1998
Outfall monitoring overview

Massachusetts Water Resources Authority

Environmental Quality Department

Report ENQUAD 00-04

1998
Outfall Monitoring Overview

submitted to

Massachusetts Water Resources Authority Environmental Quality Department lOO First
A venue
Charlestown N avy Yard Boston, MA 02129

prepared by

Christine Werme
Norwell, MA 02061
and
Carlton D. Hunt Battelle
397 Washington Street Duxbury, MA 02332

March 20,2000

Citation:

Werme C, Hunt CD. 2000. 1998 Outfall monitoring overview. Boston: Massachusetts Water Resources Authority. Report ENQUAD 00-04. 66 p.

Executive Summary

Since its creation in 1985, the Massachusetts Water Resources Authority (MWRA) has worked to minimize the effects of discharging sewage effluent to the marine environment. The MWRA program includes source reduction, improved treatment, and effective dilution. One aspect of the project, moving the treated wastewater outfall from the harbor to Massachusetts Bay, has caused some environmental concerns. To address these concerns, MWRA implemented an extensive monitoring program to measure the health of Boston Harbor and the bays. Furthermore, the joint U.S. Environmental Protection Agency (EPA) and Massachusetts Department of Environmental Protection (MADEP) permit for the new outfall, which was issued in 1999, requires extensive monitoring of the effluent, water column, sea floor, and fish and shellfish. It links the monitoring program to a contingency plan. The contingency plan identifies corrective actions for unexpected impacts resulting from operation of the outfall.

This Outfall Monitoring Overview presents a scientific summary of monitoring data collected through 1998 and includes information relevant to the contingency plan. Because the outfall is not yet operational, these data represent the baseline conditions in the vicinity of the outfall site and further afield in Massachusetts and Cape Cod bays. Most MWRA monitoring began in 1992, resulting in a relatively long period in which to conduct baseline studies. This long period has allowed MWRA to document greater natural variability than would have been observed in briefer baseline monitoring.

During 1998, effluent monitoring reflected continued improvements in effluent quality, due to source reduction and secondary treatment. In the water column, there was no spring bloom of phytoplankton, and it appears that such blooms may not be as characteristic of the area as was previously thought. The year was also marked by unusually prolonged stratification of the water column, with the lowest levels of dissolved oxygen in bottom waters occurring in December. Although low, these levels did not fail the state standard of 6 mg/L. The average number of individuals and species in soft-bottom communities near the outfall site, which decreased from 1992 to 1993 and subsequently rose, leveled off in 1997 and 1998. Concentrations of contaminants in sediment samples from the vicinity of the site were similar to those found by previous studies. Contaminant levels in muscle tissues of fish and shellfish remained well below levels of concern. During 1998, MWRA also conducted several special studies, including runs of the Bays Eutrophication Model (BEM), which indicated that relocating the outfall will not affect water quality in Massachusetts Bay, assessment of the value of a food-web model, and a study of cobble-boulder habitats, which indicated that the area around the outfall a site is not significant for settling of or habitation by recently-settled juvenile lobsters.

Table of Contents

List of Figures

List of Tables

1. Introduction

Background

Since its creation in 1985, the Massachusetts Water Resources Authority (MWRA) has worked to end long-standing violations of the Clean Water Act that resulted from the discharge of sewage sludge and primary-treated effluent into Boston Harbor. Sludge discharges to the harbor ended in 1991, and MWRA is working to minimize effects of wastewater discharge. Those efforts include source reduction to prevent pollutants from entering the waste stream, improved treatment before discharge, and effective dilution once the effluent enters the marine environment.

MWRA has undertaken projects to control flows of contaminants from combined sewer overflows (CSO). An ongoing industrial pretreatment/pollution prevention program has been implemented to remove toxic contaminants before they reach the treatment facilities. New operator training programs and process control and maintenance tracking systems are in place.

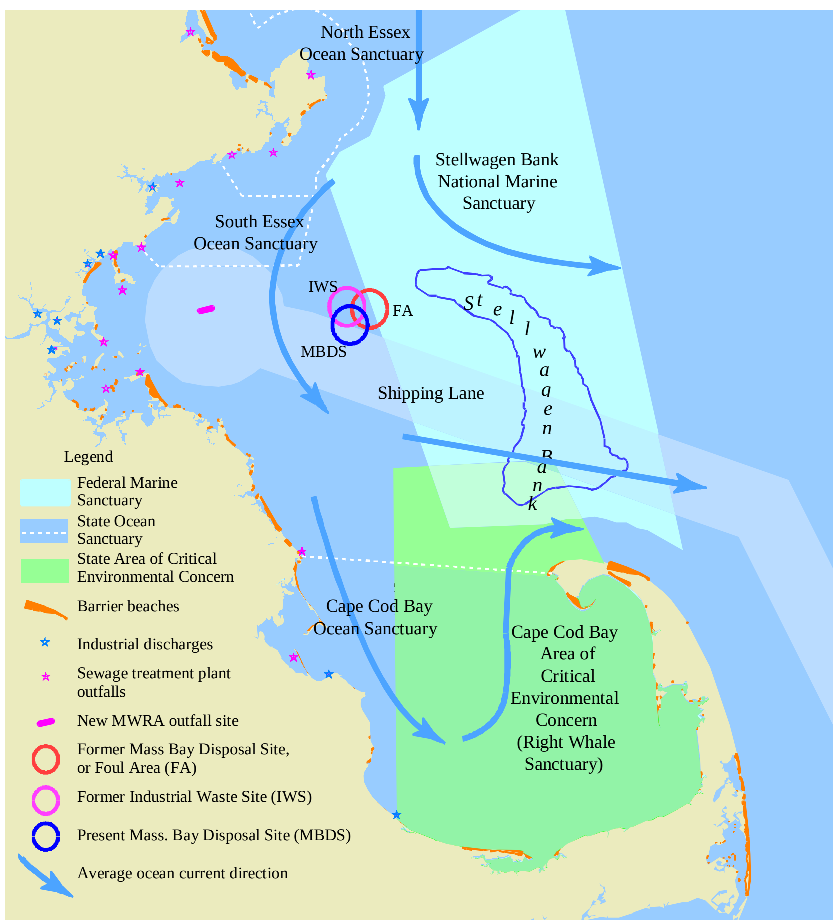
During 1995, a new primary treatment plant at Deer Island was brought on line, and disinfection facilities were completed. The first battery of secondary treatment began in 1997. During 1998, the second battery of secondary treatment was completed, and discharge from the Nut Island Treatment Plant ended. Until then, approximately 100 million gallons per day of sewage from MWRA's South System received only primary treatment before being discharged into Quincy Bay. Now, that sewage is diverted to Deer Island for secondary treatment before being discharged into the harbor.

Future improvements include bringing a final battery of secondary treatment on line and diverting the effluent discharge from Boston Harbor to a new outfall and diffuser system, located 9.5 miles offshore in Massachusetts Bay (Figure 1-1). The outfall location was selected from seven potential sites because it had a water depth and current patterns that would promote effective dilution, it was least likely to affect sensitive resources, and it was feasible to construct an outfall to the location.

The outfall tunnel is bored through bedrock. It has a diffuser system made up of 55 risers, each with 8 ports, along its final 1.25 miles. Discharge from the diffuser heads will be at the sea floor, at water depths of about 100 feet (MWRA 1997a). Initial dilution at the outfall will be about 5 times that of the existing outfall, which is also shallower, in 50 feet of water. The offshore location of the new outfall ensures that within a tidal cycle, even shoreward currents will not transport effluent to beaches or shellfish beds near Boston or Cape Cod.

MWRA's goals are to make it safe to swim in the harbor, safe to eat fish caught there, to protect marine resources, and to ensure that the harbor becomes and remains a resource that people can aesthetically enjoy, without degrading the offshore environment. For many of the components of MWRA's work, there is little or no argument that the project benefits the marine environment and the people of the region. One aspect of the project, moving the effluent outfall from the harbor to Massachusetts Bay, has caused some concerns. Those concerns have been recognized by the joint permit for the outfall issued by the U.S. Environmental Protection Agency (EPA) and the Massachusetts Department of Environmental Protection (MADEP).

Figure 1-1. Map of Massachusetts and Cape Cod Bays



Outfall Permit

The new outfall will be regulated by a permit issued by EPA and MADEP under the National Pollutant Discharge Elimination System (NPDES). The permit, issued in May of 1999, covers the treatment plant operation and maintenance, sludge, and CSO system as well as the outfall. It requires MWRA to expand and implement an ongoing pollution prevention program that encompasses all users of the system—industrial, commercial, and residential.

The permit requires MWRA to monitor the effluent and the ambient receiving waters for compliance with permit limits and in accordance with the monitoring plan developed in response to the EPA Supplemental Environmental Impact Statement (SEIS, EPA 1988). The permit also requires MWRA to update, maintain, and run the three-dimensional Bays Eutrophication Model, to track effluent plumes for evaluation of the dilution at the discharge, and to implement a contingency plan, which includes environmental quality parameters and thresholds for corrective action.

The permit establishes an independent panel of scientists to review monitoring data and provide advice on key scientific issues related to the permit. This panel, called the Outfall Monitoring Science Advisory Panel (OMSAP), is to conduct peer reviews of monitoring reports, evaluate the data, and advise EPA and MADEP on implications. OMSAP is also to provide advice concerning any proposed modifications to the monitoring or contingency plans (Table 1-1).

OMSAP may form specialized focus groups when specific technical issues require expanded depth or breadth of expertise. Two standing sub-committees also advise OMSAP. The Public Interest Advisory Committee (PIAC) represents local, non-governmental organizations, academia, and environmental groups and advises OMSAP on values and uses of the local natural systems as they relate to public concerns. The Inter-agency Advisory Committee (IAAC) represents state and federal agencies and provides OMSAP with advice concerning environmental regulations.

Table 1-1. Roster of panel and committee members

OMSAP as of December 1998	
Robert Beardsley, Woods Hole Oceanographic Institution Robert Chen, University of Massachusetts, Boston Norbert Jaworski, retired Robert Kenney, University of Rhode Island Scott Nixon, University of Rhode Island Judith Pederson, MIT Sea Grant William Robinson, University of Massachusetts, Boston James Shine, Harvard School of Public Health Andrew Solow, Woods Hole Oceanographic Institution (chair) Catherine Coniaris, New England Water Pollution Control Commission (OMSAP assistant)	
IAAC as of December 1998	**PIAC as of December 1998**
MA Coastal Zone Management Margaret Brady Christian Krahforst (alternate) MA Department of Environmental Protection Russell Isaac Steven Lipman (alternate) MA Division of Marine Fisheries Leigh Bridges Jack Schwartz (alternate) National Marine Fisheries Service Salvatore Testaverde (chair) David Dow (alternate) Stellwagen Bank National Marine Sanctuary Brad Barr US Army Corps of Engineers Thomas Fredette US Environmental Protection Agency Matthew Liebman David Tomey (alternate) US Geological Survey Michael Bothner	Association for the Preservation of Cape Cod Scott Mitchell Bays Legal Fund Wayne Bergeron The Boston Harbor Association Vivian Li Joan LeBlanc (alternate) Cape Cod Commission Patty Daley Center for Coastal Studies Peter Borrelli Conservation Law Foundation Anthony Chatwin New England Aquarium Marianne Farrington Massachusetts Audubon Society Robert Buchsbaum MWRA Advisory Board Joe Favaloro Safer Waters in Massachusetts Salvatore Genovese Polly Bradley (alternate) Save the Harbor/Save the Bay Cate Doherty (chair) Stop the Outfall Pipe Mary Loebig Wastewater Advisory Committee Susan Redlich

Monitoring Program

EPA and MADEP require monitoring to ensure compliance with the permit, to assess whether the outfall has effects beyond the area identified in the SEIS as acceptable, and to collect data useful for outfall management. In anticipation of these requirements, MWRA began baseline monitoring in 1991. During the intervening years, both baseline and discharge monitoring plans have been developed and refined. The existing plan was developed by MWRA with direction from an Outfall Monitoring Task Force (OMTF) made up of scientists, regulators, and environmental advocacy groups (Table 1-2; MWRA 1997a). The OMTF was disbanded upon creation of OMSAP.

Table 1-2. Roster of task force members

Outfall Monitoring Task Force as of August 1998	
Members of the scientific community	US Army Corps of Engineers
Robert Buchsbaum	Thomas Fredette
Donald Cheney	US Environmental Protection Agency
John Farrington	Matthew Liebman
Jonathan Garber	Janet Labonte (alternate)
Diane Gould	David Tomey (alternate)
Norbert Jaworski	US Geological Survey
Joseph Montoya	Richard Signell
Judith Pederson	Wastewater Advisory Committee
Jerry Schubel (chair)	Susan Redlich
MA Department of Environmental Protection	Save the Harbor/Save the Bay
Russell Isaac	Cate Doherty
MA Division of Marine Fisheries	Safer Waters in Massachusetts
Leigh Bridges	Polly Bradley
Jack Schwarz (alternate)	Center for Coastal Studies
MA Coastal Zone Management	Russell DeConti
Margaret Brady	Cape Cod Commission
Christian Krahforst (alternate)	Patty Daley
National Marine Fisheries Service	Susan Nickerson (alternate)
Salvatore Testaverde	

The outfall monitoring program focuses on critical constituents in treatment plant effluent, such as nutrients, toxic contaminants, organic material, pathogens, and solids. Presence and potential effects of these constituents are evaluated within the context of four environmental measurement areas: effluent, water column, sea floor, and fish and shellfish (Table 1-3). Special studies are conducted in response to specific permit requirements, scientific questions, and environmental concerns. The monitoring program is designed to compare environmental quality of the Massachusetts Bay ecosystem (including Boston Harbor) before (baseline) and after (discharge) the outfall location is moved from the harbor to the bay.

Baseline monitoring, which began in 1991 for flounder studies and 1992 for other parameters, was initially planned to last for a minimum of 3 years. Delays in outfall construction (originally planned for completion in 1995) have allowed a relatively long period for baseline studies. Thus, MWRA has been able to document greater natural variability within the system than would have been observed in briefer baseline monitoring. The extended time period has also allowed MWRA to evaluate the response in Boston Harbor to other parts of the Boston Harbor project, such as improved pretreatment, ending sludge discharges, and initiation of secondary treatment of the effluent (Leo 1995, Pawlowski 1996, Rex 1997).

Table 1-3. Summary of the monitoring program.

Task	Objective	Sampling Locations And Schedule	Analyses
Effluent			
Effluent sampling	Characterize wastewater discharge from Deer Island Treatment Plant	Weekly	Nutrients
		Daily	Organic material (cBOD)
		Several times monthly	Toxic contaminants
		3x/day	Bacterial indicators
		Daily	Solids
Water Column			
Nearfield surveys	Collect water quality data near outfall location	17 surveys/year 21 stations	Temperature Salinity Dissolved oxygen Nutrients Solids Chlorophyll Water clarity Photosynthesis Respiration Plankton Marine mammal observations
Farfield surveys	Collect water quality data throughout Massachusetts and Cape Cod bays	6 surveys/year 26 stations	
Plume-track surveys	Track locations and characteristics of discharge plume, measure dilution of discharge	To be implemented after the outfall begins operation	Salinity Temperature Currents Rhodamine dye Bacterial Indicators Nutrients Metals Solids
Mooring (USGS)	Provides continuous oceanographic data near outfall location	Continuous monitoring Single station 3 depths	Temperature Salinity Water clarity Chlorophyll
Remote sensing	Provides oceanographic data on a regional scale through satellite imagery	Available daily (cloud-cover permitting)	Surface temperature Chlorophyll
Sea Floor			
Soft-bottom studies	Evaluate sediment quality and benthos in Boston Harbor and Massachusetts Bay	20 nearfield stations 11 farfield stations	Sediment chemistry Sediment profile imagery Community composition
Hard-bottom studies	Characterize marine benthic communities in rock and cobble areas	1 survey/year 21 stations on 6 transects	Topography Substrate Community composition
Fish and Shellfish			
Winter flounder	Determine contaminant body burden and population health	1 survey/year 5 locations	Tissue contaminant concentrations Physical abnormalities, including liver histopathology
American lobster	Determine contaminant body burden	1 survey/year 5 locations	Tissue contaminant concentrations Physical abnormalities
Blue mussel	Evaluate biological condition and potential contaminant bioaccumulation	1 survey/year 5 locations	Tissue contaminant concentrations

Contingency Plan

MWRA has developed a contingency plan (MWRA 1997b), which describes how, if monitoring results indicate a possible environmental problem, MWRA and the regulatory agencies will respond to determine the cause of the problem and what corrective actions should be taken if the problem appears to be related to the discharge. The contingency plan identifies threshold parameters (Table 1-4), which are environmentally significant components of effluent or the ecosystem that, if certain levels are exceeded, indicate a potential for environmental risk. These levels are called thresholds. The plan provides a process for evaluating parameters that exceed thresholds and identifying appropriate responses.

Table 1-4. Summary of contingency plan threshold parameters

Monitoring Area	Parameter
Effluent	Fecal coliform bacteria Residual chlorine Total suspended solids Biological oxygen demand Toxicity PCBs Floatables Permit violations Total nitrogen load
Water Column	Dissolved oxygen concentration Dissolved oxygen depletion rate Chlorophyll Nuisance and noxious algae Zooplankton Effluent dilution
Sea Floor	Benthic community structure Sediment oxygen Sediment toxic metal and organic chemicals
Fish and Shellfish	PAHs, pesticides, mercury and PCBs in mussels and flounder and lobster meat Lead in mussels PAHs in caged mussels Liver disease in flounder

Threshold values, the measurements selected as indicators of the need for action, are based on permit limits, state water quality standards, and expert opinion. To alert MWRA to any changes, parameters have “caution” and “warning” thresholds. Exceeding caution levels would indicate a need for increased attention or study. If MWRA discharges cause a caution level to be exceeded, MWRA will expand its monitoring to closely track any change in effluent quality and environmental conditions, while working closely with OMSAP and the regulators to determine whether the data indicate an unacceptable effect resulting from the outfall.

Exceeding warning levels would indicate a need for a response to avoid potential adverse environmental effects. If a threshold is exceeded at a warning level, the proposed response will include both early notification to EPA and MADEP and, if the outfall has contributed to the adverse environmental effects, the quick development of a response plan. Response plans include a schedule for implementing actions, such as additional monitoring, making further adjustments in plant operations, or undertaking an engineering feasibility study regarding specific potential corrective activities.

Data Management and Reporting

The outfall monitoring program has generated extensive data sets documenting baseline environmental conditions. As of November 1999 the database included over three million measurements. Data quality is maintained through program-wide quality assurance/quality control procedures. After thorough validation, data from field surveys and laboratory analyses are loaded into a centralized project database. Data handling procedures are automated to the maximum extent possible to reduce errors, ensure comparability, and minimize reporting time. Data that are outside expected ranges are flagged for review. Data reported by the laboratory as suspect (for example, because the sample bottle was cracked in transit) are marked as such and not used in analyses, although they are retained in the database and included in raw data reports. Any corrections are thoroughly documented. Each data report notes any special data quality considerations associated with the data set.

As discharge monitoring results become available, they will be compared with contingency plan thresholds using computer programs that calculate each threshold parameter value from the data, compare it to the threshold, and notify the project staff of any caution or warning threshold exceedances. Similar computer programs will compare effluent results with contingency plan effluent thresholds.

MWRA's NPDES permit requires extensive reporting on the monitoring program, including synthesis reports for each technical area of the project, regular reports on effluent quality, changes to the monitoring program or contingency plan, and any exceedances of contingency plan thresholds and actions taken to address them (Table 1-5). Data that exceed thresholds must be reported within 5 days after the result becomes available, and MWRA must make all reasonable efforts to report all data within 90 days of each sampling event.

Selected reports are posted on MWRA's web site (www.mwra.state.ma.us), with hard copies placed in repository libraries in Boston and on Cape Cod. The permit also requires an annual report to Stellwagen Bank National Marine Sanctuary that includes all monitoring data that relate to the sanctuary and documents the effects of the discharge on sanctuary resources and qualities.

Table 1-5. List of monitoring reports

Report	Description/Objectives
Outfall Monitoring Plan Phase I—Baseline Studies (MWRA 1991) Phase II—Discharge Monitoring (MWRA 1997a)	Discusses goals, strategy, and design of baseline and discharge monitoring programs.
Quarterly Wastewater Performance Report	Summarize effluent quality, threshold exceedences, and corrective actions
Contingency Plan (MWRA 1997b)	Describes development of threshold parameters and values and MWRA's planned contingency measures.
Program Area Synthesis Reports (Annual)	Summarize, interpret, and explain annual results for effluent, water column, benthos, and fish and shellfish monitoring areas.
Toxics and Nutrients Issues Reports	Discuss, analyze, and cross-synthesize data related to toxic and nutrient issues in Massachusetts and Cape Cod bays.
The State of Boston Harbor Reports	Discuss a range of topics related to Boston Harbor and recent harbor monitoring results.
Outfall Monitoring Overviews	Summarize monitoring data and include information relevant to the contingency plan.

Outfall Monitoring Overview

Among the many reports that MWRA completes, this report, the Outfall Monitoring Overview, is prepared for each year of the monitoring program. The report provides a scientific summary of each year of monitoring and includes information relevant to the contingency plan, such as threshold exceedances, responses, and corrective activities. If monitoring data have suggested that monitoring activities, parameters, or thresholds should be added or modified, the report is to summarize those recommendations.

This year's report presents monitoring program results for baseline field data collected through 1998. Because the outfall is not yet operational, the report only compares data to the thresholds that are based upon fixed values, such as water quality criteria and other specific permit requirements. Baseline data, which are still being collected, will be used to calculate some thresholds, *e.g.*, chlorophyll, for which water quality standards or permit limits do not exist. This report also discusses parameters for which thresholds will be determined and finalized from a complete set of baseline data.

2. Effluent

Background

Effluent Treatment

The MWRA strategy for improving the environmental quality of Boston Harbor without degrading the Massachusetts and Cape Cod bays region relies upon pollutant source reduction and effective treatment. MWRA's Toxic Reduction and Control Program sets and enforces limits on what industries can discharge into the sewage system. Secondary treatment at the Deer Island Treatment Plant is designed to remove at least 85% of the total suspended solids and the biological oxygen demand, 50-90% of the toxic contaminants, 10-15% of the nutrients, and 80 to more than 99% of the pathogens (before disinfection). Making sure that the source reduction and treatment are working as designed is the most important step MWRA can take to ensure that the new outfall does not cause any harm to the environment.

Environmental Concerns

Effluent constituents of concern include nutrients, organic material, toxic contaminants, human pathogens, solids, and "floatables" (Table 2-1). Floatables include oil and grease slicks, as well as plastic and other debris, and are aesthetically unpleasant.

In marine waters, nitrogen is the limiting nutrient that controls growth of algae and other aquatic plants. Excess nitrogen can be detrimental, leading to eutrophication and low levels of dissolved oxygen, excess turbidity, and nuisance algal blooms. Nutrients, particularly dissolved forms, are the only components of sewage entering the treatment plant that are not significantly reduced by secondary treatment.

Organic material consumes oxygen as it decays. Even under natural conditions, oxygen levels decline in bottom waters during the late summer, so any effluent component that might further decrease oxygen levels is a concern.

Some toxic contaminants can accumulate in marine life, potentially affecting human health if contaminated seafood is consumed. Toxic contaminants can lower survival and reproduction of marine organisms. Toxic metals and organic contaminant levels in MWRA wastewater have dramatically declined since 1989, due to source reduction and secondary treatment. Continued source control and monitoring of contaminants in the effluent should ensure that concentrations remain at low levels.

Pathogens, including bacteria, viruses, and protozoa from human and animal waste, can cause disease. Human exposure to water-borne pathogens can occur through consumption of contaminated shellfish or through physical contact while swimming. MWRA is required to meet water quality standards for bacteria.

Suspended solids, small particles of debris in the water column, decrease water clarity, sometimes adversely affecting marine plants and algae. Excess suspended solids detract from people's aesthetic perception of the environment, as do oil and grease slicks and floating debris.

Table 2-1. Reporting requirements of the outfall permit.

Parameter	Sample Type	Frequency
Flow, million gallons/day (MGD)	Flow meter	Continuous
Flow Dry Day, MGD	Flow meter	Continuous
cBOD	24-hr Composite	1/Day
TSS	24-hr Composite	1/Day
pH	Grab	1/Day
Fecal Coliform Bacteria	Grab	3/Day
Chlorine, Total Residual	Grab	3/Day
PCB, Aroclors	24-hr Composite	1/Month
LC50	24-hr Composite	1/Month
C-NOEC	24-hr Composite	1/Month
Settleable Solids	Grab	1/Day
Chlorides (Influent only)	Grab	1/Day
Mercury	24-hr Composite	1/Month
Chlordane	24-hr Composite	1/Month
4,4 – DDT	24-hr Composite	1/Month
Dieldrin	24-hr Composite	1/Month
Heptachlor	24-hr Composite	1/Month
Ammonia-Nitrogen	24-hr Composite	1/Month
Total Kjeldahl Nitrogen	24-hr Composite	1/Month
Total Nitrate	24-hr Composite	1/Month
Total Nitrite	24-hr Composite	1/Month
Cyanide, Total Recoverable	Grab	1/Month
Copper, Total Recoverable	24-hr Composite	1/Month
Arsenic (Total)	24-hr Composite	1/Month
Hexachlorobenzene	24-hr Composite	1/Month
Aldrin	24-hr Composite	1/Month
Heptachlor Epoxide	24-hr Composite	1/Month
PCBs, Total	24-hr Composite	1/Month
Volatile Organic Compounds	Grab	1/Month

Monitoring Design

The main purpose of effluent monitoring is to measure the concentrations and variability of chemical and biological constituents of the effluent. Effluent monitoring assesses compliance with NPDES permit limits, which are based upon state and federal water quality standards and criteria, ambient conditions, and the outfall dilution. The permit includes numeric limits for suspended solids, fecal coliform bacteria, pH, chlorine, polychlorinated biphenyls (PCBs), and biological oxygen demand (BOD). In addition, state water quality standards establish limits for 158 pollutants, and the permit prohibits any discharge that would cause or contribute to an exceedance of any of those limits. Allowable concentrations of those contaminants are based on the predicted dilution at the new outfall. Actual dilution will be measured when outfall operation begins, and the allowable concentrations will be altered if dilution is less than has been predicted. The permit also prohibits discharge of nutrients in amounts that would cause eutrophication. The permit requires MWRA to test the toxicity of the effluent as a whole on sensitive marine organisms and establishes strict limits based on those tests. Effluent monitoring also provides accurate mass loads of effluent constituents so that fate, transport, and risk of contaminants can be assessed.

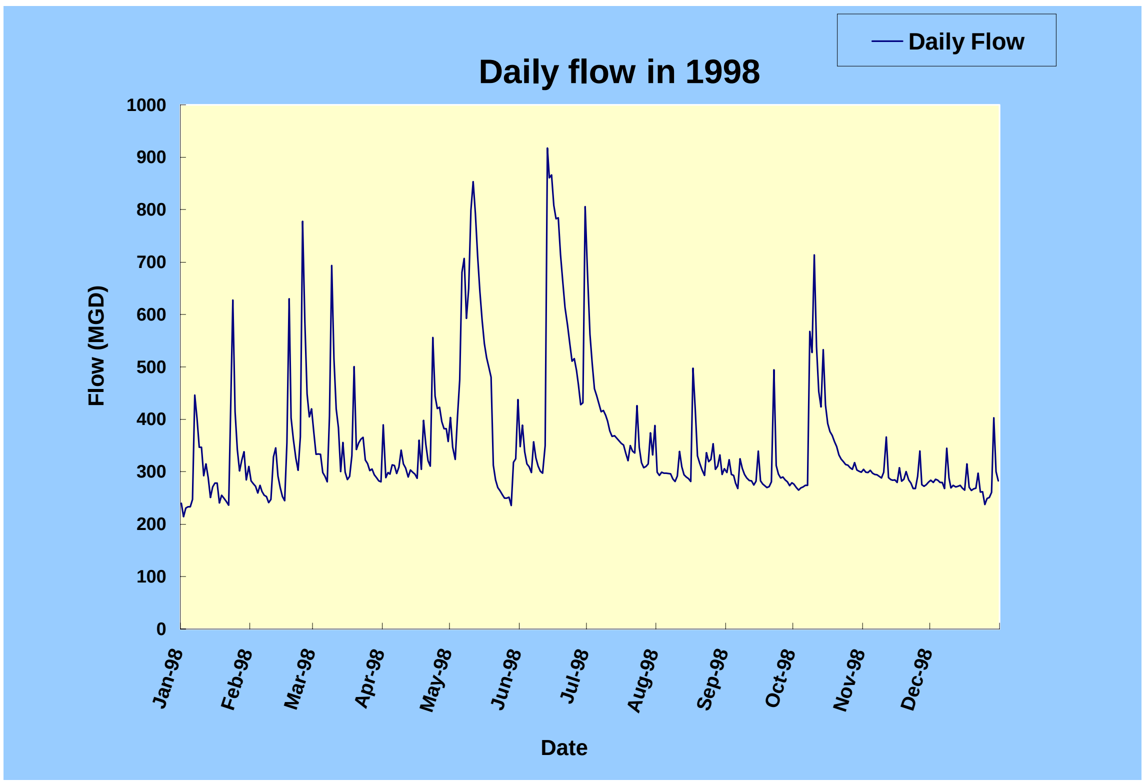
Most parameters require 24-hour composite samples, and some must meet daily, weekly, or monthly limits. Flow is measured continuously. Nutrient measurements include total Kjeldahl nitrogen, ammonia, nitrate, nitrite, total phosphorus, and phosphate. Organic material is monitored by measuring the carbonaceous biological oxygen demand (cBOD). Monitoring for toxic contaminants includes analyses for heavy metals of concern, chlorinated pesticides, PCBs, volatile organic compounds, acid-base neutral compounds, total residual chlorine, and cyanide. Toxicity is tested using whole effluent samples. Tests for acute toxicity of the effluent include 48-hour survival of mysid shrimp (*Americamysis bahia*, formerly known as *Mysidopsis bahia*) and inland silverside (*Menidia beryllina).* Chronic toxicity is assessed through inland silverside larval growth and survival and sea urchin (*Arbacia punctulata*) 1-hour fertilization tests. Pathogen monitoring consists of enumeration of fecal coliform. Total suspended solids (TSS) and settleable solids are also measured. Methods for measuring floatables are still under discussion.

Results

A major milestone was achieved during 1998, when primary sewage treatment at Nut Island ceased, and all sewage was directed to Deer Island for secondary treatment. When the second of three batteries of secondary treatment began operation in 1998, the treatment plant operated at a level that complies with the 1999 NPDES permit for the new outfall.

Daily effluent flow from the treatment plants during 1998 reflected the weather patterns for the region, with a relatively stormy winter and spring (Figure 2-1). Record rainfalls occurred throughout the spring, and there was a major storm in June.

Figure 2-1. Daily effluent flow in 1998



The total solids load discharged into Boston Harbor was less than in any previous year, reflecting the cessation of sludge discharge in 1991, and the implementation of secondary treatment in 1997 and 1998, and the transfer of Nut Island flow to Deer Island (Figure 2-2). Loads for many contaminants, including PAHs (Figure 2-3), metals, pesticides, and PCBs were lower in 1998 than in prior years.

Figure 2-2. Solids loads in 1988-1998

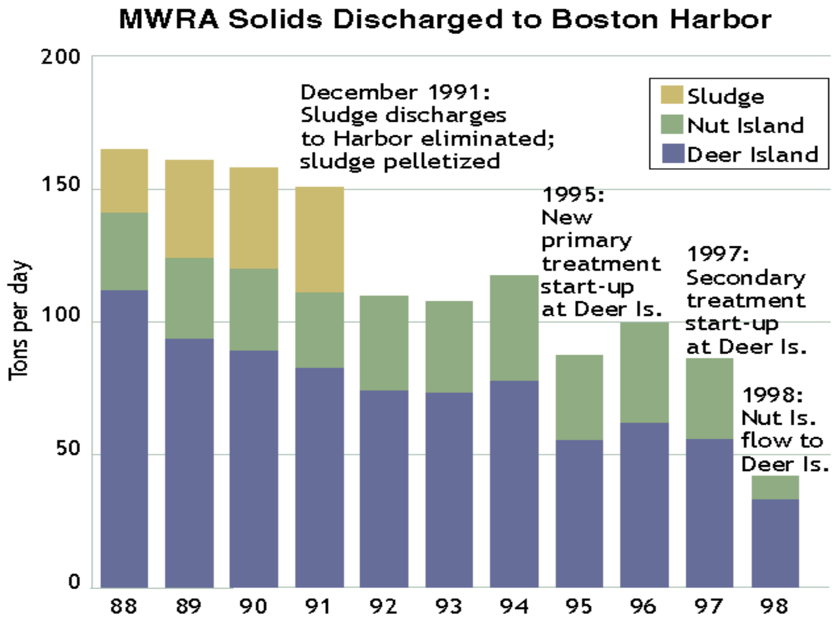
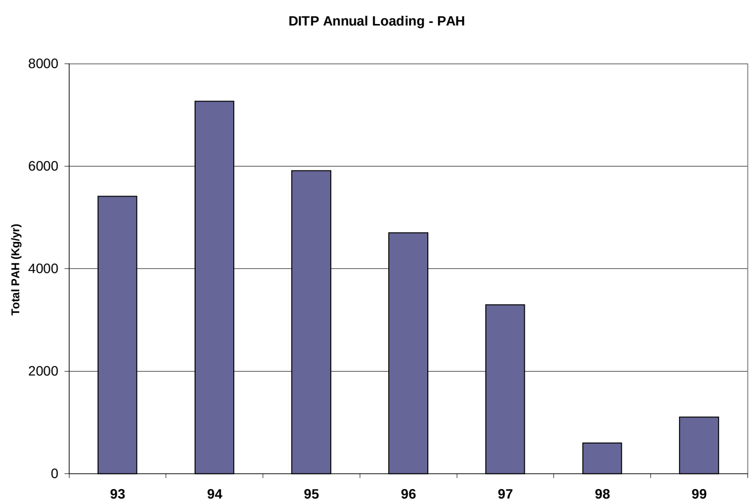


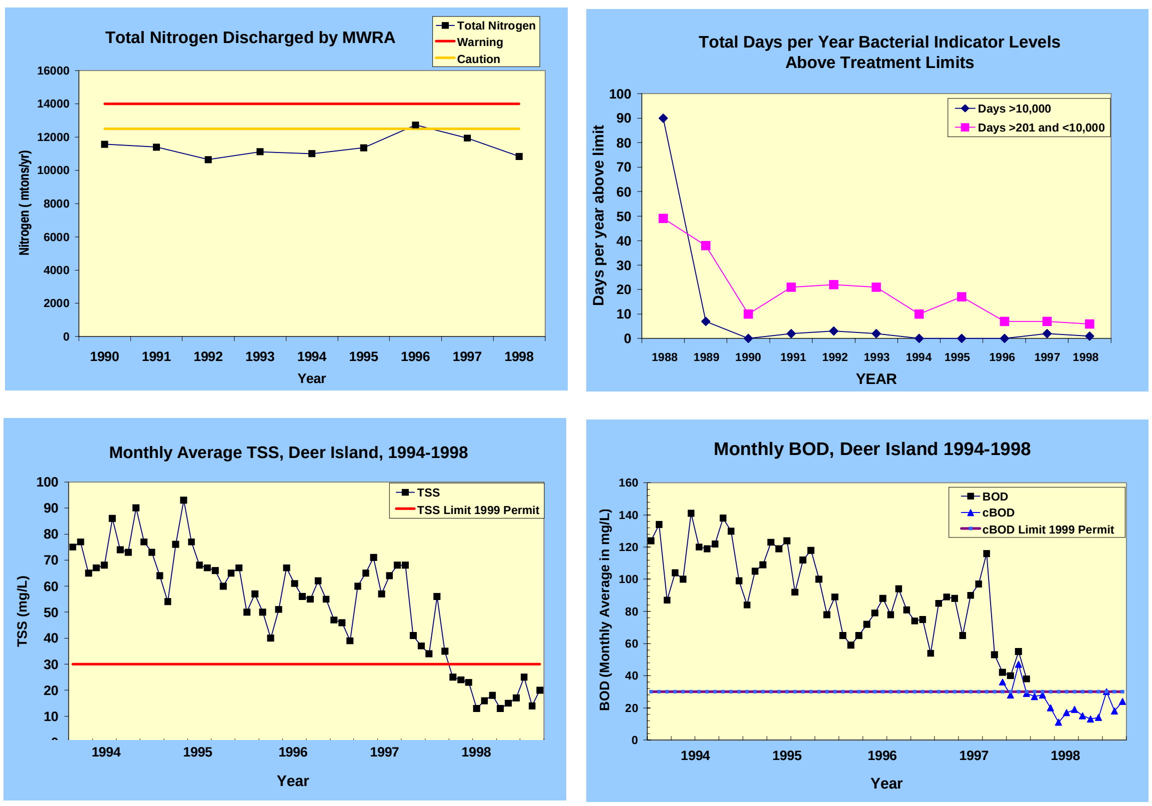
Figure 2-3. Annual loads of PAHs



Although it effectively removes most contaminants, secondary treatment yields little benefit for nutrient removal, and accordingly, annual nitrogen loads have remained relatively constant throughout the baseline-monitoring period. During 1994-1996, when primary treated effluent was discharged, loading ranged from 10,800 metric tons/year in 1992 to the 1996 high of 12,700 metric tons/year. After 1996, improvements to the system resulted in declines in total nitrogen to 10,800 metric tons/year in 1998, a level about 12% lower than had been predicted in the EPA SEIS (Figure 2-4).

Concentrations of solids, bacteria, total metals, PAHs, pesticides, and PCBs all were lower in 1998 than they were for any prior year. There were only 7 days in which the treatment plant did not meet daily standards for bacterial counts, compared to 139 days in 1988, and all weekly and monthly standards were met. These results reflect the initiation and continued implementation of secondary treatment. (Note that during 1997, the method of assessing organic material changed from measuring both carbonaceous and nitrogenous biological oxygen demand (BOD) to the more directed measuring of carbonaceous biological oxygen demand (cBOD). The 1999 permit level is for cBOD.)

Figure 2-4. Total nitrogen load, total days per year exceeding bacteria indicator levels, monthly average TSS concentrations, and monthly BOD



.

Contingency Plan Thresholds

Although the 1999 permit was not in effect in 1998, the treatment plant essentially operated in compliance with the limits that the permit set. Few results in 1998 were higher than the limits of contingency plan thresholds that will be in effect when the outfall begins operation. These measurements may have resulted from operational upsets during start-up of secondary treatment or the transfer of effluent from Nut Island to Deer Island. Contingency plan trigger parameters are shown in Table 2-2. During 1998, fecal coliform monthly average concentrations ranged from 5-11 colonies/100 ml, well below the future threshold. Biological oxygen demand, measured as BOD5, ranged from 23.1-94.5 mg/L. (Because the permit did not exist, the few measurements that exceeded thresholds were not flagged.) MWRA anticipates continued improvements as the final battery of secondary treatment becomes available and secondary treatment continues to be optimized.

Table 2-2. Threshold values for effluent monitoring

Parameter	Caution Level	Warning Level	1998 Results
Fecal coliform bacteria*		14,000 fecal coliforms/100 ml (monthly 90th percentile, weekly mean, and daily minimum—minimum of 3 consecutive samples)	Never exceeded
Chlorine, residual		631 ug/L daily, 456 ug/L monthly	Not applicable
Total suspended solids		45 mg/L weekly 30 mg/L monthly	Not applicable**
cBOD		40 mg/L weekly, 25 mg/L monthly	Not applicable
Toxicity		Acute: effluent LC50<50% for shrimp and fish Chronic: effluent NOEC for fish survival and growth and sea urchin fertilization <1.5% effluent	Not applicable
PCBs		Aroclor=0.045 ng/L	Never exceeded
Floatables		5 gal/day	Not measured
Permit violations	5 violations/year	>5% of the time	Not applicable
Total nitrogen load	12,500 mtons/year	14,000 mtons/year	Not exceeded

* Existing standard is 200 col/100 ml; threshold is based on a 70-fold dilution at the new outfall.
**During 1998, the treatment plant essentially operated in compliance with the not-yet-issued 1999 permit.

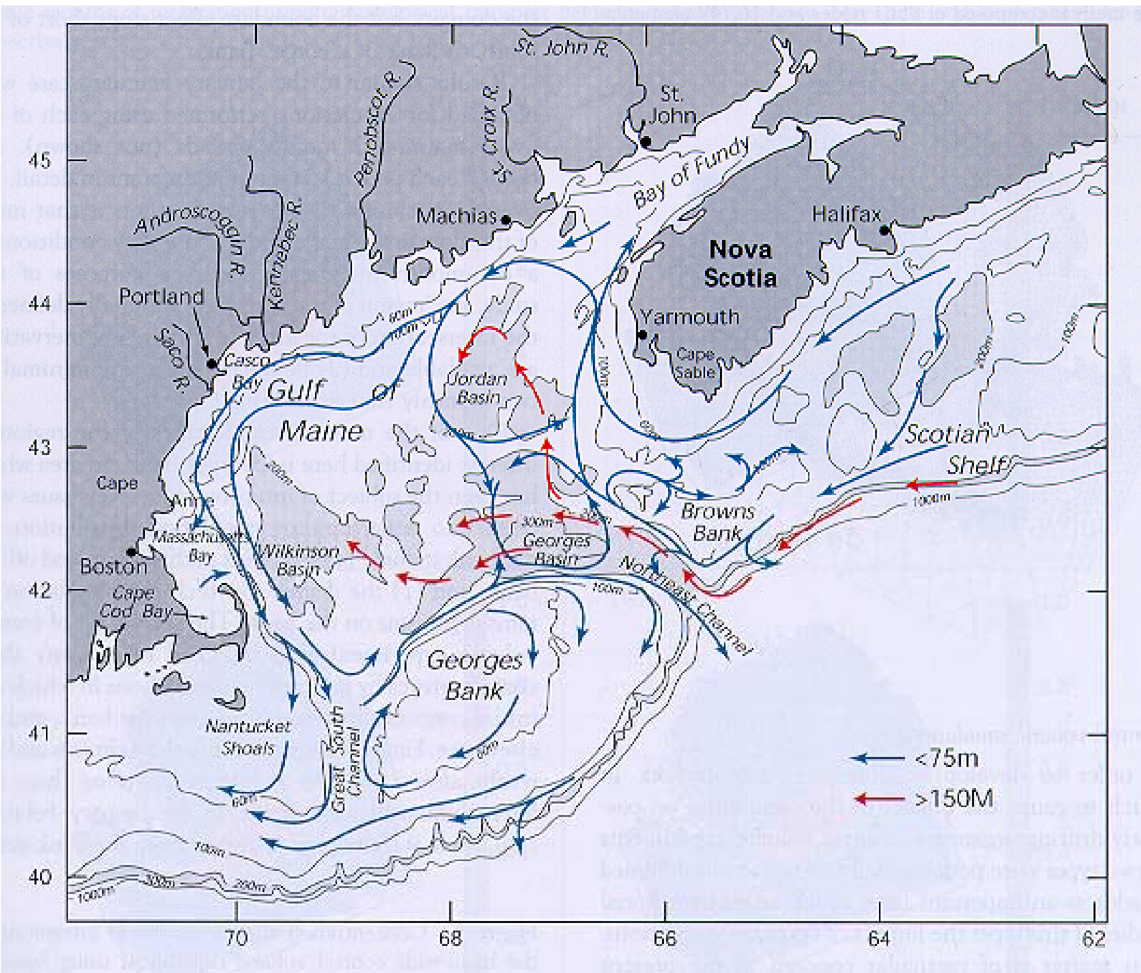
3. Water Column

Background

Circulation and Water Characteristics

Circulation, water properties and consequently, the biology of Massachusetts and Cape Cod bays are mainly driven by the larger pattern of water flow in the Gulf of Maine (Figure 3-1, from Beardsley *et al.* 1997). A general southeast coastal current flows southwestward into the bays by Cape Ann and back out of the bays to the north of Race Point at the tip of Cape Cod. During much of the year, a weak counterclockwise circulation persists within the bays.

Figure 3-1. Water circulation in the Gulf of Maine



Waters in Massachusetts and Cape Cod bays have been thought to follow a typical annual cycle, although wind and other factors greatly influence the pattern. During November through April, waters are well mixed and nutrient levels are high. As light levels increase in the early spring, phytoplankton usually begin a period of rapid growth known as a bloom. If it occurs, the spring bloom begins in the shallowest waters of Cape Cod Bay. Blooms in deeper waters follow in 2-3 weeks. While phytoplankton provide year-round food for zooplankton, spring blooms are typically followed by an increase in zooplankton abundance. Zooplankton are prey for many marine animals, including right whales.

Later in the spring, the surface waters warm and stratify (see Figures 3-4 and 3-5). Stratification effectively separates the surface and bottom waters, preventing replenishment of nutrients to the surface waters and replenishment of oxygen to the bottom waters. The surface-water phytoplankton deplete the available nutrients and undergo senescence, sinking to the bottom. Bacteria use up oxygen as they decompose the phytoplankton, and oxygen levels are typically lowest from August through October in the bottom waters. In surface waters, dissolved oxygen concentrations remain high throughout the year.

In the fall, cooling surface waters and strong winds allow mixing of the water column. Nutrients brought to the surface can stimulate a fall phytoplankton bloom. Fall blooms usually end in early winter with declining light levels. Plankton die and decay, replenishing nutrients in the water column.

Surface water temperatures show nearly the same pattern each year. Bottom water temperatures are more variable. Year-to-year variability in bottom temperature and dissolved oxygen concentrations are largely related to wind patterns. If winds are persistent southerly during the summer, this condition promotes upwelling, which leads to colder bottom temperatures and higher dissolved oxygen concentrations. Weaker southerly winds result in less upwelling, with consequently warmer bottom temperatures and lower dissolved oxygen concentrations.

Environmental Concerns

Water column monitoring focuses upon concerns that relocation of the outfall will introduce effects from the organic material, nutrients, and toxic contaminants in the effluent. Because organic material and toxic contaminants are effectively removed by secondary treatment, but nutrients are not, changes in the nutrient balance in Massachusetts and Cape Cod bays are thought to have the most potential for affecting the health of marine life in the water column of the bays.

Excess nutrients, particularly nitrogen, could promote algal blooms followed by low dissolved oxygen levels when the phytoplankton die, sink, and decompose. Changes in the relative levels of nutrients could stimulate undesirable algae to become present or dominant among the useful algae in the system. Two types of undesirable algae are of concern: nuisance species, such as brown tides, which affect the appearance of the water, and noxious species, such as some red tides, which, if sufficiently concentrated, can be toxic to marine mammals, fish, and humans. Undesirable algae can also affect the species composition of the plankton community.

Excess organic material from the wastewater effluent is another concern. Decomposition of organic material consumes the oxygen necessary for survival of marine life. Because of the concern that low dissolved oxygen levels could affect animals in the vicinity of the outfall, it has been important during the baseline-monitoring period to develop an understanding of the natural fluctuations within the system. Modeling and measurements have shown that periods of low oxygen in bottom waters near the outfall are inversely correlated with temperature. Understanding physical conditions in the region will be important in interpreting monitoring data when the outfall begins to operate. (A discussion of the monitoring of the health of the benthic community, also potentially affected by excess organic material, is included in Section 4.)

The toxic contaminants discharged in the MWRA effluent are projected to be at extremely low concentrations. Effluent dilution will be studied when the outfall begins operation, but monitoring for effects of toxic contaminants will be focused upon the sediments and fish and shellfish rather than on the water column.

Monitoring Design

Water column monitoring includes assessments of water quality and plankton in Massachusetts and Cape Cod bays. It includes five major components: nearfield surveys, farfield surveys, plume-tracking surveys after the outfall is operational, continuous recording, and remote sensing.

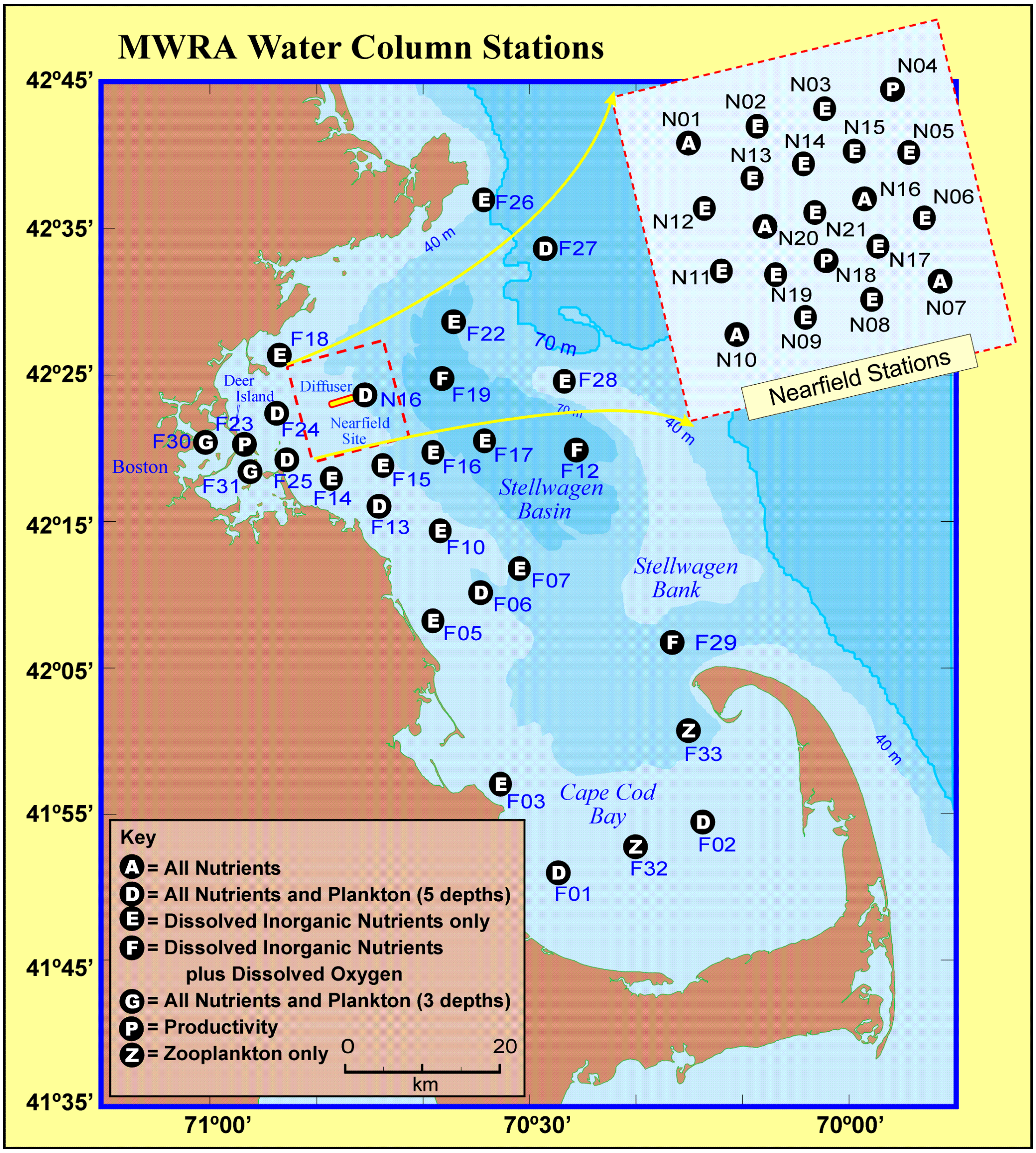
Nearfield surveys provide vertical and horizontal profiles of physical, chemical, and biological characteristics of the water column in the area around the outfall where effects of effluent may be detected. Farfield surveys assess differences across the bays and seasonal changes over a large area. In 1998, 17 nearfield and 6 farfield surveys were conducted. Samples were taken from 48 stations in Boston Harbor, Massachusetts Bay, and Cape Cod Bay (Figure 3-2). Five stations at the boundary of the monitoring area were in or near the Stellwagen Bank National Marine Sanctuary.

Parameters measured in water column monitoring include dissolved inorganic and organic nutrients, particulate forms of nutrients, chlorophyll, total suspended solids, dissolved oxygen, phytoplankton abundance and species composition, zooplankton abundance and species composition, respiration, and productivity. Nutrient measurements include the major forms of nitrogen, phosphorus, and silica.

Once the outfall becomes operational, plume-tracking surveys will determine the location, migration, and biological and chemical characteristics of the effluent plume leaving the outfall and mixing with the ambient waters. The continuous recording component of the program captures temporal variations in water quality between nearfield water surveys. Remote sensing captures spatial variations in water quality on a regional scale.

Certified whale watchers monitor marine mammals on all nearfield surveys and farfield water column surveys conducted between February and April. Besides providing monitoring data, presence of trained marine mammal observers addresses a request by the National Marine Fisheries Service.

Figure 3-2. Water column sampling stations



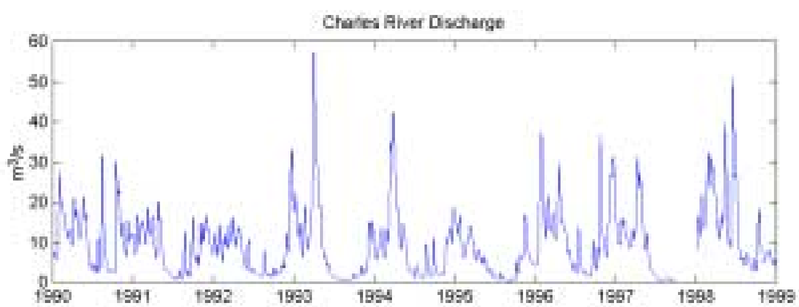
Results

Physical Conditions

During 1998, the Massachusetts and Cape Cod bays region was influenced, as was much of the country, by weather patterns associated with the El Niño event in the equatorial Pacific. The winter of 1997-1998 was relatively warm. Winter and spring were disrupted by many storms and record rainfalls. This unusual rainfall pattern was reflected in flow measurements in the Charles River, which were unusually high in the spring of 1998 (Figure 3-3). There was also a major storm in June.

These conditions resulted in warm water temperatures in the early spring and a slight delay in the onset of stratification. Due to the high river flow during late winter through mid-spring, surface salinity was lower in western Massachusetts Bay than in any year since the beginning of the monitoring program. The unusually low salinity in surface waters gave rise to strong stratification during the summer. The fall overturn and return to winter conditions were also delayed. The water column remained stratified until November in much of the nearfield, and a deep halocline was still present in December at the deeper eastern nearfield stations.

Figure 3-3. Charles River discharge 1990-1998



Over the year, average winds were favorable to upwelling. Through June of 1998, however, winds favored downwelling and strong throughflow from the Gulf of Maine to Massachusetts Bay. Relatively strong southerly winds, causing upwelling, occurred during the summer. Weak downwelling conditions were present during the final months of the year.

Water Quality

No spring phytoplankton bloom was observed in Massachusetts Bay for 1998, and elevated nutrient concentrations persisted in the surface waters until May (Libby *et al.* 1999). An early decrease in nutrient concentrations during February indicated that a bloom may have begun, but it never developed fully. In Cape Cod Bay, a bloom may have occurred prior to the first survey, which took place in February.

Figure 3-4. Temperature and dissolved inorganic nitrogen profiles. The entrance to Boston Harbor is to the left, and the eastern boundary of Massachusetts Bay is to the right.

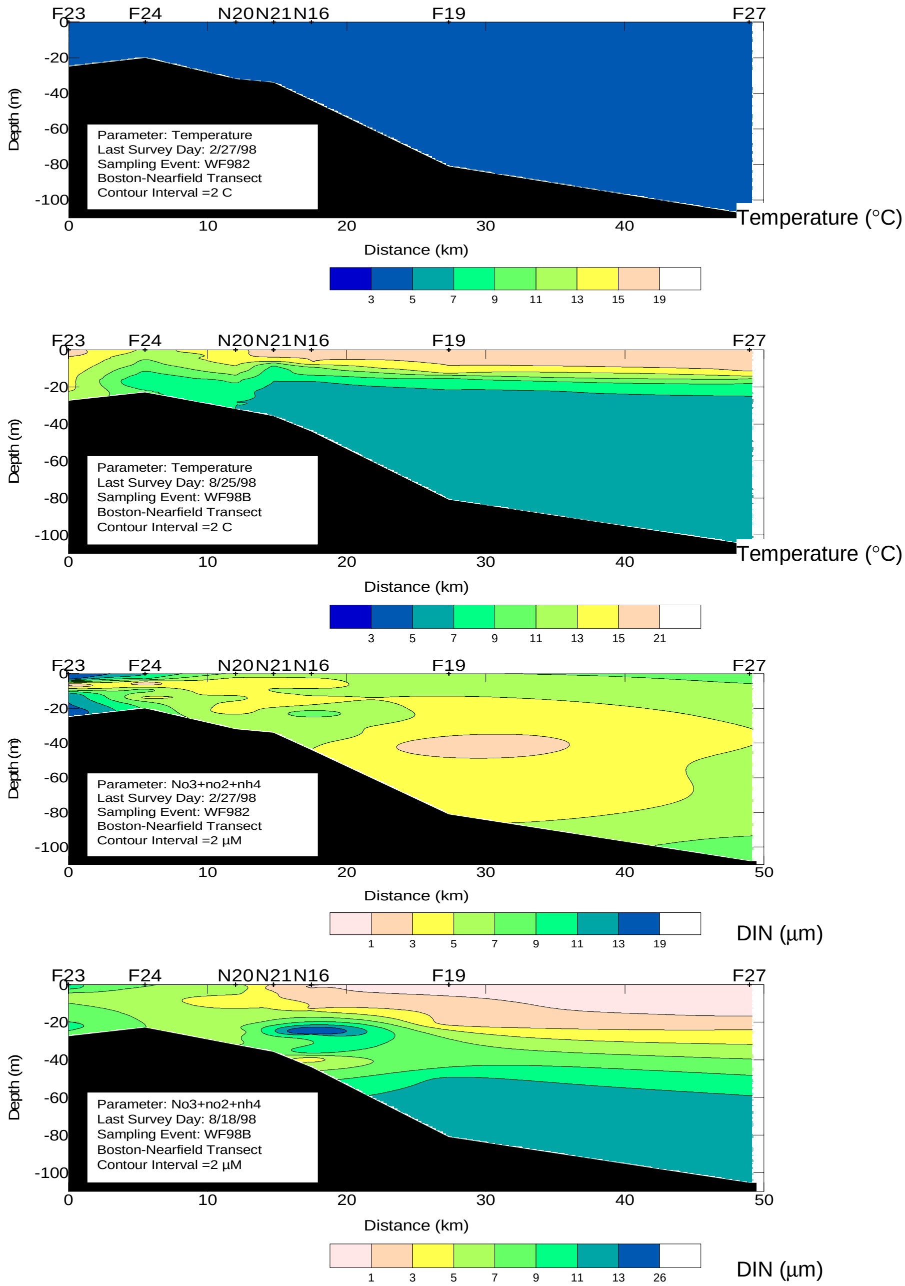
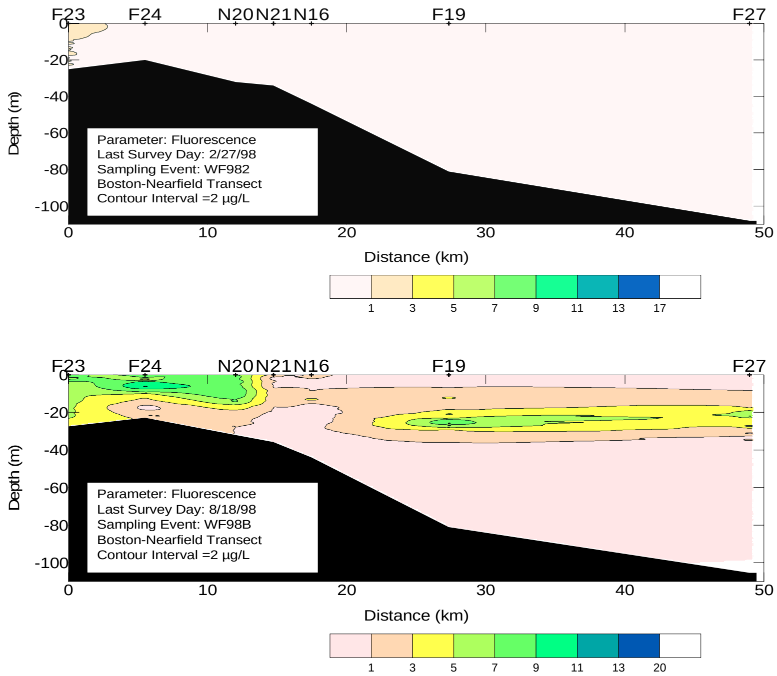


Figure 3-5. Chlorophyll profiles

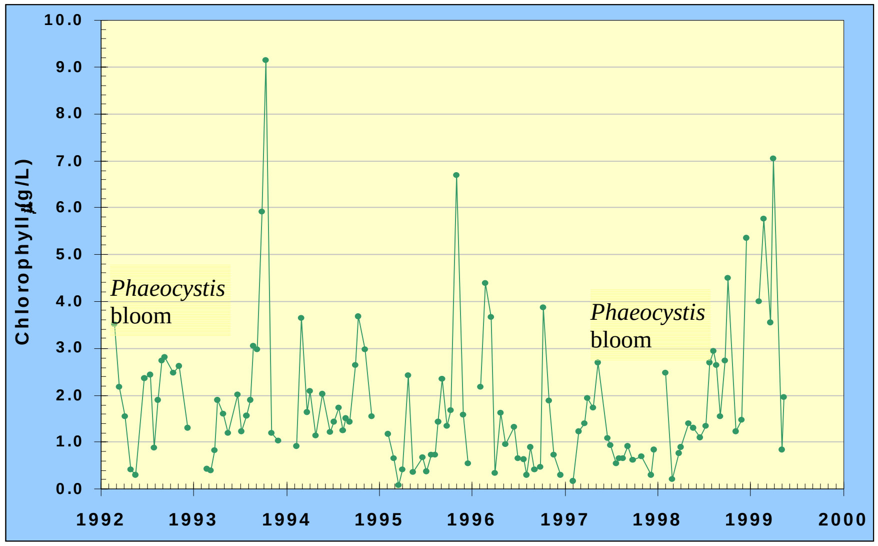


Generally, conditions were appropriate for development of a bloom (Figures 3-4, 3-5). Elevated nutrient levels, increasing light availability, increasing temperatures, and the onset of seasonal stratification were appropriate. Other factors that may have influenced phytoplankton populations include zooplankton grazing, the makeup of the resident phytoplankton assemblage, and physical, chemical, or biological forces. Possibly, the mild weather allowed relatively large zooplankton populations to persist through the winter, and these populations may have grazed phytoplankton at a rate that precluded expression of the bloom.

The years of baseline monitoring suggest that spring blooms, generally thought to be characteristic for coastal waters, may not be typical for Massachusetts Bay. Large blooms that occurred in 1992 and 1997 were dominated by the nuisance species *Phaeocystis pouchetii* (Figure 3-6). *Phaeocystis pouchetii* can occur at any time during the year, but was not present in 1998.

A fall bloom was observed in 1998, as in most previous years. The 1998 bloom developed from a general increase in the numbers of a variety of chain-forming diatoms. The bloom was more clearly observed in increased concentrations of chlorophyll and peak production rates than in phytoplankton abundance. Unusually, this bloom persisted through the winter of 1998-1999.

Figure 3-6. Survey mean chlorophyll distribution, 1992-1999



Major storm events and the lack of input of organic matter from a spring bloom resulted in relatively high concentrations of dissolved oxygen in June. Later, the persistent stratified conditions in 1998 led to decreases in bottom dissolved oxygen concentrations from June through December in the nearfield. The pulse of organic matter from the fall bloom further depressed dissolved oxygen levels to minimum concentrations in December (Figure 3-7). Rates of DO decline in 1998 were comparable to previous years (Figure 3-8). Because the early summer levels had been high, minimum dissolved oxygen concentrations were not low in comparison to prior years despite the extended period of stratification.

Figure 3-7. Survey mean dissolved oxygen in nearfield bottom waters

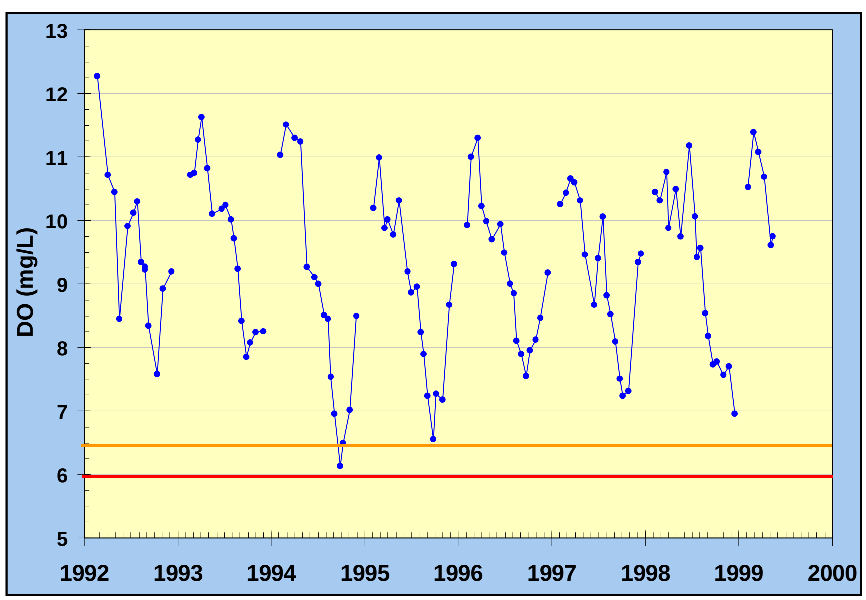
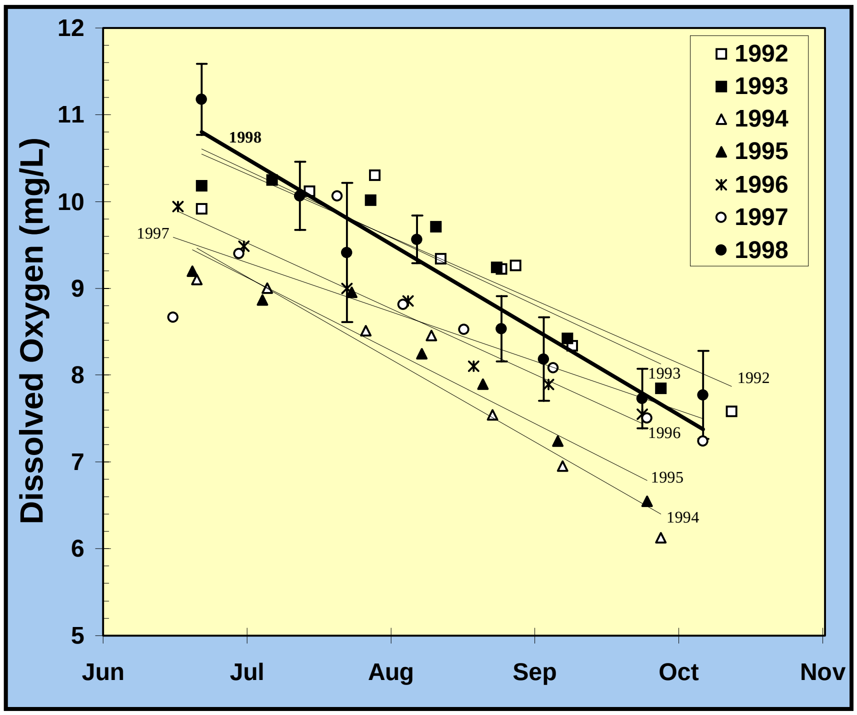


Figure 3-8. Rate of decline of dissolved oxygen concentrations in bottom waters in the nearfield

Year	Slope (mg/L/day)	Intercept* (mg/L)	R^2
1992	-0.024	11.0	0.808
1993	-0.025	11.1	0.885
1994	-0.031	10.1	0.929
1995	-0.027	9.9	0.932
1996	-0.025	10.3	0.978
1997	-0.020	9.8	0.632
1998	-0.032	11.5	0.938

*Predicted DO on June 1 based on:
DO = Slope * Date + Intercept



Phytoplankton Communities

Species composition was generally similar to previous years (Libby *et al.*1999). The size and seasonal pattern of phytoplankton abundance fell within the range of previous years. This pattern applied for the nearfield (Figure 3-9) and also for the boundary, Boston Harbor, Cape Cod Bay, and coastal regions (Figure 3-10). However, because the seasonal patterns are so variable, no one year of baseline monitoring has exactly replicated another. Overall, diatoms and microflagellates are numerically most abundant. Diatoms dominate the communities in biomass. As in previous years, winter was dominated by diatoms throughout the region. During March through May, diatoms continued to be abundant, along with the dinoflagellate *Heterocapsa rotundatum*. Cryptomonads were also present, particularly at nearshore stations. Microflagellates reached their peak abundance during the summer. A subdominant increase in pennate diatoms occurred in Boston Harbor and nearby coastal areas during late August. Localized blooms of diatoms occurred throughout the fall in the nearfield, while microflagellates continued to dominate in Cape Cod Bay.

Figure 3-9. Phytoplankton variability in the nearfield (survey mean, minimum, and maximum)

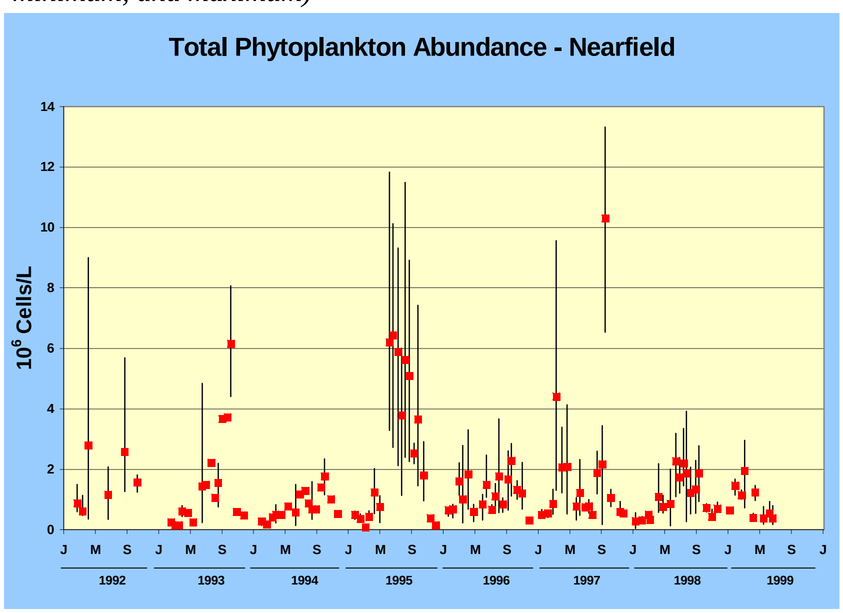
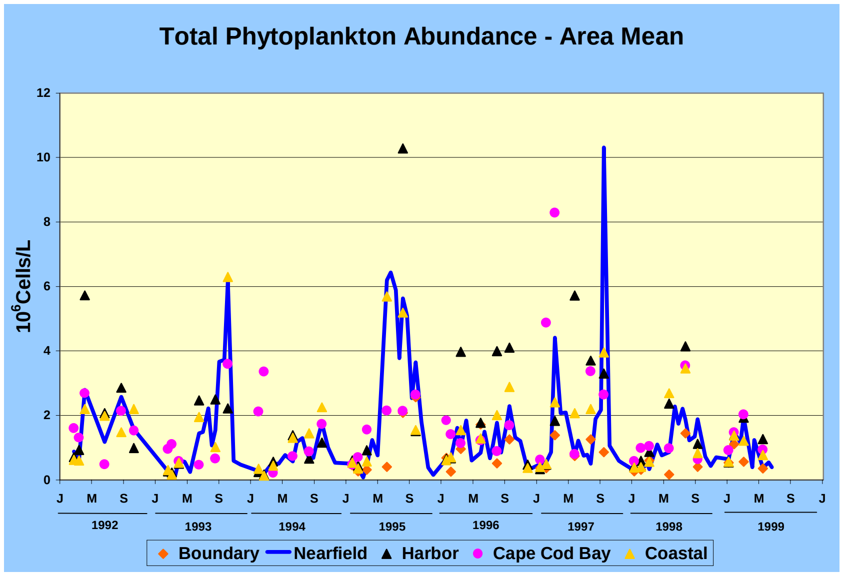


Figure 3-10. Survey mean total phytoplankton abundance—inter-annual and regional comparison



("Boundary" represents one station at the north of Massachusetts Bay.)

Zooplankton Communities

Total zooplankton abundance at nearfield stations generally increased from February through April, reached a peak in May, and remained moderately high through December (Figures 3-11, 3-12). Farfield stations followed a similar pattern, but data were quite variable.

Figure 3-11. Zooplankton variability in the nearfield

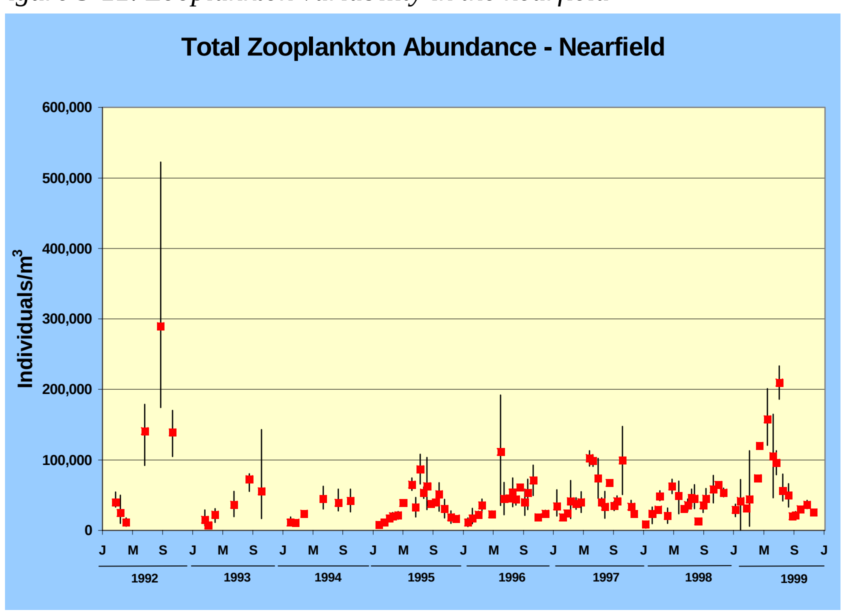
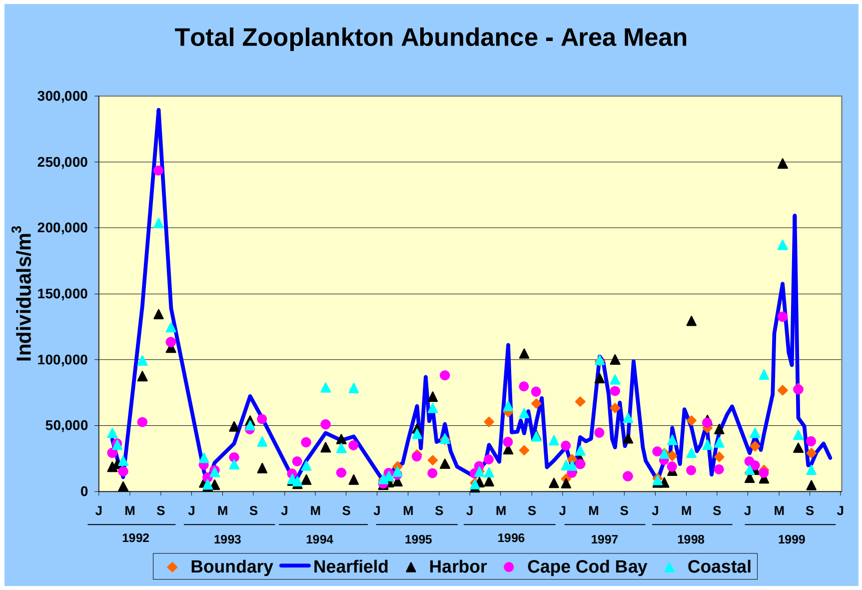


Figure 3-12.Survey mean total zooplankton abundance—inter-annual and regional comparison



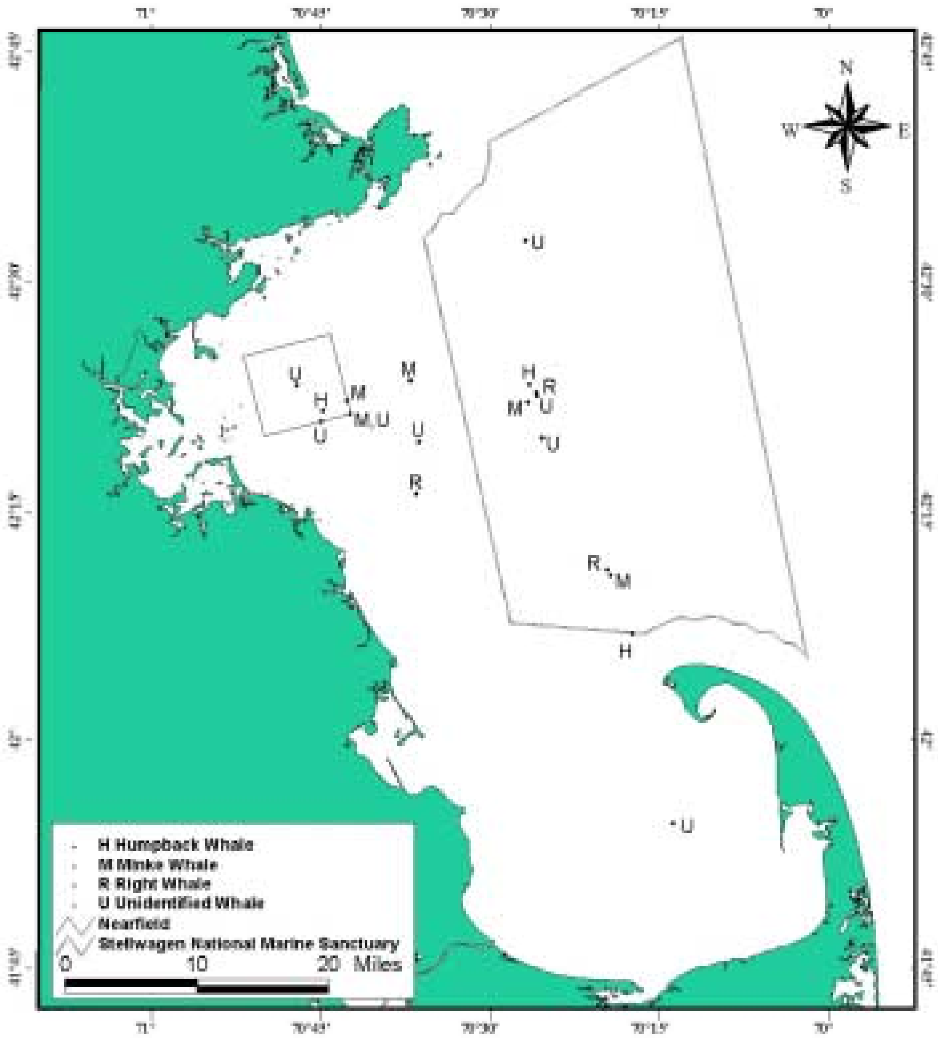
("Boundary" represents one station at the north of Massachusetts Bay.)

The zooplankton community was dominated by copepod nauplii, copepodites, and adults of the small species *Oithona similis* and *Pseudocalanus* spp., with seasonal occurrences of gastropod and bivalve veligers and other species. Overall, meroplankton are a relatively minor component of the community. As in other years, the zooplankton community in the nearfield was similar to that observed in Cape Cod Bay. The Massachusetts Bay communities are typical North Atlantic coastal assemblages, similar to those found in the broader region, including the Gulf of Maine and Buzzards Bay (Libby *et al.* 1999).

Marine Mammal Observations

Marine mammal observers were present on 21 of 37 MWRA surveys conducted during 1998, including all nearfield surveys, 3 farfield surveys, and 2 fecal coliform surveys (Figure 3-13; McLeod 1999). (As part of an agreement with the Massachusetts Division of Marine Fisheries, MWRA conducts monthly monitoring for fecal coliform bacteria in the outfall area.) Sightings included 23 individual whales, five groups of whales, and more than 32 Atlantic white-sided dolphins. Species observed included right, humpback, and minke whales. Whale sightings were distributed throughout the bays. Eight of the sightings occurred within the boundaries of the Stellwagen Bank National Marine Sanctuary, and six whales were seen in the nearfield.

Figure 3-13. Whale sightings during 1998



Contingency Plan Thresholds

Threshold parameters for water column monitoring include minimum dissolved oxygen concentration in nearfield and Stellwagen Basin bottom waters, dissolved oxygen depletion rate in nearfield bottom waters, chlorophyll level, nuisance algae, zooplankton species in the nearfield, paralytic shellfish toxin extent, and dilution (Table 3-2). During 1998, dissolved oxygen concentrations never dropped below caution or warning levels. During 1992-1998, mean dissolved oxygen concentrations ranged from 6.15 to 11.2 mg O_2/L. Concentrations were lower than the caution level twice during October 1994. Chlorophyll thresholds will be calculated from a complete set of baseline data. Through 1998, the annual mean chlorophyll level has ranged from 1.06 ug/L in 1997 to 2.28 ug/L in 1993. Phytoplankton community thresholds will focus on nuisance species and upon a spread of paralytic shellfish toxin into areas where it has not been detected (Table 3-1). *Alexandrium tamarense*, *Phaeocystis pouchetii*, and *Pseudo-nitzchia multiseries* have been extremely rare during the baseline-monitoring period. Currently, a caution level for zooplankton has been established as a shift towards the type of community, dominated by the copepod *Acartia*, currently seen nearshore, near Boston Harbor (Figure 3-14). This threshold remains under discussion. Initial dilution will be measured through a dye study when discharge begins, and a warning level would be exceeded if dilution is less than was predicted by EPA as a basis for the permit.

Figure 3-14. Survey mean abundance of the nearshore zooplankton species, Acartia

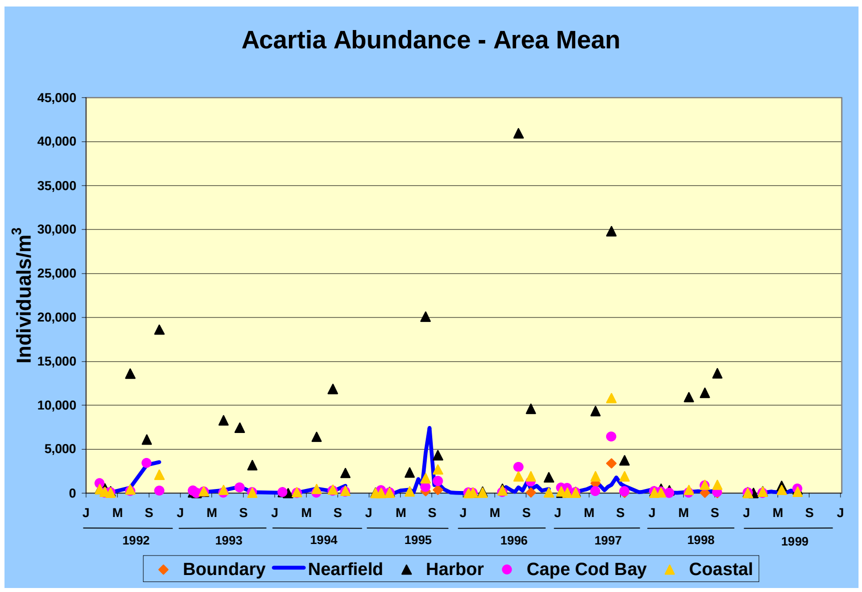


Table 3-1. Massachusetts DMF shellfish PSP monitoring stations

Primary Stations	Secondary Stations
Gloucester—Annisquam Yacht Club	Rockport—Granite Street
Hull—Point 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	Plymouth—Elisville Harbor
Dennis—Sesuit Harbor	Sandwich—Sandwich Harbor
	Barnstable—Marispan Creek
	Provincetown—The Dike

Table 3-2. Threshold values for water column monitoring

Location	Parameter	Caution Level	Warning Level	1998 Results
Bottom water (nearfield and Stellwagen Basin)	Dissolved oxygen concentration	Monthly mean <6.5 mg/L (June-October)	Monthly mean <6.0 mg/L (June-October)	Never below threshold
Bottom water (nearfield)	DO depletion rate	1.5x baseline (June-October)	2x baseline (June-October)	Not applicable, baseline monitoring
Nearfield	Chlorophyll level	Annual mean >1.5x baseline	Annual mean >2x baseline	Not applicable, baseline monitoring
Nearfield	Chlorophyll level	95th percentile of the baseline seasonal mean		Not applicable, baseline monitoring
Nearfield	Nuisance algae abundance	Appreciable change in seasonal mean concentration of *Alexandrium tamarense* or *Phaeocystis pouchetii*. Also *Pseudo-nitzchia multiseries* > 500,000 cells/L		Not applicable, baseline monitoring
Nearfield	Zooplankton abundance	Shift toward inshore community		Threshold under discussion
Farfield	PSP toxin extent	New incidence		None measured
Plume	Initial dilution		Effluent dilution less than predicted by EPA as basis for NPDES permit	Not applicable

4. Sea Floor

Background

Bottom Characteristics and Sediment Transport

The sea floor of Massachusetts and Cape Cod bays was originally shaped by the glaciers, which sculpted the bottom and deposited debris, forming basins, knolls, banks, and other features. Within Massachusetts Bay, the sea floor ranges from mud in depositional basins to coarse sand, gravel, and bedrock on topographic highs. The area around the new outfall is marked by drumlins, which are elongated hills about 10 m high, with crests covered by gravel and boulders. Cape Cod Bay, Stellwagen Basin, and Boston Harbor represent long-term sinks for fine-grained sediments (USGS 1997, 1998).

Sediment transport in the system occurs primarily during storms. Typically, strong storms with winds from the northeast resuspend sediments, which are transported by counter-clockwise currents from western Massachusetts Bay to the offshore and toward Cape Cod Bay, where they are likely to remain. Cape Cod Bay is sheltered from large waves by the arm of Cape Cod, and storm waves are rarely large enough to resuspend sediments in Stellwagen Basin, which is the deepest feature in the region.

Environmental Concerns

While studies of Boston Harbor sediments are documenting its recovery following the cessation of sludge discharge, improvements in CSOs, and improved sewage effluent treatment, there are concerns about potential effects of the relocated outfall on the sea floor. There are three specific concerns: eutrophication and related low dissolved oxygen levels, accumulation of toxic contaminants in depositional areas, and smothering of animals by particulate matter. If transfer of the nutrient loads to the offshore site were to cause eutrophication, depressed levels of dissolved oxygen could profoundly affect bottom communities. Although source control and treatment plant performance are designed to keep effluent contaminant concentrations too low to affect the sediments, the location of the outfall in an area of considerable sediment transport causes concern about accumulation of toxic contaminants in the depositional areas of Cape Cod Bay and

Stellwagen Basin. Similarly, concentrations of particulate matter are expected to be low, but there remains some concern that bottom communities could be smothered. The most likely adverse effect of the outfall would be a disruption of normal benthic community structure by increasing the amount of food available to the bottom.

Monitoring Design

Sea floor monitoring includes several components: measurements of contaminants in sediments, sediment-profile imaging to provide a rapid assessment of potential effects, studies of nearfield and farfield soft-bottom communities, and study of hard-bottom communities. For farfield stations located within Stellwagen Bank National Marine Sanctuary, MWRA has obtained a permit from the sanctuary to collect sediments. USGS has also conducted long-term studies of sediment transport and contaminant levels in Boston Harbor and Massachusetts and Cape Cod bays. These projects continue to be active.

Sediment contaminant studies were included in 1998 after a two-year hiatus. During 1996, the OMTF determined that the baseline for routine annual sediment contaminant measurements was adequate, so no sampling occurred in 1996 or 1997. During 1997, an OMTF focus group asked MWRA to institute a targeted study to examine possible short-term effects of the new outfall. This study includes four stations selected for specific parameters:

- They include a high percentage of fine-grained material, with those high percentages remaining stable over the monitoring period.
- They have high concentrations of total organic carbon (TOC).
- They are located in the zone of effluent particle deposition predicted by the Bays Eutrophication Model.
- They expand the areas sampled three times per year by USGS.

After the outfall begins operation, these stations will be sampled three times per year. A pilot study of the stations was conducted during October 1998. Samples were analyzed for spores of the sewage indicator bacterium *Clostridium perfringens*, sediment grain size, TOC, and contaminants.

Sediment-profile image surveys are conducted in August of each year at 20 nearfield and 3 farfield stations to give an area-wide assessment of sediment quality and benthic community status. They provide a more rapid assessment of benthic habitat conditions than is possible from traditional faunal analyses. A system called “Quick Look,” which uses digital video cameras along with film, provides an even faster assessment. A real-time narration of the videotape describes the substrate and estimates depth of the oxidation-reduction potential discontinuity (RPD), the depth at which sediments change from being oxic to anoxic. Quick Look was used for the first time in 1998 and yielded results that were comparable to more detailed, computer-based methods. Later, complete analyses of the films provide information on sediment grain size, sediment layering, fauna and structures, general benthic successional stage, prism penetration, surface relief, and apparent color RPD depth.

Nearfield and farfield soft-bottom surveys are also conducted in August. Sampling of 20 nearfield stations is designed to provide spatial coverage and local detail about the fauna in depositional environments within 8 km of the diffusers (see Figure 4-2). Farfield sampling of 11 stations in Massachusetts and Cape Cod bays will contribute reference data on soft-bottom habitats. Samples are analyzed for community parameters, *Clostridium perfringens* spores, sediment grain size, and TOC content.

While most studies of benthic communities, including the MWRA program, focus upon the soft bottom, areas with finer-grained sediments, such depositional habitats are relatively rare in the vicinity of the outfall. Therefore, MWRA also conducts video and photographic surveys of the hard-bottom habitats found on the tops and flanks of drumlins in western Massachusetts Bay (Figure 4-1). Video and still photographs are taken at waypoints along 6 transects and at Diffuser #44 of the new outfall. These surveys are conducted in June. Photographs are examined for substrate type, amount of sediment drape, and biota.

Figure 4-1. Location of hard-bottom transects

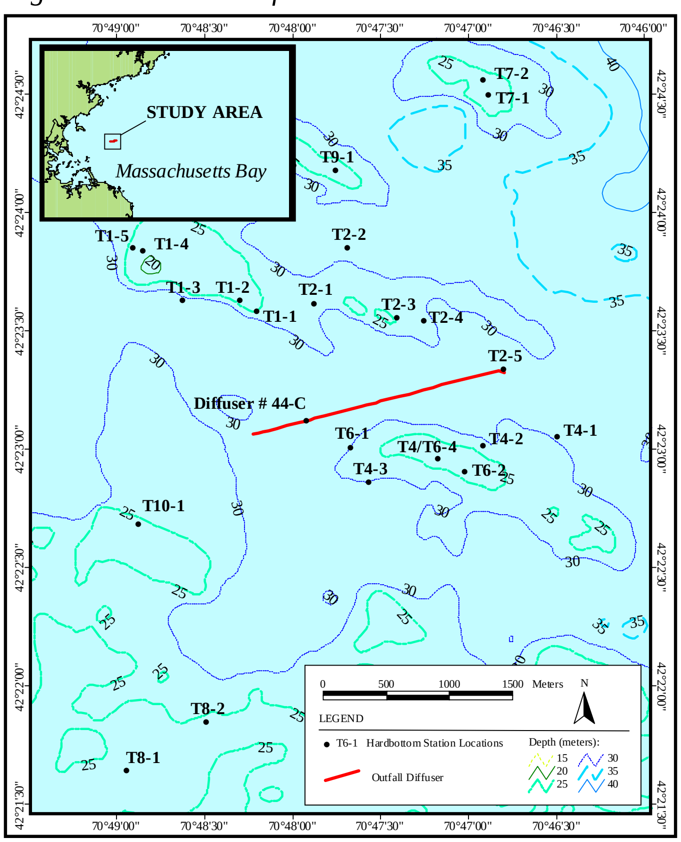
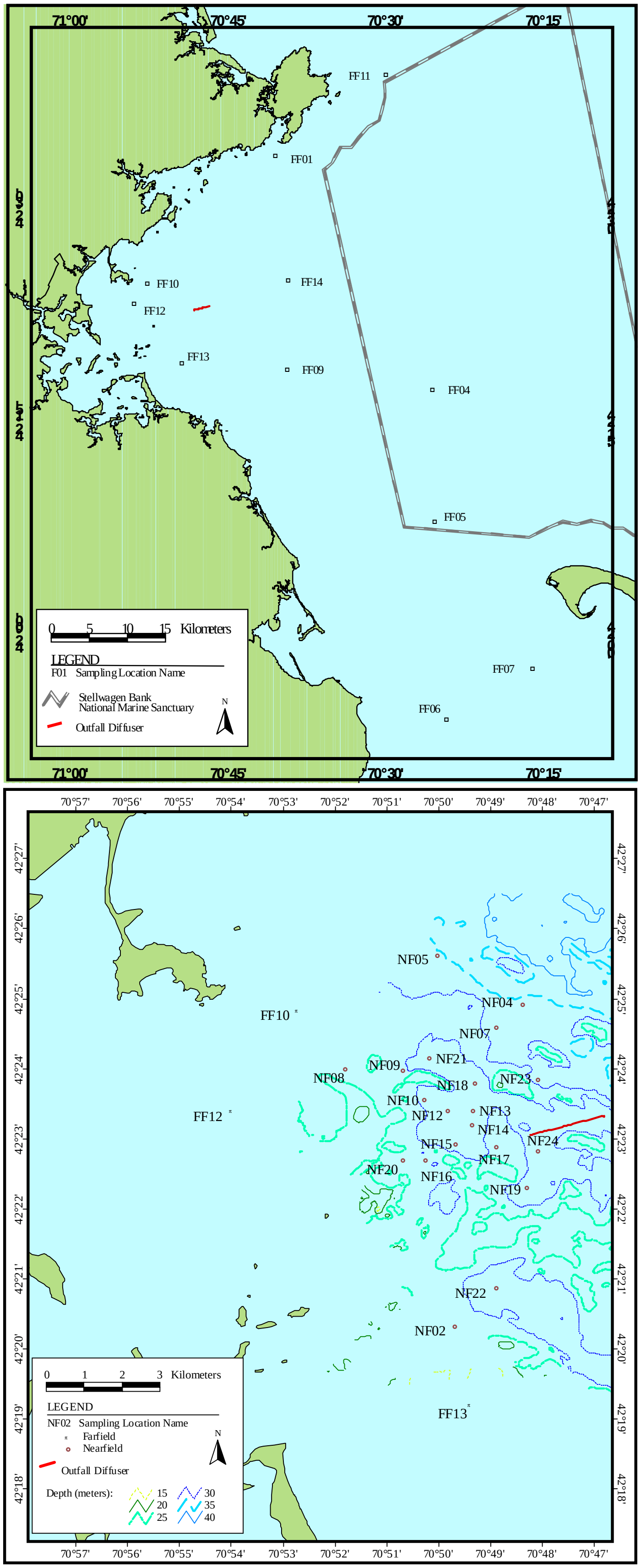


Figure 4-2. Location of soft-bottom stations



Results

Sediment Contaminants

As found in USGS studies and previous baseline monitoring, concentrations of organic and inorganic contaminants in sediments near the new outfall were low (Kropp *et al.* 1999). Levels of contaminants were well below established EPA and NOAA guidelines. Concentrations of chlorinated pesticides and PCBs were extremely low, averaging less than 10 ng/g. Although consistently low, variability in the concentrations of organic contaminants was found within and among the four stations. Higher concentrations were found in samples with fine sediments and high concentrations of TOC. Concentrations of metals were also extremely low, less than 10 times the method detection limits, and generally less variable than the organic compounds.

Sediment Profile Imaging

Sediment profile imaging surveys were conducted in 1992, 1995, 1997, and 1998 (Figure 4-3). Throughout that time, the sediments were consistent, with very fine sand to silty-fine sand as the dominant sediment type (Kropp *et al.* 1999). Assessment of the apparent color RPD through time has been complicated by shallow penetration of the prism. At many stations, one or more replicate image has not penetrated deeply enough to see the RPD layer. Allowing for that difficulty, it appears that the RPD layer depth became shallower between 1992-1995 and 1997-1998. Pioneering or "Stage I" communities prevailed in the nearfield during 1992 to 1997, whereas Stage II fauna were more common in 1998. The occurrence of Stage III fauna, those animals representing the highest successional stage, also increased in 1998, although these advanced successional communities did not lead to a deepening of the RPD. The monitoring data reflect the physically dynamic processes that dominate the nearfield. Data from 1998 may indicate a recent increase in the importance of biological processes in structuring the sediment environment.

Figure 4-3. Typical sediment profile image

Soft-bottom Communities

During the course of baseline monitoring, samples from the bays have routinely had twice as many species as those from Boston Harbor. Total infaunal abundance and numbers of species have varied (Figures 4-4 to 4-5; Kropp *et al.* 1999). Two distinct patterns have been noted in comparing data from nearfield and farfield stations. At farfield stations, mean total species and log-series alpha, a measure of species diversity, remained roughly stable from 1992 through 1995, then increased substantially in 1996 and 1997. In contrast, the average number of species at nearfield stations decreased about 33% from 1992 to 1993. Numbers of species subsequently rose until they leveled off in 1997 and 1998. In 1998, total species and log-series alpha were similar to 1997 values for both nearfield and farfield stations.

Figure 4-4. Mean (± 95 % confidence intervals) numbers of individuals per sample for those collected from 1992 to 1998

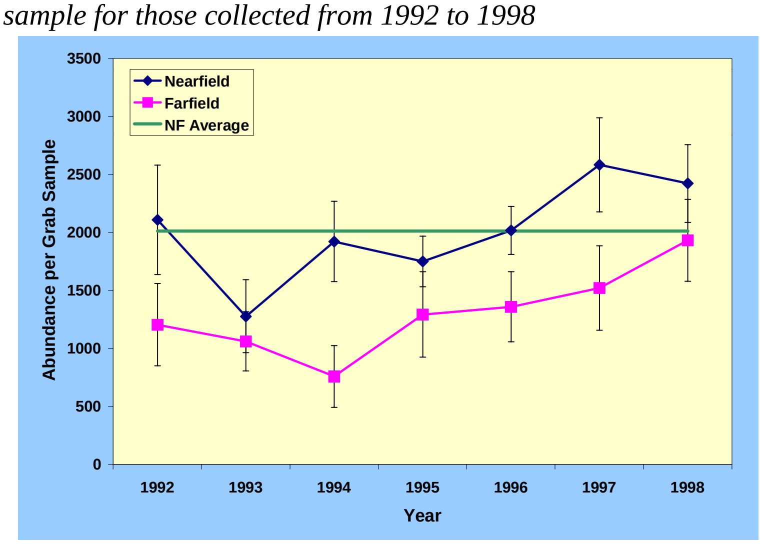


Figure 4-5. Mean (± 95 % confidence intervals) number of species per sample collected from 1992 to 1998

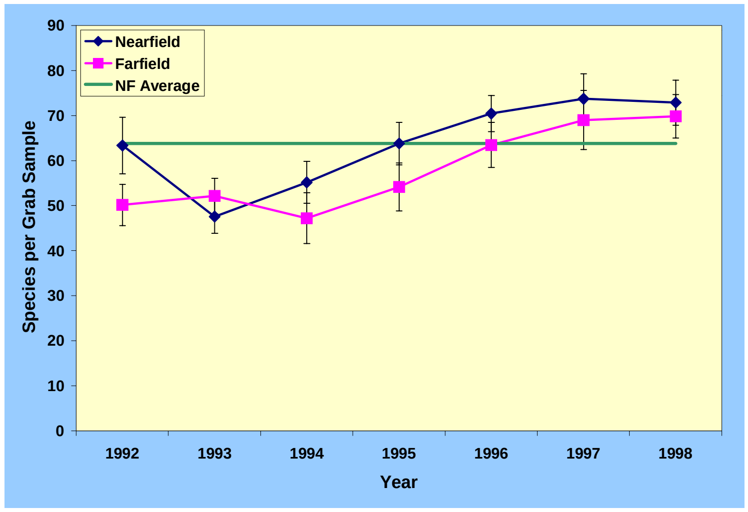
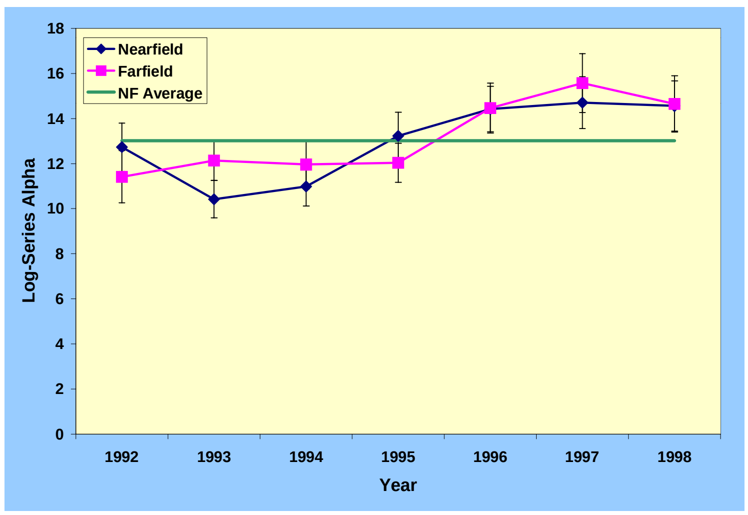


Figure 4-6. Mean (± 95 % confidence intervals) diversity measured as log-series alpha for nearfield samples collected from 1992 to 1998



Multivariate analyses of the 1998 nearfield data indicated that the stations could be separated into two major groups. One group was associated with medium to fine sandy sediments and was distinguished by high abundances of the annelid worms, *Polygordius* sp. A and *Spiophanes bombyx*. The other group was dominated by the annelid species, *Prionospio steenstrupi*, *Mediomastus californiensis*, and *Aricidea catherinae*. These taxa are often associated with somewhat "muddy" sediments, although they can found in a wide range of sediment types.

Multivariate analyses of the farfield data divided the stations into three dissimilar groups. One cluster included stations characterized by the annelid, *Prionospio steenstrupi*, and the nut clam, *Nucula delphinodonta*. The second group included stations located along the eastern portions of the bay, from Cape Ann to Cape Cod, and included a diverse fauna. The third cluster comprised only samples from one station in Cape Cod Bay, dominated by the annelid, *Tharyx acutus*, and the amphipod, *Leptocheirus pinguis*.

In the nearfield, the temporal patterns of total individual and species richness indices reflect destruction and recovery from storm surges that occurred during December 1992. The storm surges associated with a December 12, 1992 storm were quite high, among the highest measured since the early 1980s. Extreme changes in bottom characteristics of some stations occurred during that winter, including one station changing from more than 80% mud to 99% sand and gravel.

The patterns of increasing species richness during 1994 and 1995 have not been explained. MWRA has evaluated possible explanations:

- Are Massachusetts Bay benthic populations exhibiting a cyclic pattern, driven by long-term weather patterns?
- Is the bay undergoing eutrophication?
- Have methodological differences in treatment of samples occurred as technicians have learned more about the bay?

Only one of these possible explanations, a cyclic pattern, is likely. Cycles of 7-8 years have been observed in other benthic systems. It would be important to understand such a cycle, as ignoring it could lead to misinterpreting monitoring results. If a natural cycle in Massachusetts Bay resulted in a decrease in species richness at the same time that the outfall began operation, the response could be interpreted as an outfall effect. Thus, it will be important to compare changes in the nearfield with those in the farfield.

The other possible explanations are not likely. The baseline data to date do not indicate that the bay is undergoing eutrophication. Water-column monitoring documented lower average concentrations of chlorophyll in both nearfield and farfield waters during 1995-1997, compared to 1992-1994 or 1998. Nor is there evidence for changes in methodology or taxonomic expertise. The total number of species identified during each year has changed very little since 1992, and periodic changes in analysts have not corresponded with substantial changes in species richness.

Hard-bottom Communities

Analyses of the past four years of video and still photographs have shown a temporally stable pattern in the structure of hard-bottom communities (Kropp *et al.* 1999, Figure 4-7). The amount of sediment drape varied within sites, with totally clean rocks adjacent to rocks heavily covered with sediment. Consequently, there was considerable small-scale, within-site heterogeneity in distributions of many taxa. However, the consistency over time indicates that a major change between years should be readily detectable.

Algae usually dominated the tops of drumlins, while encrusting or attached invertebrates were increasingly dominant on the flanks. The encrusting coralline algae *Lithothamnion* spp. were the most common algae. Abundance of *Lithothamnion* spp. was inversely correlated with sediment drape, percent cover being greatest in areas with the least sediment. This relationship is not surprising, because the encrusting growth form of *Lithothamnion* spp. makes them susceptible to smothering. Consequently, *Lithothamnion* spp. may be good future indicators of outfall effects.

Figure 4-7. Typical hard-bottom survey photograph

Contingency Plan Thresholds

Threshold parameters for sea floor monitoring include contaminant concentrations, RPD depth, and benthic diversity and species composition in soft-bottom communities (Table 4-1). For contaminants, a caution level has been set at 90% of EPA or NOAA sediment guidelines, and to date, all contaminant concentrations have been well below those levels. A caution level of decline in RPD depth to half its baseline level would be readily observed. Levels measured during monitoring ranged from 1.73 cm in 1998 to 3.02 in 1995. If only data collected through 1998 were used, the caution level would be set at 1.26. The caution level for benthic diversity will also be based upon a full set of baseline data and has not yet been determined. Caution and warning levels for species composition are based on the premise that increases in opportunistic species would indicate environmental stress. Pollution-tolerant species, such as *Capitella* spp., *Streblospio benedicti*, *Polydora cornuta*, and *Mulinia lateralis*, and moderately pollution-tolerant species, such as *Ampelisca abdita/vadorum*, make up about 50% of the species in Boston Harbor. Opportunistic species have been rare in the nearfield and farfield throughout the baseline period.

Table 4-1. Threshold values for sea floor monitoring

Parameter	Caution Level	Warning Level	1998 Results
Depth of redox potential discontinuity	Redox potential discontinuity declines to less than half the baseline depth		To be based on baseline data
Contaminants	90% of EPA or NOAA sediment guidelines	EPA sediment criteria	Never exceeded
Benthic diversity	Appreciable change after allowing for storm effects		To be based on baseline data
Species composition	25% of abundance is opportunistic species	50% of abundance is opportunistic species	Not exceeded

5. Fish and Shellfish

Background

Fisheries

The fish and shellfish industry is an important part of the regional identity and economy of Massachusetts. During 1998, the total Massachusetts fishery was valued at more than $200 million. Almost 25% of that value was attributed to the lobster fishery. Sea scallops, cod, winter flounder, and goosefish, also known as monkfish, made up another 40% (NMFS fisheries statistics). Although many shellfish beds in the region are closed due to coastal bacterial contamination, the fishery for oysters and clams remains substantial.

Recreational fishing is also important to the region. In 1998, striped bass, bluefish, flounders, and cod were the most popular sports fisheries within the Massachusetts territorial sea (NMFS recreational fisheries data).

Environmental Concerns

One concern about relocating the sewage effluent offshore, into relatively clean waters, is that contaminants will adversely affect resource species, either through direct damage to the fishery stocks or by contamination of the fish, lobster, and other shellfish. Because many toxic contaminants adhere to particles, animals that live on the bottom, in contact with sediments, and those animals that eat bottom-dwelling organisms are most likely to be affected. Exposure to contaminated sediments could result in fin erosion, black gill disease, or other, more subtle, abnormalities in flounder, lobster, or other bottom-dwelling animals. Shellfish that feed by filtering suspended matter from large quantities of water are also potential bioaccumulators of toxic contaminants. Consumption of these animals by predators could result in transferring contaminants up the food chain and ultimately to humans.

Monitoring Design

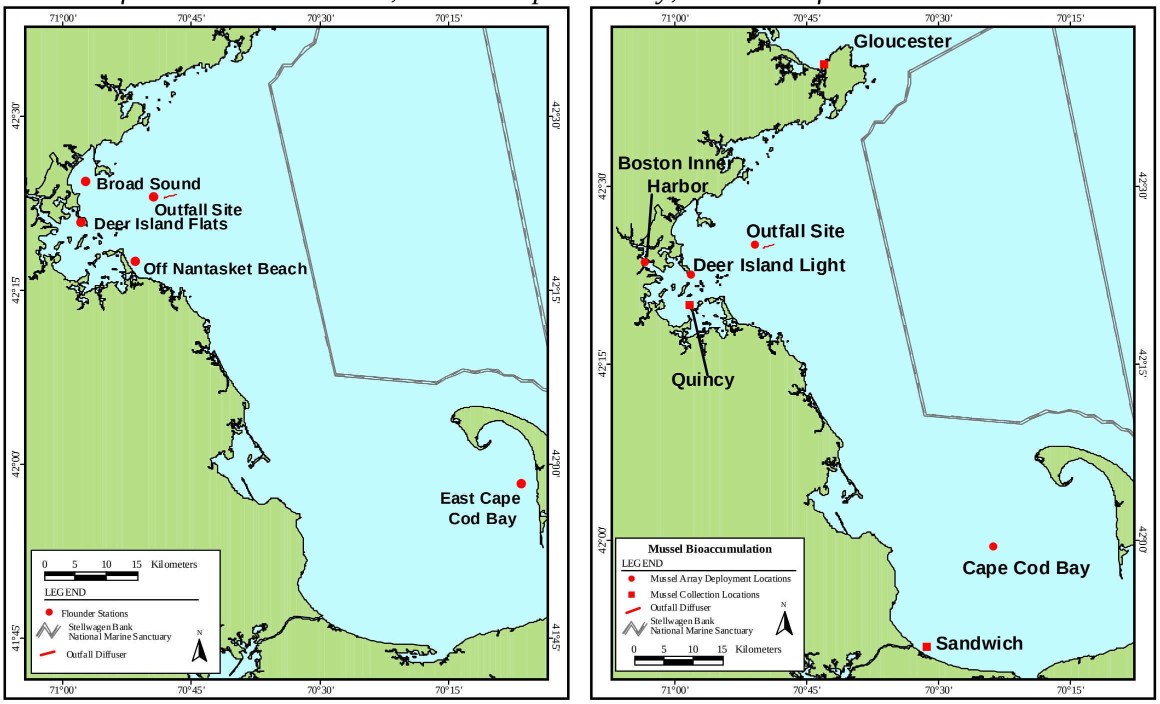
The monitoring program focuses on three indicator species: winter flounder, lobster, and blue mussel. Winter flounder and lobster are important resource species, and the blue mussel, deployed in caged arrays, is a common biomonitoring species.

Like all flatfish, winter flounder live on and eat food from the bottom, often burying themselves in the sediments. Consequently, flounder can be exposed to contaminants directly, through contact with the sediments, or indirectly, by ingesting contaminated prey. Flounder are collected from stations within Boston Harbor and the bays to obtain specimens for age determination, gross examination of health, chemical analyses, and liver histology (Figure 5-1). Chemical analyses of tissues are made to determine tissue burden and whether contaminant burdens approach human health consumption limits. Chemical analyses of composite samples of fillets and livers include PCBs/pesticides and mercury. Liver samples are also analyzed for PAHs, lead, silver, cadmium, copper, nickel, and zinc. Livers are examined to quantify three types of vacuolation (centrotubular, tubular, and focal), macrophage aggregation, biliary duct proliferation, and neoplasia. These histology parameters have been associated with chronic exposure to contaminants.

Lobsters live on a variety of surfaces within the region, including mud, sand, gravel, and rock outcrops. Lobsters are collected from Deer Island Flats, the area near the new outfall in Massachusetts Bay, and eastern Cape Cod Bay to determine specimen health and tissue burden of contaminants. Chemical analyses are performed on composite samples. Edible meat and hepatopancreas are analyzed for PCBs/pesticides and mercury. Hepatopancreas samples are also analyzed for PAHs, lead, silver, cadmium, chromium, copper, nickel, and zinc.

Like other filter feeders, blue mussels process large volumes of water and can concentrate toxic metals and organic compounds in their tissues. Mussels can be readily maintained in fixed cages, so they are convenient monitoring tools. Mussels are collected from reference sites in Gloucester and Sandwich and deployed in replicate arrays at five sites. (Two of the sites, Quincy Bay and Cape Cod Bay, were new to the program in 1998.) Gloucester mussels provide a reference for organic contaminant analyses, and Sandwich mussels provide a reference for inorganic contaminants. Separate groups are used as references, because mussels harvested in Gloucester have very low levels of organic contaminants, and mussels from Sandwich have very low levels of metals. After a minimum deployment of 40 days or a preferred deployment of 60 days, chemical analyses are performed on composite samples of mussel tissue. Gloucester mussel tissue is analyzed for PCBs/pesticides and PAHs. Sandwich mussel tissue is analyzed for mercury and lead.

Figure 5-1. Flounder sampling stations (left) and mussel deployment sites (right). Lobsters are taken from Deer Island Flats, eastern Cape Cod Bay, and the outfall site.



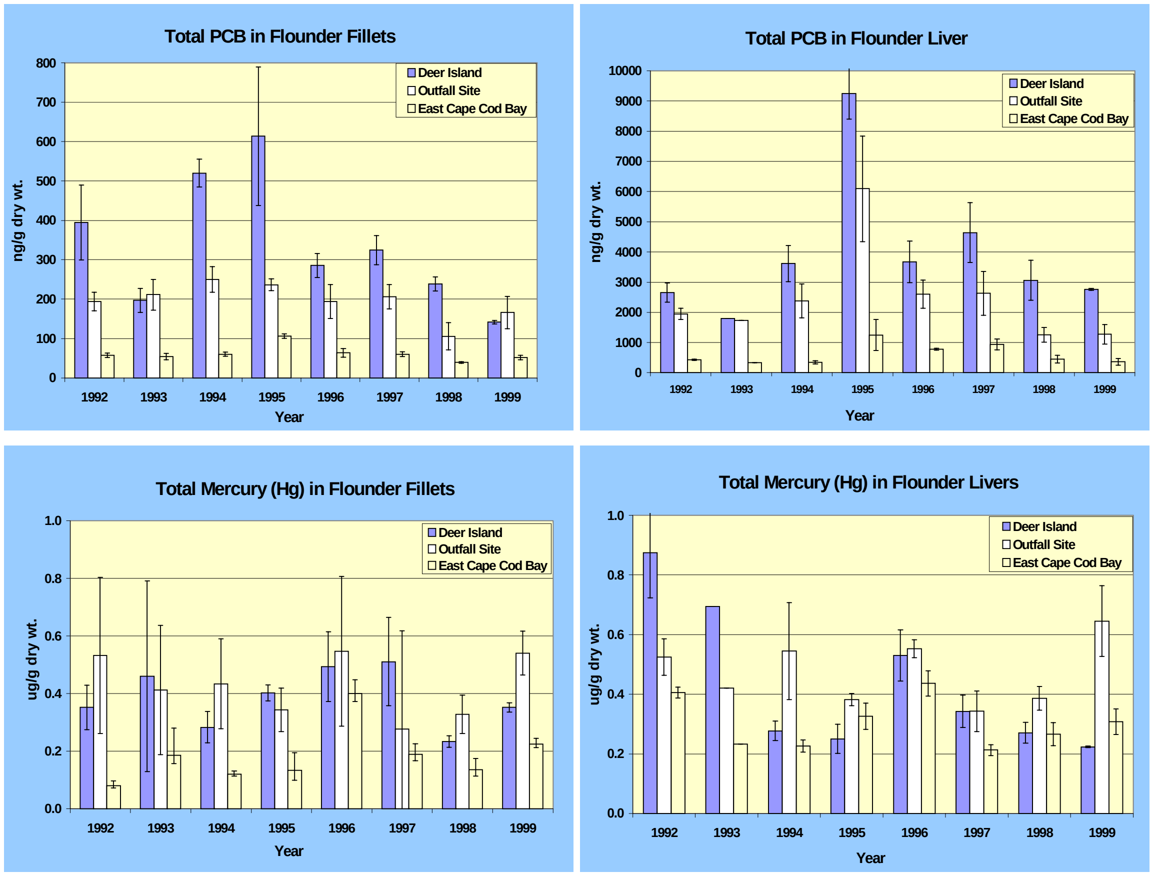
Results

Winter Flounder

Winter flounder, each a minimum of 30 cm in length, were caught during April 1998 at each of the five stations (Lefkovitz *et al.* 1999). Catch per unit effort, defined as number of fish obtained per minute of bottom trawling, was highest at the outfall site and Broad Sound and lowest in eastern Cape Cod Bay. Total length and weight were comparable to recent years at all stations.

As in other years, concentrations of organic compounds in edible tissues were highest in fish from Deer Island Flats (Figure 5-2). Body burdens were consistently similar to or lower than those measured in previous years. Chlorinated pesticide concentrations have been relatively constant since 1992. Total PCB concentrations have been somewhat variable, with maximum concentrations measured in 1995. Concentrations of mercury, the only metal measured in edible tissues, have also been variable, with the lowest concentrations consistently measured in fish from Cape Cod Bay.

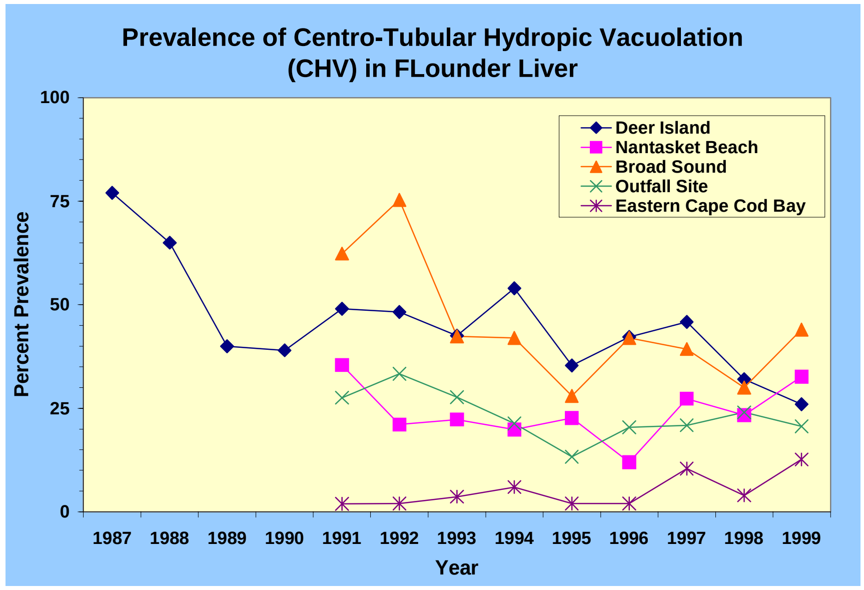
Figure 5-2. Concentrations of contaminants in flounder fillets and liver



Concentrations of organic compounds in liver tissues mirrored the trends observed in edible tissues and were generally lower than in prior years. Highest concentrations were generally found in fish from Deer Island Flats and lowest in those from Cape Cod Bay.

Fin erosion was significantly more common in fish from Deer Island Flats than at other stations, but those levels were lower than those observed a decade ago, before the baseline monitoring program began. Neoplasia and hydropic vacuolation were absent except for one neoplasm occurrence in a fish from Broad Sound. The prevalence of tubular and centrotubular hydropic vacuolation was highest at Deer Island Flats and Broad Sound, intermediate at the outfall site and off Nantasket Beach, and lowest at the eastern Cape Cod Bay site. Overall, levels of tubular and centrotubular vacuolation have not changed significantly between 1991 and 1998 (Figure 5-3).

Figure 5-3. Prevalence of centrotubular hydropic vacuolation (CHV)



Lobster

For analysis of contaminant concentrations, fifteen lobsters were collected from each location by commercial lobstermen (Lefkovitz *et al.* 1999). Sampling was completed in September. Lobsters were approximately the same length and weight at all sites, but sex ratio varied. Roughly equal numbers of both sexes were taken from Deer Island Flats, mostly males were taken at the outfall site, and only males were taken from eastern Cape Cod Bay. With minor exceptions, no deleterious conditions, such as black gill disease, were noted.

Mean concentrations of organic compounds in lobster meat were highest in samples taken from Deer Island Flats and lowest in those from Cape Cod Bay (Figure 5-4). This general pattern has been constant throughout the baseline period, indicating that either lobsters do not migrate between the sites, or that contaminants are quickly equilibrated within an organism. Concentrations of all organic compounds measured in 1998 were among the lowest measured throughout the duration of the program (Figure 5-5). Following a different pattern, mercury concentrations were highest in samples from the outfall site and lowest in those from Cape Cod Bay. Mercury concentrations were lower than in 1997 but have not varied much throughout the baseline period.

Across the study area, mean concentrations of organic compounds in lobster hepatopancreas showed the same trend as edible tissue, with the highest concentrations in lobsters from Deer Island Flats. Metals concentrations showed a different pattern. Concentrations of metals tended to be highest at the outfall site and lowest in eastern Cape Cod Bay. Unlike meat, concentrations of organic compounds in hepatopancreas tended to have remained the same or increased in 1998. Concentrations of most metals in hepatopancreas samples have remained relatively constant since 1992. Concentrations of silver appear to have increased since 1995.

Figure 5-4. DDT in lobster from Deer Island Flats (DIF), the outfall site, and eastern Cape Cod Bay (ECCB)

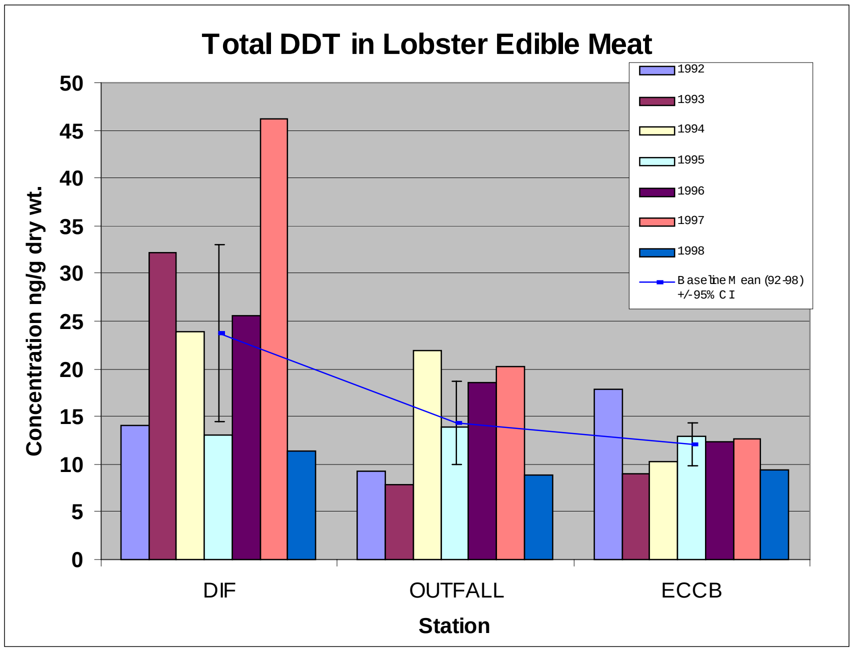
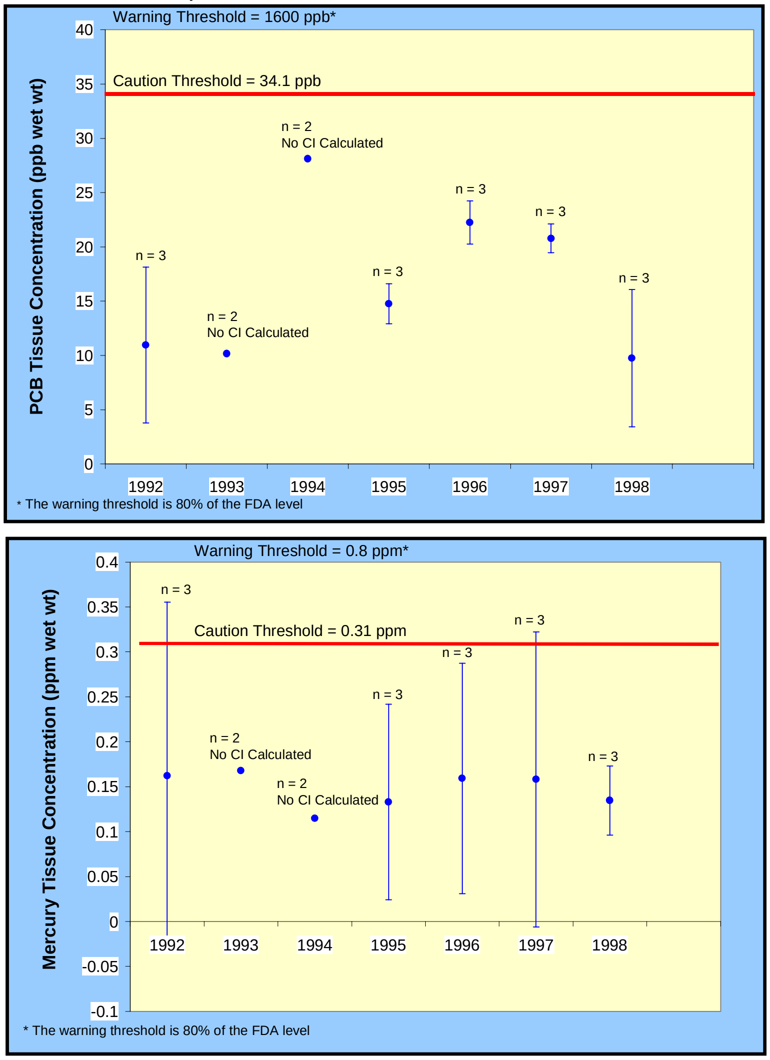


Figure 5-5. Annual average concentrations of PCBs and mercury in lobster meat at the outfall site

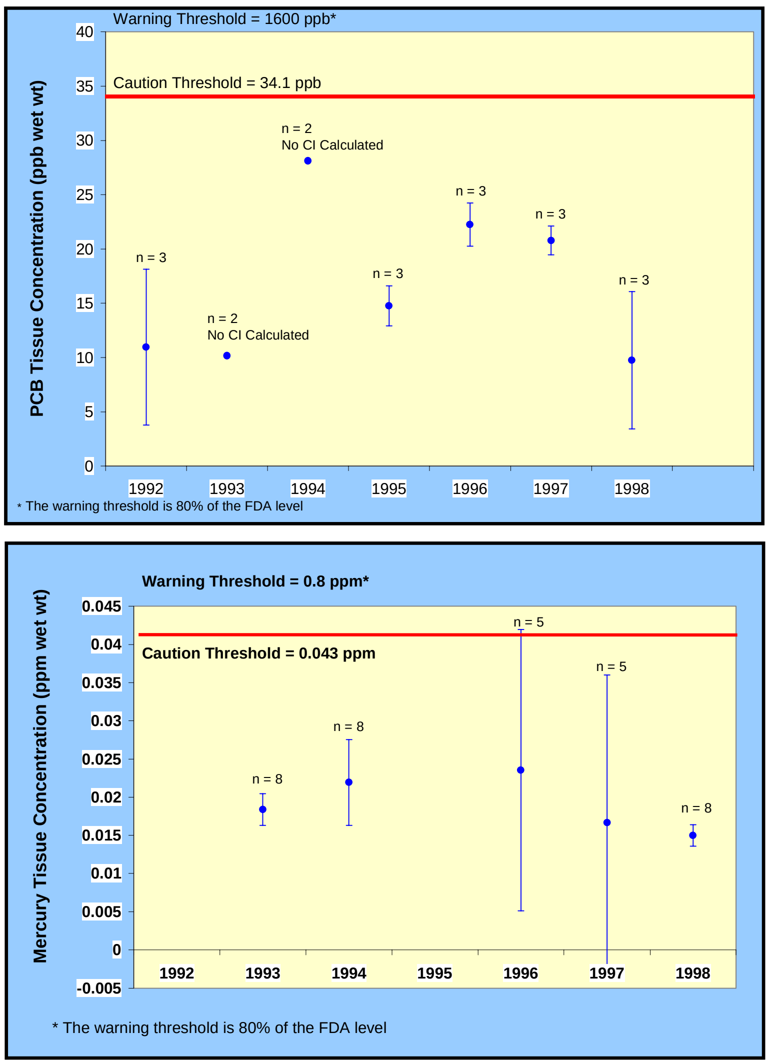


Blue Mussel

Recovery of caged mussels in 1998 was unfortunately not perfect (Lefkovitz *et al.* 1999). After 40 days, arrays were recovered from all sites except Quincy Bay, where only the Sandwich mussels used as the reference for inorganic contaminants were recovered. After 60 days, full arrays were recovered from the Inner Harbor and Cape Cod Bay. No cages were recovered from the outfall or Deer Island sites. In Quincy Bay, only Sandwich mussels were recovered. Consequently 40-day samples were used in analyses for the outfall and Deer Island site. The Sandwich mussels had to serve as a reference for organic as well as inorganic contaminants for Quincy Bay.

Among the stations previously studied, concentrations of contaminants have been highest at the Boston Inner Harbor site and lowest at the outfall site. That relation continued in 1998, with concentrations in mussels deployed in Cape Cod Bay being lower than other stations. Overall, contaminant levels measured in 1998 were among the lowest measured since 1991, particularly at Deer Island and the outfall site (Figure 5-6). Lead and mercury concentrations have varied more than concentrations of organic compounds, but overall concentrations were lower than those measured in 1997.

Figure 5-6. Average annual concentrations of PCBs and mercury in mussels at the outfall site



Contingency Plan Thresholds

For fish and shellfish monitoring, contingency plan thresholds are based upon U.S. Food and Drug Administration (FDA) limits for maximum concentrations of specific contaminants in edible portions of fish and fishery products or will be developed from a complete set of baseline data. Trigger parameters include mercury, chlordane, dieldrin, DDT, and PCBs in winter flounder, lobster, and mussel, lead and PAHs in mussels, and liver disease in flounder (Table 5-1).

In 1998, as in previous baseline monitoring years, concentrations of contaminants in muscle tissues of flounder and lobster and in total edible tissue from mussels were well below thresholds based upon FDA limits. Concentrations of PCBs in hepatopancreas in lobsters taken from Deer Island Flats have slightly exceeded FDA limits since 1996. In lobsters taken from the outfall site, concentrations of PCBs in hepatopancreas have come close to the FDA limits since 1995. These results are consistent with a Massachusetts advisory regarding consumption of lobster hepatopancreas, known as tomalley, from lobsters caught in Massachusetts waters.

Originally thresholds for contaminants in edible tissues were set at caution levels of 50% of the FDA advisory and warning levels of 80% of the FDA advisory concentrations. During 1997, the OMTF recommended a more protective caution level for PCBs, and MWRA decided to take a similar approach for all tissue thresholds. MWRA has also proposed using non-normalized tissue concentrations rather than lipid-normalized concentrations for lower and more easily calculated thresholds. This proposal was presented in the 1997 fish and shellfish report (Mitchell *et al.*1998), but it has not yet been evaluated by OMSAP. In the 1998 fish and shellfish report (Lefkovitz *et al.* 1999), MWRA is further proposing to simplify the thresholds by basing all of them on wet weights, rather than using dry weights for those contaminants that do not have FDA limits.

Several thresholds for fish and shellfish monitoring will be calculated from baseline monitoring results. For contaminant analyses, caution levels are now set as twice baseline levels. The caution level for flounder liver pathology is based upon the baseline prevalence of centrotubular hydropic vacuolation (CHV) in fish from Boston Harbor. As in previous years, no results from the 1998 baseline were near the projected range for those thresholds.

Table 5-1. Threshold values for fish and shellfish monitoring

Organism	Parameter	Caution Level	Warning Level	1998 Results
Mussels, flounder, lobster meat	Toxic compounds, PAH, pesticides, mercury, total PCBs	2x baseline	80% of FDA advisory level for all listed contaminants	Never exceeded
Mussels	Lead	2x baseline	3 ug/g wet weight	Never exceeded
Flounder	Liver disease incidence	Flounder liver disease (CHV) greater than harbor baseline prevalence	None	Not applicable, part of baseline

6. Special Studies

Background

Besides monitoring the effluent, water column, bottom, and fish and shellfish, MWRA conducts special studies in response to specific permit requirements, scientific questions, and public concerns. In 1998, MWRA conducted several studies:

- Model runs to evaluate the effects of nutrient load and point of discharge on water quality.
- Consideration of whether a model should be developed to characterize the seasonal abundance of important prey species for endangered species.
- Ongoing assessment of the role of the sediments in nutrient cycling.
- Assessment of potential lobster habitat in the vicinity of the new outfall site.

Bays Eutrophication Model

The outfall permit requires that MWRA update, maintain, and run the Bays Eutrophication Model (BEM) developed by Hydroqual, Inc. and USGS. The model predicts conditions caused by nutrient loading and will be used to support decisions about the need for nutrient limits and the appropriate level for any such limit for the discharge.

The BEM was initially calibrated using data from the 1992 baseline harbor and outfall monitoring program (Hydroqual and Normandeau 1995) and prior studies of Massachusetts Bay (Geyer *et al.* 1992, Townsend *et al.* 1991). Recently, a new run of the 1992 data with updated hydrodynamic functions was generated, along with runs for 1993 and 1994 (HydroQual 2000). The results of the comparison indicate that the BEM captures the principal processes that relate primary production and dissolved oxygen to bay-wide circulation, water column temperature and stratification, nutrients, and light. The model does not reproduce the single-species blooms that occur occasionally, but it does reproduce a number of the spatial and temporal features of phytoplankton biomass and primary production observed in Boston Harbor and Massachusetts and Cape Cod bays.

The BEM was then used to evaluate the effects of the magnitude of nitrogen loading and the point of discharge on the system. Five new runs were conducted to complement the results using the current outfall location and 1992 organic carbon and nutrient levels. The new runs compared the current outfall location with the new location. Organic carbon and nutrient levels were set at zero, the 1992 level, and twice the 1992 level.

The results of the model runs indicated that relocation of effluent from Boston Harbor to the new outfall site would have little effect upon the water quality of Massachusetts and Cape Cod bays, while significantly improving conditions in the harbor. The model results indicated that the region is more sensitive to the magnitude of nutrient inputs than to the location of the discharge. The results also suggested that a large change, such as doubling nutrient inputs, would be necessary for perceivable changes in plankton biomass in Cape Cod Bay to occur.

The results from the model runs were not surprising in the context of total nutrient loading to the system. Using the 1992 base conditions, the BEM computes that over an annual cycle, only 3% of the total nitrogen entering Massachusetts Bay derives from the effluent outfall. Approximately 93% of the nitrogen enters with inflowing waters from the Gulf of Maine. These observations are consistent with observations that the majority of waters within the system are more representative of oligotrophic than eutrophic conditions.

Food Web Model

Besides updating, maintaining, and running the BEM, the outfall permit notes that during 1998, MWRA developed a scope of work for a food web model to characterize the seasonal abundance of important prey species for endangered species in Massachusetts and Cape Cod bays. The permit required EPA and MADEP to comment on the scope of work, MWRA to submit a revised plan, and the regulators to determine whether developing a food web model was warranted.

MWRA planned an incremental approach to assessing the value of developing a food web model and presented it to OMSAP at the end of 1998. The scope of work included four parts:

- Evaluate recent monitoring data to determine whether conditions assumed in the SEIS for the proposed outfall and NOAA Biological Opinion concerning endangered species remained true.
- Compare dilution fields and expectations based on more recent three-dimensional modeling.
- Perform the BEM sensitivity and mass balance analysis.
- Review approaches to food web modeling.

Review of monitoring data and refined model projections, completed during 1998 (Hunt *et al.* 1999), indicated that changes in Massachusetts and Cape Cod bays will not be worse than predicted by the SEIS and NOAA's 1993 Biological Opinion on the outfall. Rather, nitrogen loading from MWRA sewage effluent is less than had been predicted in 1988. Thus, changes to the system will probably be less than had been predicted—plankton biomass and species distributions are not expected to change.

Preliminary review of modeling approaches has led MWRA to agree with right whale biologists that development of a food-web model will not be the best means for protecting right whales in the region. Such models are most effective when measuring major perturbations, which are not expected. Further, information on species-by-species plankton biomass and the degree of importance of the bays to the whales is incomplete. Rather than developing a Massachusetts-specific model, taking a broader approach to whale research over the entire species range would be more protective of the populations.

Nutrient Flux

Sediments in coastal areas such as Boston Harbor can play an important role in nutrient cycling and oxygen dynamics. Breakdown of organic matter in the sediments consumes oxygen and releases nutrients. Through denitrification, coastal sediments can also act as a nitrogen sink, converting nitrate to gaseous forms of nitrogen, which is lost to the atmosphere. If denitrification rates are high within the harbor, then moving the outfall into deeper waters with lower denitrification rates may change the nitrogen load to the region.

Since 1992, MWRA has conducted studies of benthic nutrient cycling in Boston Harbor. In 1998, studies were conducted at four sites: the central outer harbor, off Long Island in the former sludge disposal area, Hingham Bay in the southern harbor, and Quincy Bay in the southern harbor (Tucker *et al.* 1999). Results of those studies have shown that denitrification rates within the harbor sediments are typically high, with more than half the nitrogen mineralized in the sediments subsequently being lost through denitrification. However, only a relatively minor percentage of the nitrogen inputs to Boston Harbor is cycled through the sediments, so only a small percentage of the nitrogen introduced to the system is lost to denitrification. Moving the outfall is not likely to affect the total nitrogen load to the bay.

MWRA also conducts studies of nutrient cycling and oxygen dynamics in Massachusetts Bay. These studies may be important in evaluating the causes of low dissolved oxygen levels after discharge from the outfall begins. Baseline studies were conducted from 1992-1997. No measurements were made in 1998, but the studies were resumed in 1999.

Lobster Settling

One concern not addressed in routine monitoring was whether or not the area near the new outfall could be an important habitat for young lobsters. If it were, the outfall could affect young lobsters as they settle from the plankton to a benthic life stage. The outfall could also affect yearling and older juvenile lobsters, which are thought to be relatively nonmobile, obligate shelter-dwellers. It was not known if the area around the outfall is a significant site for lobster settling, although some experts suggested that the cobble habitats in the nearfield were too deep and too cold to be preferred.

Therefore, in 1998, a study of cobble-boulder habitats in the vicinity of the new outfall was conducted to determine the density of the early benthic-phase lobsters, particularly new recruits and yearlings (Lavalli and Kropp 1998). Potential lobster habitats were selected for evaluation by examining videotape and reports, identifying the habitats most likely to shelter juvenile lobsters. Three sites near the outfall were then compared to two inshore, reference sites, known to be juvenile lobster habitat. The study was conducted during the period of peak settling. Lobsters were sampled by suction, enumerated, and measured for carapace length.

The assessment of lobster habitat was completed in early September. Data from the reference stations were similar to observations of those sites in previous years, indicating that 1998 was a typical year for lobster settlement. Significantly fewer young-of-the-year, yearling, and early benthic-phase lobsters were taken from stations near the outfall site, indicating that those sites are not significant sites for lobster settlement. The distinct pycnocline that develops at the outfall site and the depth of the water probably keep lobsters from settling in great numbers. The relatively few lobsters that may settle near the new outfall may be at a further disadvantage compared to those lobsters at inshore sites, because the lower water temperatures would slow growth and prevent the juveniles from outgrowing predators.

7. Summary

Background

Since its creation in 1985, MWRA has worked to end long-standing violations of the Clean Water Act that resulted from discharge of sewage sludge and poorly treated effluent into Boston Harbor. Sludge discharges have ended, and MWRA is working to minimize the effects of effluent discharge. The MWRA program includes source reduction, improved treatment, and effective dilution once the effluent reaches the marine environment. Dilution will be accomplished by diverting the effluent to a new outfall and diffuser system, located 9.5 miles offshore in Massachusetts Bay.

MWRA's goals are to make it safe to swim in the harbor, safe to eat fish caught there, to protect marine resources, and to ensure that the harbor becomes and remains a resource that people can aesthetically enjoy, without degrading the offshore environment. For many of the components of MWRA's work, there is general agreement that the project benefits the marine environment and the people of the region. One aspect of the project, moving the effluent outfall from the harbor to Massachusetts Bay, has caused some concerns.

EPA and MADEP recognized these concerns when they issued the NPDES permit for the new outfall. The permit includes high standards for plant performance, a monitoring program to ensure compliance with permit conditions and assess potential effects, and a contingency plan, which describes how MWRA and the regulatory agencies will respond to determine causes for problems detected by monitoring and implement corrective actions. The contingency plan identifies environmentally significant components of effluent or the ecosystem and threshold levels, which, if exceeded, indicate a potential for environmental risk.

This Outfall Monitoring Overview is one of a series of annual reports required by MWRA. It provides a scientific summary of each year of monitoring and includes information relative to the contingency plan, such as threshold exceedances, responses, and corrective actions. This year's report presents monitoring results for baseline field data collected from 1991 through 1998.

Effluent

The MWRA strategy for improving the environmental quality of Boston Harbor without degrading the offshore environment relies upon source reduction and improved treatment. Ensuring that the effluent meets permit limits is the most important action MWRA can take to ensure that the outfall does not cause any harm to the environment.

Effluent constituents of concern include nutrients, organic material, toxic constituents, human pathogens, solids, and floatables. Effluent monitoring assesses compliance with permit limits for contaminant concentrations, which are based upon national water quality criteria, ambient conditions, and projected outfall dilution. (Actual dilution will be measured when the outfall begins operation.) Monitoring also provides calculations of total loads of contaminants to the system.

When the second of three batteries of secondary treatment began operation in 1998, the treatment plant essentially began to operate in compliance with the 1999 permit. Loading for many contaminants was lower than had been predicted by early 1997 data, and few exceedances of thresholds established in the 1999 permit occurred.

Water Column

Circulation, water properties, and biology of Massachusetts and Cape Cod bays are mainly driven by the larger pattern of water flow from the Gulf of Maine. During much of the year, a weak, counterclockwise current persists. The water column has been thought to follow a typical annual cycle of spring and fall phytoplankton blooms, but wind and other factors greatly influence the pattern.

Water column monitoring focuses upon concerns that relocation of the outfall will introduce effects from the organic material, nutrients, and toxic contaminants in the effluent. Of the possible outcomes, changes in the nutrient balance are thought to have the most potential for affecting the health of the bays. Water column monitoring includes five major components: nearfield surveys, farfield surveys, future plume-tracking surveys, continuous recording, and remote sensing.

During 1998, Massachusetts and Cape Cod bays, like much of the country, were influenced by weather patterns associated with the El Niño event in the equatorial Pacific. The winter of 1997-1998 was relatively warm, and winter and spring were disrupted by many storms and record rainfalls. Over the year, average winds were favorable to upwelling.

No spring phytoplankton bloom was observed in Massachusetts Bay for 1998, although elevated nutrient concentrations, increasing light availability, and increasing temperatures were appropriate for development of a bloom. Reasons for lack of a bloom were not clear. Heavy zooplankton grazing following a warm winter, the lack of dominance by a single species, and other physical, chemical, or biological factors may have contributed to the outcome.

Major storm events and lack of a declining spring bloom resulted in relatively high concentrations of dissolved oxygen during June. Later, persistent stratified conditions led to decreasing bottom dissolved oxygen concentrations from June through December. The pulse of organic matter from the fall bloom further depressed dissolved oxygen concentrations.

Threshold parameters for water column monitoring include dissolved oxygen concentration in nearfield and Stellwagen Bank bottom waters, dissolved oxygen depletion rate in nearfield bottom waters, chlorophyll level, nuisance algae, zooplankton species in the nearfield, paralytic shellfish toxin extent, and dilution. Despite the protracted period of oxygen depletion, dissolved oxygen concentrations did not drop below contingency plan thresholds. Most other thresholds will be based upon a complete set of baseline monitoring data. Initial dilution will be measured when discharge begins, and a warning level would be exceeded if dilution is less than was predicted by EPA as a basis for the permit.

Sea Floor

Sediment transport within the system occurs primarily during storms. Typically, strong storms with winds from the northeast resuspend and transport fine sediments, which are transported by currents to western Massachusetts Bay to the offshore and toward Cape Cod Bay, where they are likely to remain. Cape Cod Bay is sheltered from large waves by the arm of Cape Cod, and waves are rarely large enough to resuspend sediments in Stellwagen Basin, which is the deepest feature in the region.

There are several environmental concerns about the possible effects of the new outfall on the sea floor: eutrophication and related low dissolved oxygen levels, accumulation of toxic contaminants in depositional areas, smothering of animals by particulate matter, and disruption of normal community structure by excess food input. Sea floor monitoring includes measurements of contaminants in sediments, sediment profile imaging, studies of near- and farfield of soft-bottom communities, and study of hard-bottom communities. Sediment contaminant studies were included in 1998 after a two-year hiatus. They focused on stations that will be used to examine possible short-term effects of the new outfall.

As in previous studies, concentrations of all organic and inorganic contaminants near the new outfall were low, well below EPA or NOAA guidelines. Sediment profile images indicated that the RPD layer depth became shallower between 1992-1995 and 1997-1998. This change appears to be linked to the interaction of physical and biological processes that structure bottom communities. Total infaunal abundance and species abundance have varied throughout baseline monitoring. Overall the average number of species decreased about 25% from 1992 to 1993. Number of species subsequently rose until they leveled off in 1997 and 1998. This pattern is not fully understood but may reflect destruction and recovery from December 1992 storms. Hard bottom communities have been stable during baseline monitoring.

Threshold parameters for sea floor monitoring include contaminant concentrations, RPD depth, benthic diversity in soft-bottom communities, and species composition. All contaminant concentrations were well below the established thresholds, and baseline data indicate that any exceedances of thresholds based on baseline monitoring will be easily detected.

Fish and Shellfish

The fish and shellfish industry is an important part of the regional identity and economy of Massachusetts. One concern about relocating the sewage effluent off shore is that contaminants will adversely affect resource species, either through direct damage to the fishery stocks or by contamination of the fish, lobster, and other shellfish.

The monitoring program focuses on three indicator species. Winter flounder and lobsters are important resources to the region. The blue mussel, deployed in caged arrays, is a common biomonitoring species. Monitoring includes examination of health and measurement of organic and inorganic contaminants.

As in previous monitoring years, most contaminant levels and prevalence of liver disease were highest in flounder taken from Deer Island Flats. Similarly, levels of most contaminants were highest in lobsters from Deer Island Flats. Among stations previously studied, concentrations of contaminants in mussels were highest in Boston Inner Harbor and lowest at the outfall site. Contaminant concentrations in mussels from a new site in Cape Cod Bay were even lower than at the outfall site.

Contingency plan thresholds for fish and shellfish monitoring are based upon FDA limits for maximum concentrations of specific contaminants in edible portions of fish and fisheries products or will be developed from a complete set of baseline data. In 1998, as in previous baseline monitoring years, concentrations of contaminants in muscle tissues of flounder and lobster and in total edible tissue from mussels were well below thresholds based upon FDA limits. Concentrations of PCBs in hepatopancreas in some lobsters have come close to or exceeded FDA levels. Accordingly, Massachusetts has an advisory regarding consumption of lobster hepatopancreas, known as tomalley.

Special Studies

Besides monitoring the effluent, water column, bottom, and fish and shellfish, MWRA conducts special studies in response to specific permit requirements, scientific questions, and public concerns. In 1998, MWRA conducted several studies.

The outfall permit requires that MWRA update, maintain, and run the Bays Eutrophication Model (BEM) developed by Hydroqual, Inc. and USGS. During 1998, five new model runs were made to evaluate the effects of the magnitude of nitrogen loading and the point of discharge on the system. These runs indicated that relocation of the outfall would have little or no effect on the water quality of Massachusetts or Cape Cod bays. The model indicates that only 3% of the total nitrogen entering Massachusetts Bay derives from the outfall. Approximately 93% of the nitrogen enters with inflowing waters from the Gulf of Maine.

The outfall permit also requires MWRA to assist its regulators in determining whether developing a food web model to characterize abundance of prey of endangered species is warranted. MWRA reviewed monitoring data and modeling approaches to reach a conclusion that a food web model would not be the most appropriate means for protecting the right whale and other endangered species in Massachusetts and Cape Cod bays. Nitrogen loading from MWRA effluent is less than had been predicted and is not likely to cause any changes in plankton biomass or species composition. Food web models are most effective when they measure larger perturbations. Further, exact information on species-by-species plankton biomass, which would be necessary for an appropriate model, is incomplete.

MWRA has conducted ongoing assessments of nutrient cycling and oxygen dynamics of the sediments to determine whether moving the outfall offshore could cause a change in the nutrient budget. Those studies have indicated that denitrification rates are high in Boston Harbor sediments, but that only a small portion of the total nitrogen in the system is cycled through the sediments. Moving the outfall offshore is not expected to change the nitrogen budget of the region.

Another concern not addressed by routine monitoring has been that juvenile lobsters would be affected if the area around the outfall were a significant lobster nursery. Therefore, in 1998 a study of cobble-boulder habitats in the vicinity of the new outfall was conducted to determine the density of the early benthic-phase lobsters, particularly new recruits and yearlings. The assessment found that the area around the outfall is not significant lobster habitat. The distinct pycnocline that develops at the sites and the depth of the water probably keep lobsters from settling in great numbers. The relatively few lobsters that do settle near the new outfall may be at a disadvantage compared to lobsters at inshore sites, because the lower water temperatures may slow growth and prevent the juveniles from outgrowing predators.

MWRA will continue to conduct special studies as they are required by the permit or warranted by monitoring results, scientific questions, or public concerns. The primary mechanism for initiating special studies is expected to be the regular review of monitoring data by OMSAP and their committees.

References

Beardsley RC, Butman B, Geyer WR, Smith P. 1997. Physical oceanography of the Gulf of Maine: An update. In: Wallace G, Braasch E, editors. Proceedings of the Gulf of Maine ecosystem dynamics: a scientific symposium and workshop: RARGOM. p 352.

EPA. 1988. Boston Harbor Wastewater Conveyance System. Supplemental Environmental Impact Statement (SEIS). Boston: Environmental Protection Agency Region I.

Geyer WR, Gardner GB, Brown WS, Irish J, Butman B, Loder T, Signell RP. 1992. Final report: Physical oceanographic investigation of Massachusetts and Cape Cod bays. Boston: Massachusetts Bays Program. Report MBP-92-03. 497p.

Hunt CD, Kropp RK, Fitzpatrick JJ, Yodzis P, Ulanowicz RE. 1999. A review of issues related to the development of a food web model for important prey of endangered species in Massachusetts and Cape Cod Bays. Boston: Massachusetts Water Resources Authority. Report ENQUAD 99-14. 62p.

HydroQual. 2000. Bays Eutrophication Model (BEM): modeling analysis for the period 1992-1994. Boston: Massachusetts Water Resources Authority. Report ENQUAD 00-02. 158 p.

HydroQual, Normandeau. 1995. A water quality model for Massachusetts and Cape Cod bays: calibration of the Bays Eutrophication Model (BEM). Boston: Massachusetts Water Resources Authority. Report ENQUAD 95-8. 403p.

Kropp RK, Dahlen D, Boyle JD, Diaz. 1999. 1998 outfall benthic monitoring report. Boston: Massachusetts Water Resources Authority. Report ENQUAD 99-15. 320 p.

Lavalli KL, Kropp RK. 1998. Abundance of juvenile lobsters at the new outfall site: comparisons with inshore abundances and discussion of potential outfall impacts on lobster populations. Boston: Massachusetts Water Resources Authority. Report ENQUAD 98-14. 26p.

Lefkovitz L, McLeod LA, Moore M. 1999. 1998 Annual fish and shellfish report. Boston: Massachusetts Water Resources Authority. Report ENQUAD 99-11. 200 p.

Leo WS, Rex AC, Carroll SR, Connor MS. 1995. The state of Boston Harbor 1994: connecting the Harbor to its watersheds. Boston: Massachusetts Water Resources Authority. Report ENQUAD 95-12. 37 p.

Libby PS, Albro CS, Hunt CD, Keller AA, Oviatt CA, Turner J. 1999. 1998 Annual water column monitoring report. Boston: Massachusetts Water Resources Authority. Report ENQUAD 99-16. 180 p.

McLeod LA. 1999. Summary of marine mammal observations during 1998 surveys. Boston: Massachusetts Water Resources Authority. Report ENQUAD 99-01. 9p.

Mitchell DF, Sullivan K, Moore M, Downey P. 1998. 1997 Annual fish and shellfish report. Boston: Massachusetts Water Resources Authority. Report ENQUAD 98-12.

MWRA. 1991. Massachusetts Water Resources Authority effluent outfall monitoring plan Phase I: baseline studies. Boston: Massachusetts Water Resources Authority. Report ENQUAD ms-2. 95p.

MWRA. 1997a. Massachusetts Water Resources Authority effluent outfall monitoring plan: Phase II post discharge monitoring. Boston: Massachusetts Water Resources Authority. Report ENQUAD ms-44. 61p.

MWRA. 1997b. Contingency plan. Boston: Massachusetts Water Resources Authority. 41p.

Pawlowski C, Keay KE, Graham E, Taylor DI, Rex AC, Connor MS. 1996. The state of Boston Harbor 1995: the new treatment plant makes its mark. Boston: Massachusetts Water Resources Authority. Report ENQUAD 96-06. 22 p.

Rex AC, Connor MS. 1997. The state of Boston Harbor 1996: questions and answers about the new outfall. Boston: Massachusetts Water Resources Authority. Report ENQUAD 97-05. 32 p.

Townsend D, Cammen LM, Christensen JP, Ackelson SG, Keller MD, Haugen, EM, Corwin S, Bellows WK, Brown JF. 1991. Seasonality of oceanographic conditions in Massachusetts Bay. Boston: Massachusetts Water Resources Authority. Report ENQUAD ms-01. 114p.

Tucker J, Giblin AE, Hopkinson CS. Jr. 1999. Metabolism, nutrient cycling and denitrification in Boston Harbor sediments in 1998. Boston: Massachusetts Water Resources Authority. Report ENQUAD 99-08. 33.p.

USGS. 1997. Predicting the long-term fate of sediments and contaminants in Massachusetts Bay. Woods Hole: U.S. Geological Survey. USGS Fact Sheet FS-172-97. 6p.

USGS. 1998. Mapping the sea floor and biological habitats of the Stellwagen Bank National Marine Sanctuary region. Woods Hole: U.S. Geological Survey. USGS Fact Sheet 078-98. 2p.

List of Acronyms

BOD	Biological oxygen demand
cBOD	Carbonaceous biological oxygen demand
CHV	Centrotubular hydropic vacuolation
C-NOEC	No observable effect concentration
CSO	Combined sewer overflow
DIF	Deer Island Flats
ECCB	Eastern Cape Cod Bay
EPA	U.S. Environmental Protection Agency
FDA	U.S. Food and Drug Administration
IAAC	Inter-agency Advisory Committee
LC50	50% mortality concentration
MADEP	Massachusetts Department of Environmental Protection
MGD	Million gallons per day
MWRA	Massachusetts Water Resources Authority
NPDES	National Pollutant Discharge Elimination System
OMSAP	Outfall Monitoring Science Advisory Panel
OMTF	Outfall Monitoring Task Force
PAH	Polyaromatic hydrocarbon
PCB	Polychlorinated biphenyl
PIAC	Public Interest Advisory Committee
RPD	Redox potential discontinuity
SEIS	Supplemental Environmental Impact Statement
USGS	U.S. Geological Survey
TOC	Total organic carbon
TSS	Total suspended solids

Massachusetts Water Resources Authority
Charlestown Navy Yard
100 First Avenue
Boston, MA 02129
(617) 242-6000
http://www.mwra.state.ma.us