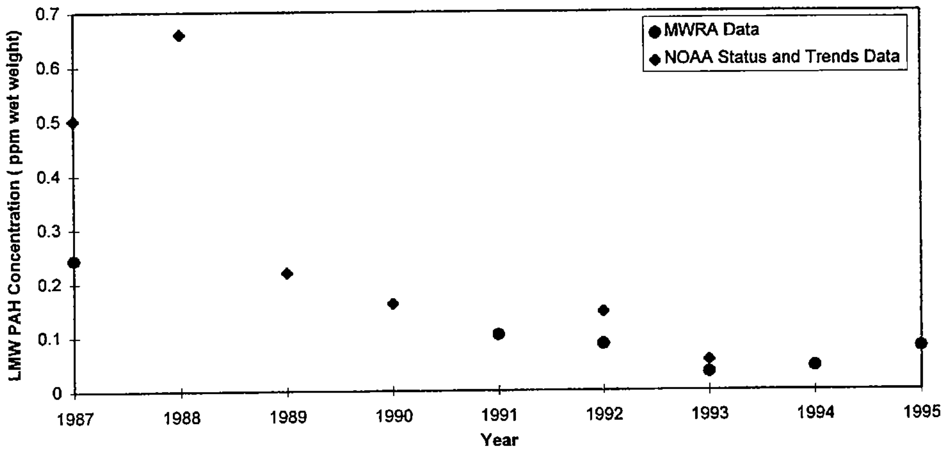


FIGURE 5-4
Total LMW PAH Bioaccumulation in Mussels Near Deer Island Discharge, 1987-1995. [Previous to 1995 mussels were analyzed for the NOAA status and trends list for PAHs. In 1995, mussels were analyzed for an extended set of PAHs, which includes the NOAA list, but modestly overestimates the concentrations. See Mitchell et. al. 1996]

Overall, study contaminant levels at the Boston Harbor stations (Deer Island and Discovery) have decreased significantly since 1987. For example, as shown in Figure 5-4, low molecular weight PAH levels near the Deer Island outfall decreased by over a factor of five between 1987 and 1995. The spatial distribution of contaminant concentrations shows higher levels of most contaminants at the Discovery site, and lower levels at the Deer Island Flats sampling location. The 1995 predeployment contaminant levels were substantially lower than all locations, for all contaminants.

PAH and pesticide (DDT, chlordane, dieldrin) body burdens for all sites were comparable to 1994 levels (Table 5-2). Lead tissue concentrations were somewhat higher at the Discovery site than at Deer Island in 1995. Mercury concentrations in mussel tissue were low in 1995, and not appreciably different among sites. The low concentration of mercury at Deer Island compared to the previous year may indicate the need for further study.

TABLE 5-2
Comparison of Average Body Burdens of Deployed Mussels for Selected Organic Compounds and Metals

Parameters	1994				1995		
	Predeployment Gloucester	Future Outfall Site	Deer Island	Discovery Average	Predeployment Gloucester	Deer Island	Discovery Average
PAH (ppb wet weight)							
LMW PAH	21.2	12.2	43.4	15.8	21.0	68.0	41.2
HMW PAH	31.6	12.2	126	435	21.8	84.2	247.6
Total PAH	52.8	24.4	170	451	42.8	152.1	288.8
Pesticides (ppb wet wt)							
Total Chlordane	2	1.8	5.4	5.8	0.79	2.6	4.4
Total DDT	5.4	3.8	10	17.2	5.75	9.0	18.4
Polychlorinated Biphenyls (ppb wet weight)							
Total PCB	21.4	17.8	32.2	100	18.7	43.1	88.2
Metals (ppb wet wt)							
Mercury	.036	0.026	0.042	.032	0.013*	0.011	0.014
Lead	1.72	.96	1.8	1.33	1.212	1.598	1.708

Source: Downey et al., 1995
* predeployment Sandwich, MA

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Glossary

The following descriptions are not formal definitions but convey the sense of usage in this report.

Algae - phytoplankton, the microscopic plants that drift with the currents. They are usually single celled but may form colonies. There are many species that form the community assemblage in a sample of seawater. Phytoplankton are eaten (grazed on) by zooplankton, larger but still very small animals which also drift with the currents. Zooplankton, in turn, are eaten by animals higher up the food chain. Large multicellular algae are called macroalgae and are usually attached to the sea floor. Although plants are an essential part of the food chain, excess nutrients may make them too numerous or favor undesirable forms.

Apparent redox potential discontinuity depth - RPD. The visually measured thickness of upper light-colored, and thus apparently well-oxygenated, layer in bottom sediments.

Bioturbation - mixing of the sediment strata by animals, which bring deeper sediment to the surface as they burrow, and flush aerated bottom water into the mud by way of their burrows and feeding activity.

Chlorophyll - the green pigment in plants that supports photosynthesis in the presence of adequate light. Chlorophyll a is commonly used as a measure of total algal biomass.

Denitrification - the reduction of nitrate to nitrite and then to nitrogen gas.

Drumlin - elongated piles of glacial debris left behind after the glacier recedes.

Epibenthic organisms - bottom-dwelling animals that live upon, rather than within, a substrate such as impenetrable rock.

Eutrophication - a process of excessive algal growth that may result in dissolved oxygen depletion (hypoxia).

Hypoxia - a state of low dissolved oxygen in which sensitive animals may suffocate.

Infauna - bottom-dwelling animals that live within the sediments.

Mixing zone - region in the immediate vicinity of the diffuser where initial mixing and dilution occurs. The defined size of the mixing zone reflects the designed dilution properties of the diffusers. An outfall would violate expectations if dilution is not sufficient to meet water quality criteria at the edge of the mixing zone.

Nearfield or near field - a region near the new outfall which receives more intensive sampling due to the expectation that effects are most likely to be manifest there. The definition of the nearfiled varies with the study type, reflecting the mobility of water as compared to sediments. Water column monitoring defines the nearfield as the area within a rectangle with sides 5 km from the outfall. Beyond that is the farfield, which includes the rest of Massachusetts Bay, Cape Cod Bays, and Boston Harbor. Benthic monitoring defines the nearfield as the area within 2 km of the new outfall. Beyond that is the midfield (2-7 km away) and the farfield (greater than 7 km).

Primary production - the process by which algae produce organic carbon from carbon dioxide through photosynthesis. Growth requires this carbon as well as nitrogen for protein and phosphorus for nucleic acids. In addition, silica is required by diatoms for their outer cell walls.

Remineralization - Degradation of algal biomass into soluble components which are then available again for uptake and growth by other algae. The carbon, nitrogen, and phosphorus in particulate organic matter are decomposed to carbon dioxide, urea, nitrate, ammonia, and phosphate. Remineralization is the reverse of growth.

Respiration - the process of dissolved oxygen consumption by living organisms. It is the reverse of photosynthesis.

Acronym Summary

BOD biochemical oxygen demand
cBOD carbonaceous biochemical oxygen demand
CHV centrotubular hydropic vacuolation, a fish liver lesion
DECS Detailed Effluent Characterization Study
DIN dissolved inorganic nitrogen
DO dissolved oxygen
EPA U.S. Environmental Protection Agency
ER-L NOAA low effects range values for sediment, rarely associated with toxic effects
ER-M NOAA median effects range values, often associated with toxic effects
LABs linear alkyl benzenes
LC50 concentration for 50% lethality of bioassay test organisms
MADEP Massachusetts Dept. of Environmental Protection
nBOD nitrogenous biochemical oxygen demand
NMFS National Marine Fisheries Service
NOEC no observable effect concentration
NPDES National Pollutant Discharge Elimination System
PAHs polyaromatic hydrocarbons
PCBs polychlorinated biphenyls
ppb parts per billion
ppm parts per million
RPD redox potential discontinuity
TSS total suspended solids
USGS U.S. Geological Survey
WQC Water Quality Criteria