2000
Outfall monitoring overview

Massachusetts Water Resources Authority

Environmental Quality Department
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submitted to

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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 to prevent pollutants from entering the sewage system, improved treatment, and effective dilution. One aspect of the program, moving the treated wastewater outfall from Boston Harbor to Massachusetts Bay, which was accomplished in 2000, has raised some environmental concerns. To address these concerns, MWRA implemented an extensive monitoring program to measure the health of Boston Harbor and the bays. Further, the joint federal and state permit for the new outfall requires extensive monitoring of the effluent, water column, sea floor, and fish and shellfish. The permit links the monitoring program to a contingency plan, which identifies corrective actions for unexpected effects of the outfall.

This document, an annual outfall monitoring overview, presents a scientific summary of monitoring data collected through 2000 and includes information relevant to the contingency plan. These data include information on effluent quality, baseline conditions, special studies, and the first results of outfall monitoring. The report also includes a report on the Gerry E. Studds Stellwagen Bank National Marine Sanctuary.

Most MWRA studies began in 1992, resulting in a relatively long period in which to conduct baseline studies. This long period as allowed MWRA to document greater natural variability than would have been observed in briefer baseline monitoring. These results will allow a more informed interpretation of results following the diversion of effluent to the bay.

The first information following start-up of the new outfall provided initial assurances that actual plume behavior matched the model predictions. They also indicated that ammonia and salinity were sensitive indicators of the presence of the plume. Other studies that were conducted by the end of 2000 included a water-column survey, a sediment-contaminant survey, and a nutrient-cycling study. Chlorophyll concentrations were already elevated throughout the region when the outfall was commissioned. Subsequently, the winter/spring contingency plan threshold for chlorophyll was exceeded. The high value was independent of the outfall and reflected the conditions of the wider region. Preliminary information shows that chlorophyll levels were lower than the thresholds for the spring of 2001.

To date, there are no indications that the outfall affects the water quality or biology of the sanctuary. Water-column sampling has indicated that the stations within the sanctuary are healthy and similar to other farfield stations. Monitoring also showed no increase in indicator bacteria at offshore stations following outfall start-up.

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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 ended in 1991, and MWRA has taken several steps to minimize effects of wastewater discharge. These efforts include source reduction to prevent pollutants from entering the waste stream, improved treatment before discharge, and better dilution once the effluent enters the marine environment.

Source reduction has included projects to lessen household hazardous waste disposal and minimize mercury discharges from hospitals and dentists. An ongoing industrial pretreatment/pollution prevention program ensures that toxic contaminants are removed before they reach the sewer system. In addition, best management practices are employed at sewer facilities to mitigate accidental discharge of pollutants. Operator training programs and process control and maintenance tracking systems are also in place.

Improved treatment began in 1995, when a new primary treatment plant at Deer Island was brought on line, and disinfection facilities were completed. The first and second batteries of secondary treatment began operation in 1997 and 1998. Also during 1998, discharge from the Nut Island Treatment Plant into Quincy Bay ended. All sewage is now conveyed to Deer Island for treatment. A final battery of secondary treatment was completed in 2000 and became operational in 2001.

Better dilution has been achieved by 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 because it had a water depth and current patterns that would promote effective dilution, it was the least likely to affect sensitive resources, and it was feasible to construct an outfall tunnel to the location. The new outfall began operation on September 6, 2000.

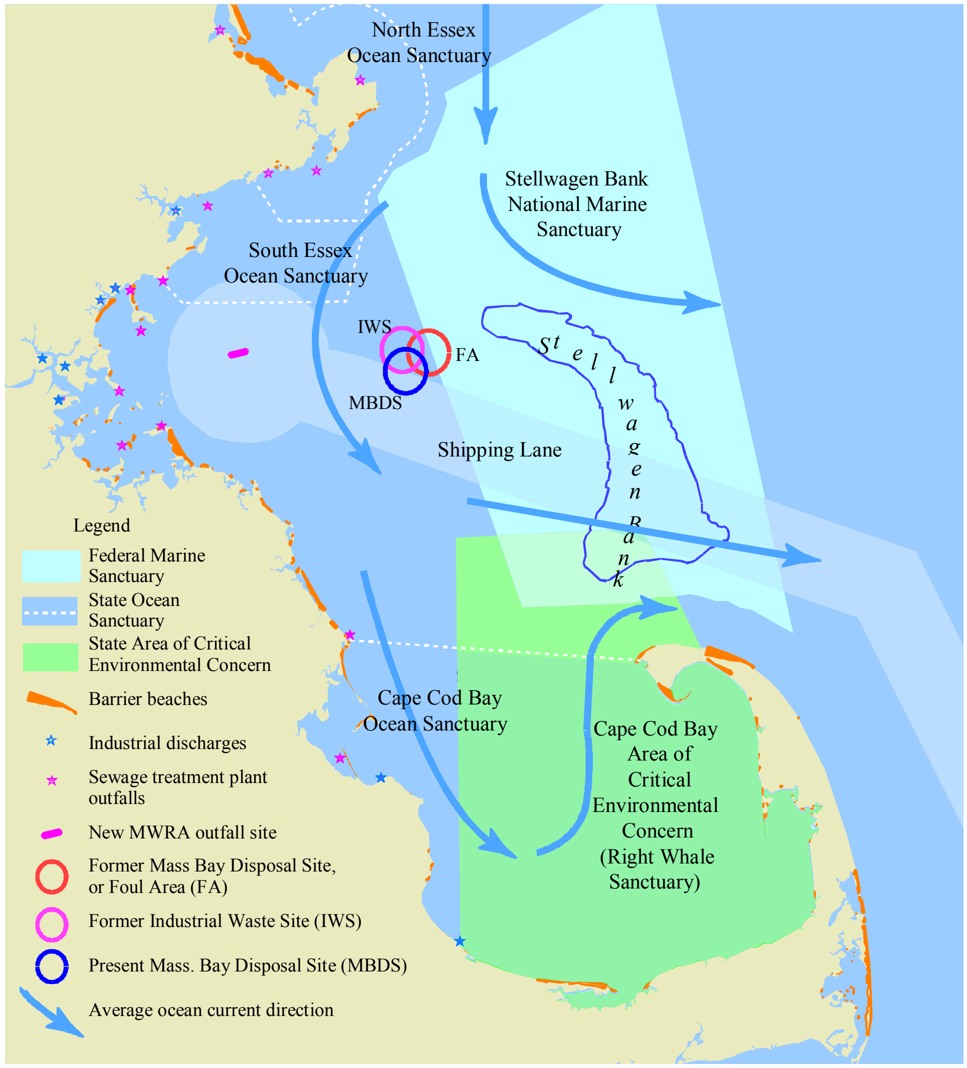

Figure 1-1. Map of Massachusetts and Cape Cod bays

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 is at the sea floor, at water depths of about 100 feet (MWRA 1997a). Initial dilution at the outfall is about 5 times that of the Boston Harbor outfall, which was shallower, in 50 feet of water. The offshore location of the new outfall diffuser ensures that within a tidal cycle, even shoreward currents will not transport effluent to beaches or shellfish beds near Boston, the North Shore, the South Shore, 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 has been 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 raised some concerns. The concerns have been recognized by MWRA and by the joint permit for the outfall issued by the U.S. Environmental Protection Agency (EPA) and the Massachusetts Department of Environmental Protection (MADEP).

Outfall Permit

Discharges from the new outfall are regulated by a permit issued by EPA and MADEP under the National Pollutant Discharge Elimination System (NPDES). The permit, first drafted in May of 1999 and finalized in July 2000, limits discharges of pollutants and requires reporting on the treatment plant operation and maintenance. It requires MWRA to continue an ongoing pollution prevention program that encompasses all users of the system—industrial, commercial, and residential and to implement best management practices aimed at preventing accidental discharge of pollutants to the sewer system.

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 (MWRA 1991, 1997a) developed in response to the EPA Supplemental Environmental Impact Statement (SEIS, EPA 1988). The permit requires MWRA to update, maintain, and run the three-dimensional Bays Eutrophication Model, and measure the dilution at the discharge. MWRA must implement a contingency plan (MWRA 1997b, 2001), which identifies relevant environmental quality parameters and thresholds, which, if exceeded, would require a response.

EPA and MADEP have established an independent panel of scientists to review monitoring data and provide advice on key scientific issues related to the permit. This panel is called the Outfall Monitoring Scientific Advisory Panel (OMSAP, Table 1-1). OMSAP conducts peer reviews of monitoring reports, evaluates the data, and advises EPA and MADEP on implications. OMSAP also provides advice concerning any proposed modifications to the monitoring or contingency plans.

OMSAP may form specialized focus groups when specific technical issues require expanded depth or breadth of expertise. For example, the Model Evaluation Group meets periodically to review MWRA's water quality model. Two standing sub-committees also advise OMSAP. The Public Interest Advisory Committee (PIAC) represents local, non-governmental organizations and environmental groups and advises OMSAP on values and uses of the harbor and the bays. 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 2000	
Andrew Solow, Woods Hole Oceanographic Institution (chair) Robert Beardsley, Woods Hole Oceanographic Institution Norbert Jaworski, retired Robert Kenney, University of Rhode Island Scott Nixon, University of Rhode Island Judy Pederson, MIT Sea Grant Michael Shiaris, University of Massachusetts, Boston James Shine, Harvard School of Public Health Juanita Urban-Rich, University of Massachusetts, Boston Catherine Coniaris, New England Interstate Water Pollution Control Commission (OMSAP assistant)	
IAAC as of December 2000	**PIAC as of December 2000**
Salvatore Testaverde (chair, representative of National Marine Fisheries Service) MA Coastal Zone Management Christian Krahforst Jan Smith (alternate) MA Department of Environmental Protection Russell Isaac Steven Lipman (alternate) MA Division of Marine Fisheries Jack Schwartz James Fair (alternate) National Marine Fisheries Service David Dow (alternate) Stellwagen Bank National Marine Sanctuary Craig MacDonald US Army Corps of Engineers Thomas Fredette US Environmental Protection Agency Matthew Liebman David Tomey (alternate) US Geological Survey Michael Bothner	Polly Foley (chair, representative of Save the Harbor/Save the Bay) Association for the Preservation of Cape Cod Maggie Geist Bays Legal Fund Wayne Bergeron The Boston Harbor Association Vivian Li Joan LeBlanc (alternate) Cape Cod Commission John Lipman Steve Tucker (alternate) Center for Coastal Studies Peter Borrelli Conservation Law Foundation Anthony Chatwin New England Aquarium Marianne Farrington Massachusetts Audubon Society Robert Buchsbaum MWRA Advisory Board Joseph Favaloro Safer Waters in Massachusetts Salvatore Genovese Polly Bradley (alternate) Save the Harbor/Save the Bay Bruce Berman (alternate) Stop the Outfall Pipe Mary Loebig Wastewater Advisory Committee Katherine O'Meara

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. During 1989-1991, in anticipation of these requirements, MWRA began to study winter flounder with the Woods Hole Oceanographic Institution (WHOI), eutrophication issues with the Bigelow Laboratory for Ocean Sciences, and long-term sediment transport with the U.S. Geological Survey (USGS). A broader baseline-monitoring program began in 1992. During the intervening years, both baseline and discharge ambient monitoring plans have been developed and refined

(MWRA 1991, 1997a). These plans were developed by MWRA, under the direction of an Outfall Monitoring Task Force (OMTF), made up of scientists, regulators, and environmental advocacy groups. The OMTF was disbanded upon creation of OMSAP in 1998.

The outfall-monitoring program focuses on critical constituents in treatment plant effluent, such as nutrients, organic material, toxic contaminants, pathogens, and solids (Table 1-2). 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. This basic program is augmented by special studies that 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 system, including Boston Harbor and Cape Cod Bay, before and after the outfall location moved from the harbor to the bay.

Baseline monitoring was initially planned to last for a minimum of three years, as the outfall was originally planned for completion in 1995. Delays in outfall construction have allowed a relatively long period for baseline studies. Consequently, MWRA has been able to document greater natural variability and develop a better understanding of the system than would have been possible in a briefer baseline period. The extended time 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 *et al.* 1995, Pawlowski *et al.* 1996, Rex and Connor 1997, Rex 2000). Finally, the extended period has meant that the discharges to Massachusetts Bay, when they did begin, had the benefit of nearly complete implementation of secondary treatment.

The monitoring plan is a "living document." That is, every effort is made to incorporate new scientific information and improved understanding resulting from the monitoring program into appropriate thresholds. MWRA's NPDES permit requires an annual list of proposed changes to the monitoring plan.

Contingency Plan

The original MWRA contingency plan (MWRA 1997b and available at www.mwra.com) 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 to specify the corrective actions that should be taken if the problem appears to be related to the discharge. The contingency plan identifies the parameters that represent environmentally significant components of the effluent or the ecosystem that, if specific levels are exceeded, indicate a potential for environmental risk (Table 1-3). These levels are called thresholds. The plan provides a process for evaluating parameters that exceed thresholds and formulating appropriate responses.

Table 1-2. Summary of the monitoring program

Task	Objective	Sampling Locations And Schedule	Analyses
Effluent			
Effluent sampling	Characterize wastewater discharge from Deer Island Treatment Plant	Monthly	Toxicity
		Weekly	Nutrients
		Daily	Organic material (cBOD)
		Several times monthly	Toxic contaminants
		3x/day	Bacterial indicators, total chlorine residual
		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	2 surveys planned for 2001	Rhodamine dye Salinity Temperature Currents Nutrients Solids Selected metals Bacterial indicators
Mooring (USGS)	Provides continuous oceanographic data near outfall location	Continuous monitoring Two locations 3 depths	Currents 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	1 survey/year 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 3 locations	Tissue contaminant concentrations Physical abnormalities
Blue mussel	Evaluate biological condition and potential contaminant bioaccumulation	1 survey/year 4 locations	Tissue contaminant concentrations

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, most parameters have "caution" as well as "warning" thresholds. Exceeding thresholds could indicate a need for increased attention or study. If a threshold, is exceeded, MWRA, with guidance from OMSAP and the regulatory agencies, may expand the monitoring to track effluent quality and environmental conditions. The data are examined to determine whether it is likely that an unacceptable effect resulting from the outfall has occurred.

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

Table 1-3. Summary of contingency plan threshold parameters

Monitoring Area	Parameter
Effluent	pH Fecal coliform bacteria Residual chlorine Total suspended solids Biological oxygen demand Toxicity PCBs Plant performance Total nitrogen load Floatables, Oil and grease
Water Column	Dissolved oxygen concentration Dissolved oxygen percent saturation Dissolved oxygen depletion rate Chlorophyll Nuisance and noxious algae Effluent dilution
Sea Floor	Benthic community structure Sediment oxygen Sediment toxic metal and organic chemicals
Fish and Shellfish	Mercury, PCBs, and lipid-normalized toxic compounds in mussels and flounder and lobster meat Lead in mussels Liver disease in flounder

Like the monitoring plan, every effort is made to incorporate new scientific information and improved understanding resulting from the monitoring program into appropriate thresholds. A process for modifying the contingency plan is set forth in MWRA's NPDES permit.

In November 2000, MWRA requested several modifications to the contingency plan. After review by OMSAP and regulatory comment and public comment, a revised contingency plan was issued in May 2001. Several changes were made to the plan:

- Adding the benthic opportunist thresholds and making those thresholds more stringent than had been suggested in the ambient monitoring plan.
- Removing the zooplankton threshold but requiring MWRA to report annually on appreciable changes to the zooplankton community and on ongoing special zooplankton studies.
- Removing the floatables threshold but requiring MWRA to carry out sampling studies to develop a new threshold.

Other changes were made on an interim basis and will be submitted by MWRA for agency review and public comment in November 2001. Those interim changes include

- Calculation of background conditions for the dissolved oxygen percent saturation and concentration thresholds.
- Change in the nearfield *Alexandrium* (red tide) cell count threshold from the 95th percentile of the seasonal mean to 100 cells/L in any sample. In addition, MWRA and the Woods Hole Oceanographic Institution are deriving an improved threshold for "new evidence" of paralytic shellfish poisoning toxin in shellfish.

Data Management

The outfall-monitoring program has generated extensive data sets documenting baseline environmental conditions. Data quality is maintained through program-wide quality assurance and quality control procedures. After 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 the 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 interpretation, although they are retained in the database and included in raw data reports. Any corrections are documented. Each data report notes any special data quality considerations associated with the data set.

As discharge and monitoring results become available, they are compared with contingency plan thresholds. Computer programs calculate each threshold parameter value from the data, compare it to the threshold, and notify the project staff if any caution or warning levels are exceeded.

Reporting

MWRA's NPDES permit requires extensive reporting on the monitoring program, including a variety of reports submitted to OMSAP for review and regular reports on effluent quality (Table 1-4). Changes to the monitoring program or contingency plan must be reviewed by regulators and published in the *Environmental Monitor*. Data that exceed contingency plan thresholds and corrective actions must also be reported. Data that exceed thresholds must be reported within five days after the results become available, and MWRA must make all reasonable efforts to report all data within 90 days of each sampling event.

Reports are posted on MWRA's web site (www.mwra.com), with copies placed in repository libraries in Boston and on Cape Cod. OMSAP also holds public workshops where outfall-monitoring results are presented.

Table 1-4. List of monitoring reports submitted to OMSAP

Report	Description/Objectives
Outfall Monitoring Plan Phase I—Baseline Studies (MWRA 1991) Phase II—Discharge Ambient Monitoring (MWRA 1997a)	Discusses goals, strategy, and design of baseline and discharge monitoring programs.
Contingency Plan (MWRA 1997b, 2001)	Describes development of threshold parameters and values and MWRA's planned contingency measures.
Program Area Synthesis Reports	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.
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 (Gayla *et al.*1996, 1997a, 1997b, Werme and Hunt 2000a, 2000b). The report includes a scientific summary of each year of monitoring. Overviews for 1995-1999 included only baseline information. With the outfall operational, this report will include information relevant to the contingency plan, such as data that exceed thresholds, responses, and corrective activities. When data suggest that monitoring activities, parameters, or thresholds should be changed, the report will summarize those recommendations.

This year's outfall monitoring overview presents monitoring program results for baseline effluent and field data collected up to the date the outfall was commissioned, September 6, 2000. The report discusses the final baseline results and contingency plan thresholds that are based on those results. The report also gives the first observations of discharge monitoring (September 6-December 31, 2000), together with the Contingency Plan report for that period. It also provides a section on data relevant to the Stellwagen Bank National Marine Sanctuary.

2. Effluent

Background

Pollution Prevention and Wastewater Treatment

MWRA's strategy for improving the environmental quality of Boston Harbor without degrading Massachusetts and Cape Cod bays relies on reduction of pollutants at their sources, along with effective treatment. The MWRA Toxic Reduction and Control Program sets and enforces limits on the types and amounts of pollutants that industries can discharge into the sewer system. Continuing the source reduction program and making sure that the treatment plant is working as designed are the most important actions MWRA can take to ensure that the relocated outfall does not cause any harm to the environment.

To mitigate accidental discharge of pollutants to the system, MWRA has developed best management practice plans for the Deer Island plant, its headworks facilities, the combined sewer overflow facilities, and the sludge pelletizing plant. These plans have been implemented. They include inspections, which are conducted at least once a year by non-facility staff.

Environmental Concerns

Effluent constituents of concern include pathogens, chlorine, solids, organic matter, nutrients, toxic contaminants, pH, and "floatables." Floatables include oil and grease slicks, as well as plastic and other debris.

Pathogens, including bacteria, viruses, and protozoa are found in human and animal waste and can cause disease. Human exposure to water-borne pathogens can occur through consumption of contaminated shellfish or through ingestion or physical contact while swimming. MWRA disinfects the effluent and is required to meet water quality standards for fecal coliform bacteria, an indicator of the presence of pathogens.

Disinfection is accomplished by addition of a form of chlorine, sodium hypochlorite, which is the active ingredient in bleach. Unfortunately, while sodium hypochlorite is effective in destroying pathogens, at high enough concentration, it is also harmful to marine life. Better solids removal by secondary treatment and the longer time that the effluent is exposed to chlorine in the outfall tunnel allow MWRA to minimize the amount of chlorine added while still achieving effective disinfection.

Suspended solids, small particles of debris in the water column, decrease water clarity and consequently affect growth and productivity of algae and other marine plants. Excess suspended solids also detract from people's aesthetic perception of the environment. As noted above, suspended solids can also interfere with disinfection.

Organic material, a major constituent of sewage effluent, 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. Too much organic material could also disrupt the sea-bottom ecosystem.

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 substantially reduced by secondary treatment.

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.

Seawater is noted for its buffering capacity, that is, its ability to neutralize acids and bases. However, state water quality standards dictate that effluent discharges not change the pH of the ambient seawater more than 0.5 standard units. Consequently, the outfall permit sets both upper and lower values for pH of the effluent. Because of the pure oxygen used in the activated sludge reactors, the effluent pH tends to be at the lower, more acidic, limit of the allowable pH range.

The oil and grease slicks and floating debris that comprise floatables pose an aesthetic concern. Plastic debris can also be harmful to marine life, as plastic bags are sometimes mistaken for food and clog the digestive systems of turtles and mammals. Plastic can also entangle animals and cause them to drown.

Monitoring Design

The main purpose of effluent monitoring is to measure the concentrations and variability of constituents of the effluent. Effluent monitoring is designed to assess compliance with NPDES permit limits, which are based on state and federal water quality standards and criteria, ambient conditions, and the projected dilution at the outfall (Table 2-1). Effluent monitoring also provides accurate mass loads of effluent constituents, so that fate, transport, and risk of contaminants can be assessed.

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
Total Residual Chlorine	Grab	3/Day
PCB, Aroclors	24-hr Composite	1/Month
LC50	24-hr Composite	2/Month
C-NOEC	24-hr Composite	2/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	Grab	1/Month
Copper, Total	24-hr Composite	1/Month
Total Arsenic	24-hr Composite	1/Month
Hexachlorobenzene	24-hr Composite	1/Month
Aldrin	24-hr Composite	1/Month
Heptachlor Epoxide	24-hr Composite	1/Month
Total PCBs	24-hr Composite	1/Month
Volatile Organic Compounds	Grab	1/Month

The permit includes numeric limits for suspended solids, fecal coliform bacteria, pH, chlorine, polychlorinated biphenyls (PCBs), and carbonaceous biochemical oxygen demand (cBOD). In addition, state water quality standards establish limits for 158 pollutants, and the permit prohibits any discharge that would cause or contribute to exceeding of any of those limits. 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 organisms and establishes strict limits based on the tests. Allowable concentrations of contaminants were based on the predicted dilution at the new outfall. Actual dilution is being measured now that the outfall is discharging. Preliminary results suggest that dilution is as great as had been predicted.

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 cBOD. Monitoring for toxic contaminants includes analyses for heavy metals of concern, chlorinated pesticides, PCBs, volatile organic compounds, PAHs, total residual chlorine, and cyanide. Toxicity is tested using whole effluent samples. Tests for acute toxicity 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 growth and survival and sea urchin (*Arbacia punctulata*) one-hour fertilization tests. Pathogen monitoring consists of enumeration of fecal coliform bacteria. Total suspended solids (TSS) and settleable solids are also measured. Methods for measuring floatables remain under development.

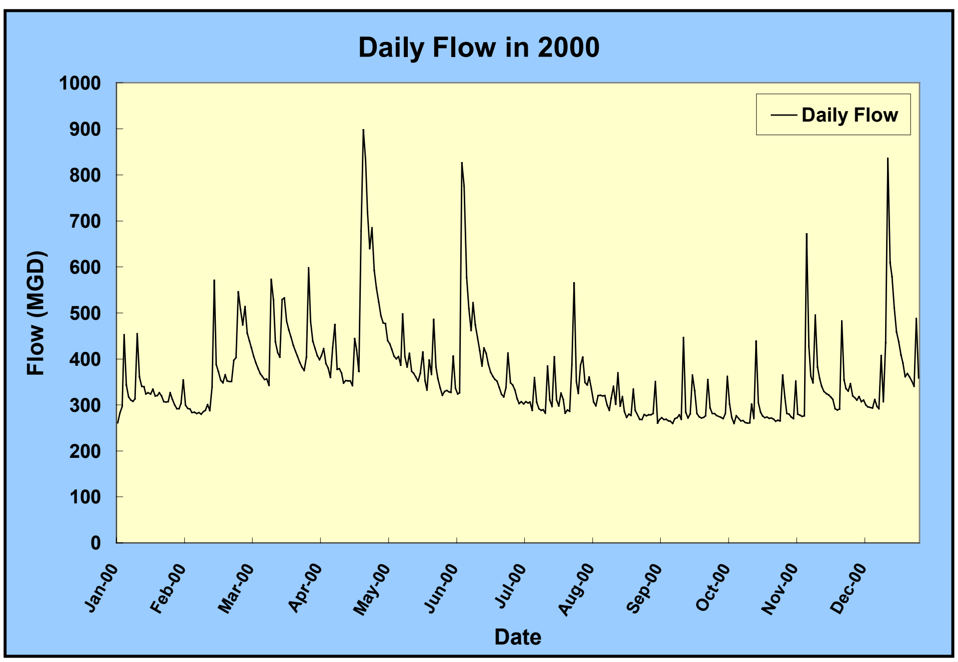

Figure 2-1. Daily effluent flow in 2000

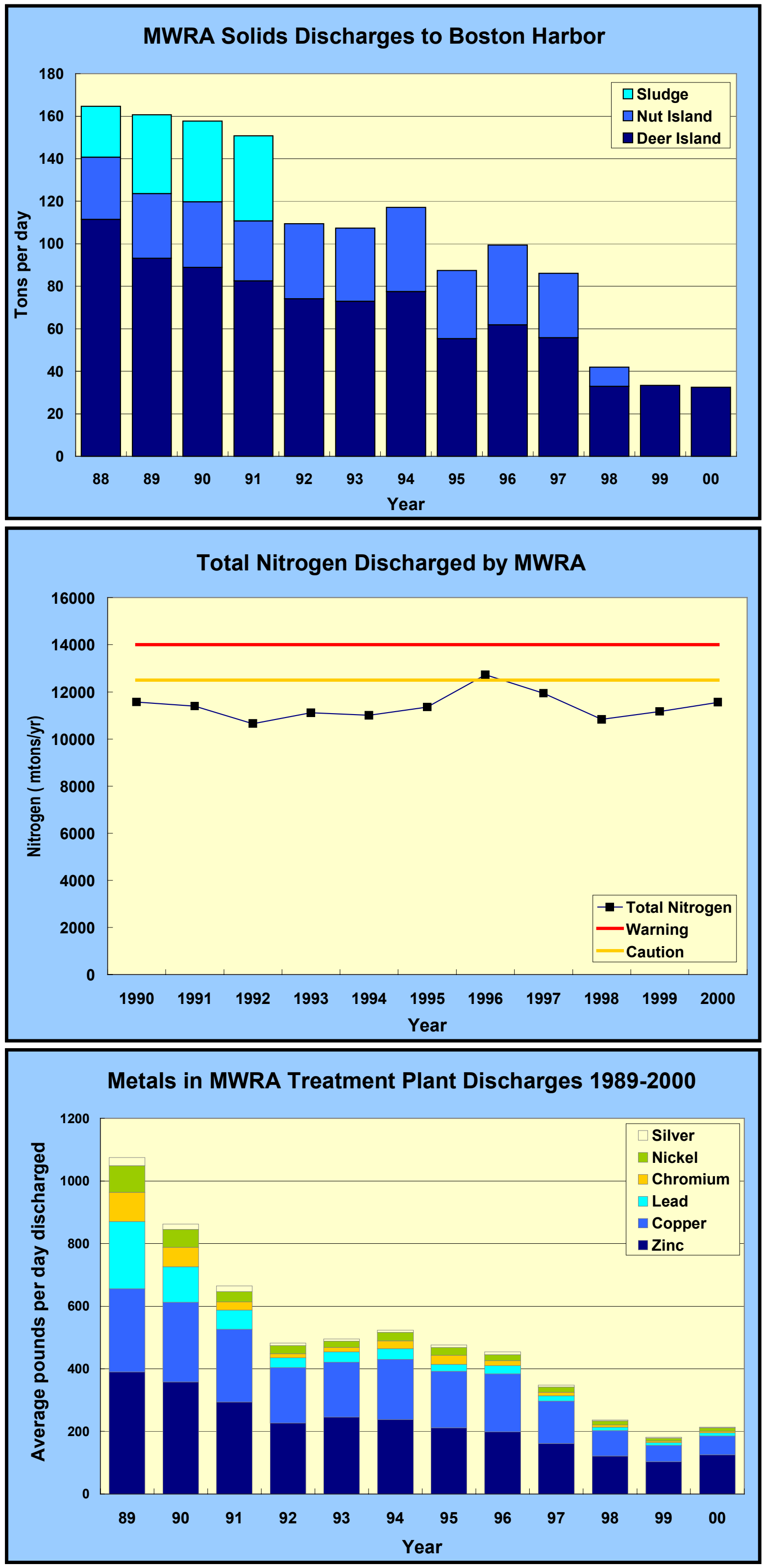

Figure 2-2. Annual solids, nitrogen, and metals discharges

Results

Average daily flow of effluent from the Deer Island treatment plant in 2000 was 362 million gallons per day (Figure 2-1), slightly more than 1999, which had been a year of drought. Because of the higher flows, approximately 85% of the flow received secondary treatment, slightly less than 1999. With the final battery of secondary treatment operational, MWRA anticipates that 98% of the flow will receive secondary treatment.

Total solids discharged in the effluent remained low, about 32 tons per day (Figure 2-2). Solids removal has steadily increased over the past 10 years and will continue to improve with the addition of the third battery of secondary treatment. As a result, monthly average TSS and cBOD have declined and remained low in 2000, reflecting the implementation of secondary treatment (Figure 2-3).

Although secondary treatment effectively removes most contaminants, it has less effect on nutrients. As a result of implementation of secondary treatment in 1997 and 1998, nitrogen loads have been reduced to levels that meet contingency plan thresholds (Figure 2-2). Of the nitrogen released, 20% is organic nitrogen, 72% is ammonium and 8% is nitrate. Ammonium levels have increased slightly, due to the secondary treatment and the addition of "pressate" from the sludge treatment process. When the final battery of secondary treatment comes on line, total nitrogen loads should slightly decrease.

Discharge of toxic compounds in 2000 was similar to 1999. Metals loads were slightly higher due to the somewhat higher flow, however metals loads have declined dramatically since 1989 (Figure 2-2). Organic contaminant loads have also declined. No data are available from the 1980s, as detection limits achieved by the available analytical methods were not low enough to detect the toxic compounds of concern until the mid-1990s. Since 1996, before implementation of secondary treatment, until 1999-2000, with 87% secondary treatment, PAH concentrations declined 88%, from 8,250 to 980 ng/l. Likewise, PCB concentrations declined 79%, from 11 to 2.3 ng/l, and DDT concentrations declined 78%, from 5 to 1.1 ng/l.

Overall, many contaminant loads are less than had been predicted in EPA's SEIS for the outfall. These differences result from lower than expected flows, effective industrial pretreatment, and dramatic improvements to analytical methods since the preparation of the SEIS. Predictions in the SEIS were based on presumptions of contaminant concentrations that were reported as "below detection limits." With analytical improvements that lowered detection limits, MWRA found that concentrations of contaminants are lower than had been presumed.

Loadings of many contaminants are also lower than had been predicted in a 1997 pilot plant study. That study evaluated high flow and stressed conditions. The actual treatment plant under ambient conditions performs better than the test plant. The lower than predicted loads suggest that potential effects of the outfall may also be less than the minimal effects predicted in the SEIS.

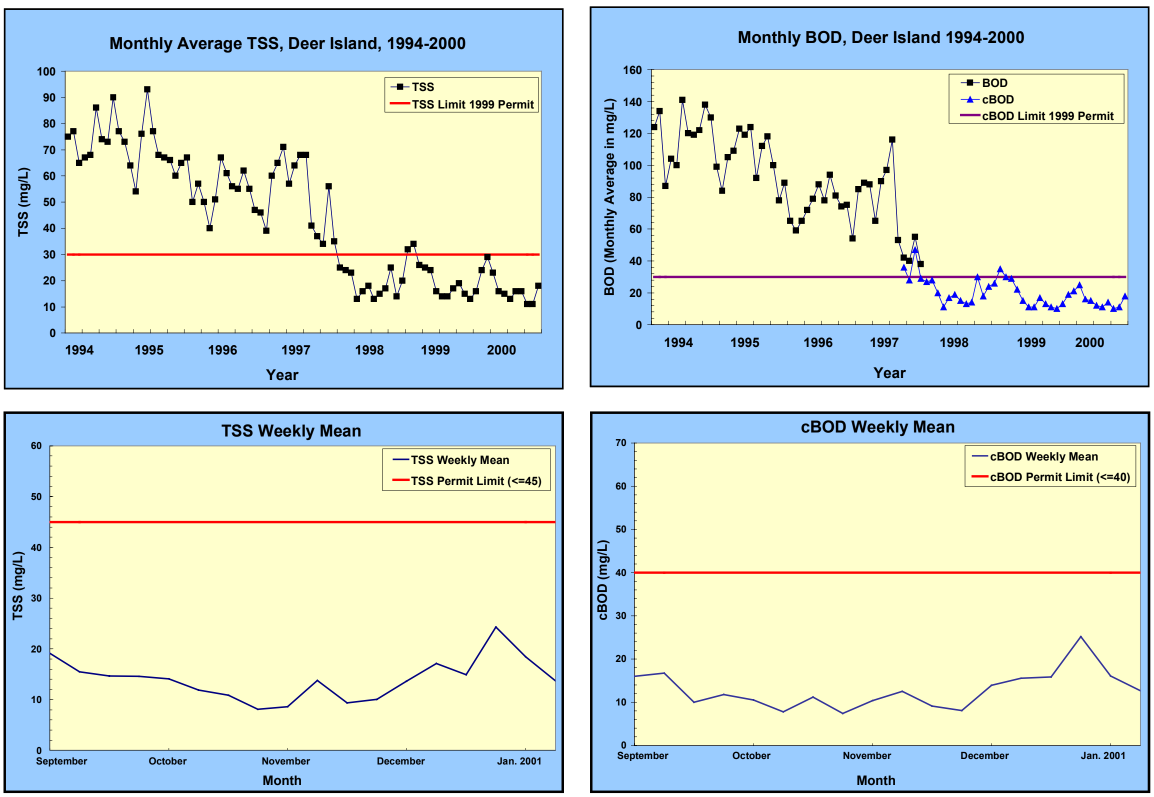

Figure 2-3. Monthly average TSS and monthly BOD (measured as cBOD since 1997) from 1994-2000. Weekly TSS and cBOD during the period in 2000 that the offshore outfall was discharging.

Table 2-2. Contingency Plan threshold values and 2000 results for effluent monitoring

Parameter	Caution Level	Warning Level	September 6 – December 31, 2000 Results
Fecal coliform bacteria	None	14,000 fecal coliforms/100 ml (monthly 90th percentile, weekly geometric mean, maximum daily geometric mean, and minimum of 3 consecutive samples)	Not exceeded
Chlorine, residual	None	631 ug/l daily, 456 ug/l monthly	One warning level exceedance = 900 ug/l; should not be repeated with implementation of feedback for dechlorination
Total suspended solids	None	45 mg/l weekly 30 mg/l monthly	Not exceeded
cBOD	None	40 mg/l weekly, 25 mg/l monthly	Not exceeded
Toxicity	None	Acute: effluent LC50<50% for shrimp and fish Chronic: effluent NOEC for fish survival and growth and sea urchin fertilization <1.5% effluent	Not exceeded
PCBs	Aroclor=0.045 ng/l		Not exceeded
Plant performance	5 violations/year	Noncompliance >5% of the time	Not applicable
pH	None	<6 or >9	One warning level exceedance = 5.8, due to sampling artifact
Flow	None	Flow >436 for annual average of dry days	Not applicable
Total nitrogen load	12,500 mtons/year	14,000 mtons/year	Not applicable
Oil and Grease	None	15 mg/l weekly	Not exceeded
Floatables			Threshold revision pending

Contingency Plan Thresholds

Two permit violations were reported after the contingency plan became effective on September 6, 2000, one for pH level and one for residual chlorine (Table 2-2, Figure 2-4). Subsequent testing suggested that the low pH level did not result from plant operations but from a flawed sampling protocol. During regular plant operations, the effluent "off-gasses" during transit in the disinfection basins, resulting in an increased pH. The effluent sampling site and method did not allow for this off-gassing to occur. Consequently, measured pH values were typically low by approximately 0.2 standard units. As a result of the violation, MWRA has improved its sampling technique and worked to ensure that pH levels are high enough to result in no further violations.

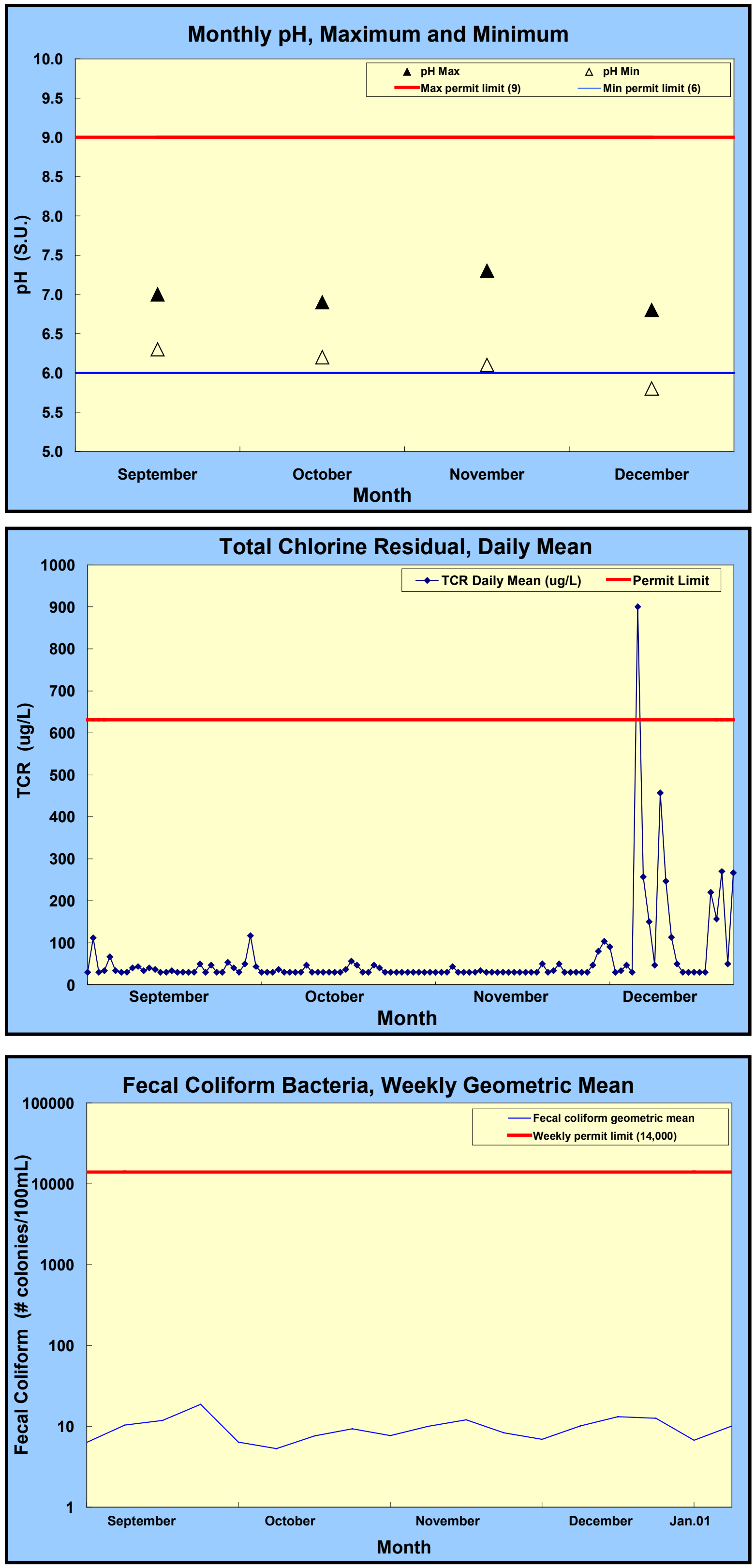

Figure 2-4. Monthly pH, daily mean chlorine residual, and fecal coliform bacteria data from the period in 2000 in which the outfall was discharging

The total chlorine residual (TCR) level was exceeded once while MWRA was in the start-up phase of commissioning the outfall. After disinfection, the effluent is dechlorinated by the additions of sodium bisulfite. Automated TCR sensors now aid in determining how much sodium bisulfite to use, but the sensors had not yet been installed. The exceedance occurred during a rainstorm, when flow through the treatment plant was changing rapidly. These conditions made adding the appropriate amounts of sodium bisulfate difficult. Since the automated TCR sensors were installed, the problem has not recurred. Although a permit violation, the actual chlorine levels were low, 900 ppb, and no adverse impact resulted.

No other contingency plan exceedances for effluent occurred. Fecal coliform bacteria levels remained well below the 14,000 bacteria per 100 ml established by the permit (Figure 2-4). Acute and chronic toxicity tests results indicated that toxicity of the whole effluent was within permit limits. Contaminant concentrations were also well below permit limits.

3. Water Column Baseline

Background

When MWRA's ocean outfall began operations on September 6, 2000, it marked the completion of baseline monitoring. This section summarizes results from water column monitoring through the year 2000. It primarily discusses baseline data, understanding that September through December were in the discharge monitoring period. A more detailed discussion of discharge monitoring, along with a report on contingency plan thresholds, is in Section 6, Outfall Monitoring.

Circulation and Water Properties

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). A general coastal current flows southwestward and may enter the bays by Cape Ann to the north of Boston. Water flows 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 eastern Massachusetts Bay and Cape Cod Bay.

When the MWRA monitoring program began, scientists assumed that the water quality and biology of the bays followed an annual cycle typical for coastal waters. In fact, monitoring has shown that wind, regional conditions, and other factors greatly influence the pattern. According to the typical coastal cycle, waters are well mixed, and nutrient levels are high during November through April. As light levels increase in the early spring, phytoplankton begin the period of rapid growth known as a spring bloom. Monitoring has shown that spring blooms do not occur every year. During the years in which they do, the bloom begins in the shallowest waters of Cape Cod Bay. Blooms in deeper waters begin two to three weeks later. Spring phytoplankton blooms are typically followed by an increase in zooplankton abundance. These zooplankton populations are food for many animals, including the endangered right whale.

Later in the spring, the surface waters warm, and the water column stratifies. Inputs of freshwater from rivers contribute to the stratification, with lower salinity water remaining at the surface. Stratification effectively separates the surface and bottom waters, preventing replenishment of nutrients to the surface and of oxygen to the bottom. Phytoplankton in the surface waters deplete the available nutrients and then undergo senescence, sinking to the bottom. Oxygen levels remain high in the surface waters throughout the year, but oxygen is depleted in the bottom waters. Bottom-dwelling animals respire, and bacteria use up oxygen as they decompose the phytoplankton, so bottom-water oxygen levels are typically lowest during August through October.

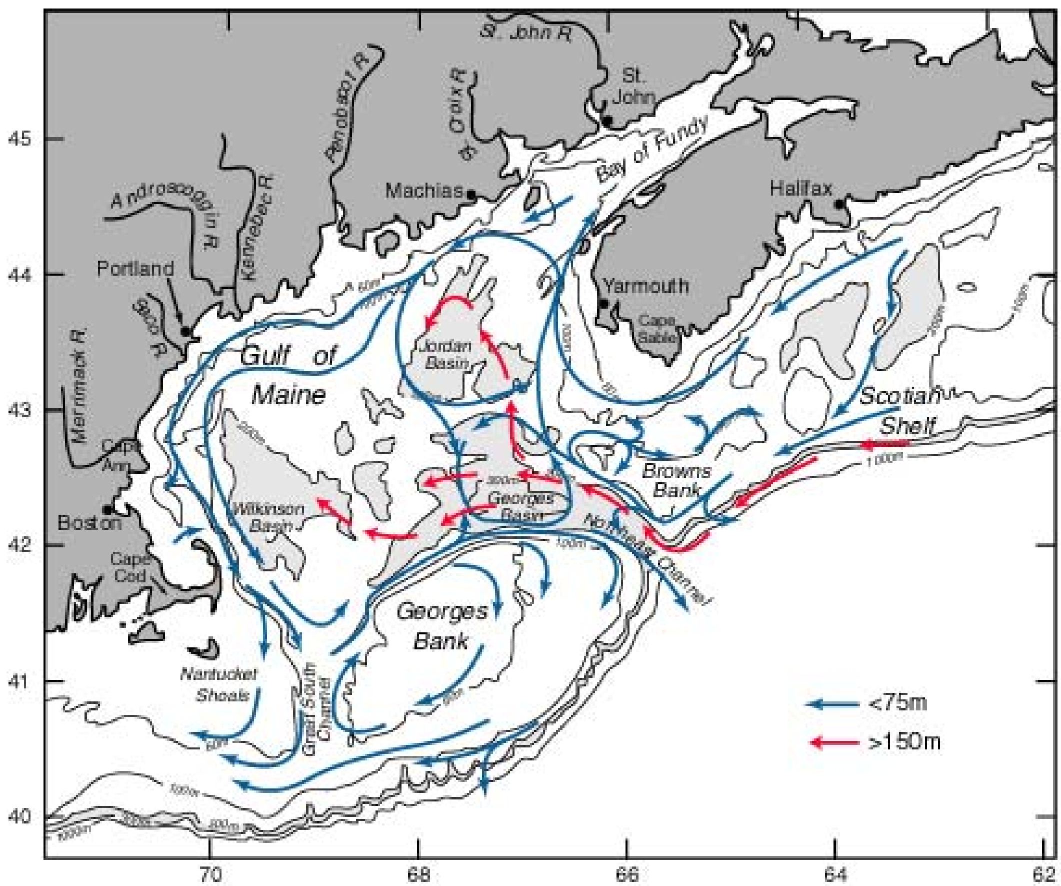

Figure 3-1. General circulation on Georges Bank and in the Gulf of Maine during the summer, stratified season. Figure courtesy of Jack Cooke, WHOI graphics.

In the fall, cooling surface waters and strong winds promote mixing of the water column. Oxygen is replenished in the bottom waters, and nutrients brought to the surface can stimulate a fall phytoplankton bloom. Typically, fall blooms end in the early winter, when declining light levels limit photosynthesis. 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 and are affected by wind patterns. If strong southerly or southwesterly winds, that is, winds from the south or southwest, persist during the summer, then upwelling occurs.

Upwelling leads to colder bottom-water temperatures and also higher concentrations of dissolved oxygen. Weaker southerly winds result in less upwelling, with warmer bottom-water temperatures and lower levels of dissolved oxygen.

Environmental Concerns

Water column monitoring focuses on concerns that relocation of the outfall will introduce effects from 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, nutrient issues cause the greatest concerns.

The concern is that excess nutrients, particularly nitrogen, could promote algal blooms followed by low levels of dissolved oxygen when the phytoplankton die, sink, and decompose. Another fear is that changes in the relative levels of nutrients could stimulate growth of undesirable algae. Three nuisance or noxious species are of particular concern: the dinoflagellate *Alexandrium tamarense*, the diatom *Pseudo-nitzschia multiseries*, and the colonial flagellate *Phaeocystis pouchetii*. *Alexandrium tamarense* typically blooms during April to June and can cause paralytic shellfish poisoning, known as PSP or red tide. The toxin, when sufficiently concentrated, can be fatal to marine mammals, fish, and humans. Paralytic shellfish poisoning toxin has been periodically found in Massachusetts since the 1970s. *Pseudo-nitzschia multiseries* blooms can occur at any time of the year. In high concentrations, more than 1 million cells per liter, it may produce domoic acid, which can cause a condition known as amnesic shellfish poisoning. *Phaeocystis pouchetii* blooms usually occur during the late winter and spring. The species is not toxic, but individual cells can aggregate in gelatinous colonies that are poor food for zooplankton.

Although it is effectively removed by secondary treatment, organic material from the wastewater effluent remains a concern. Decomposition of organic matter consumes the oxygen necessary for survival of marine life. Because of the concern that low levels of dissolved oxygen 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 the periods of low oxygen that are typical in bottom waters appear to correlate with saltier bottom waters.

Due to source reduction and treatment, toxic contaminants discharged in the MWRA effluent are present at extremely low concentrations. Most monitoring for the effects of toxic contaminants will be focused on the sediments, which are known to be contaminant sinks, and on fish and shellfish, which could accumulate organic compounds or metals.

Monitoring Design

Water column monitoring includes assessments of water quality, phytoplankton, and zooplankton in Massachusetts and Cape Cod bays. Baseline monitoring includes four major components: nearfield surveys, farfield surveys, continuous recording, and remote sensing. Results from preliminary plume-tracking studies are presented in Section 6, Discharge Monitoring; detailed studies will occur in 2001.

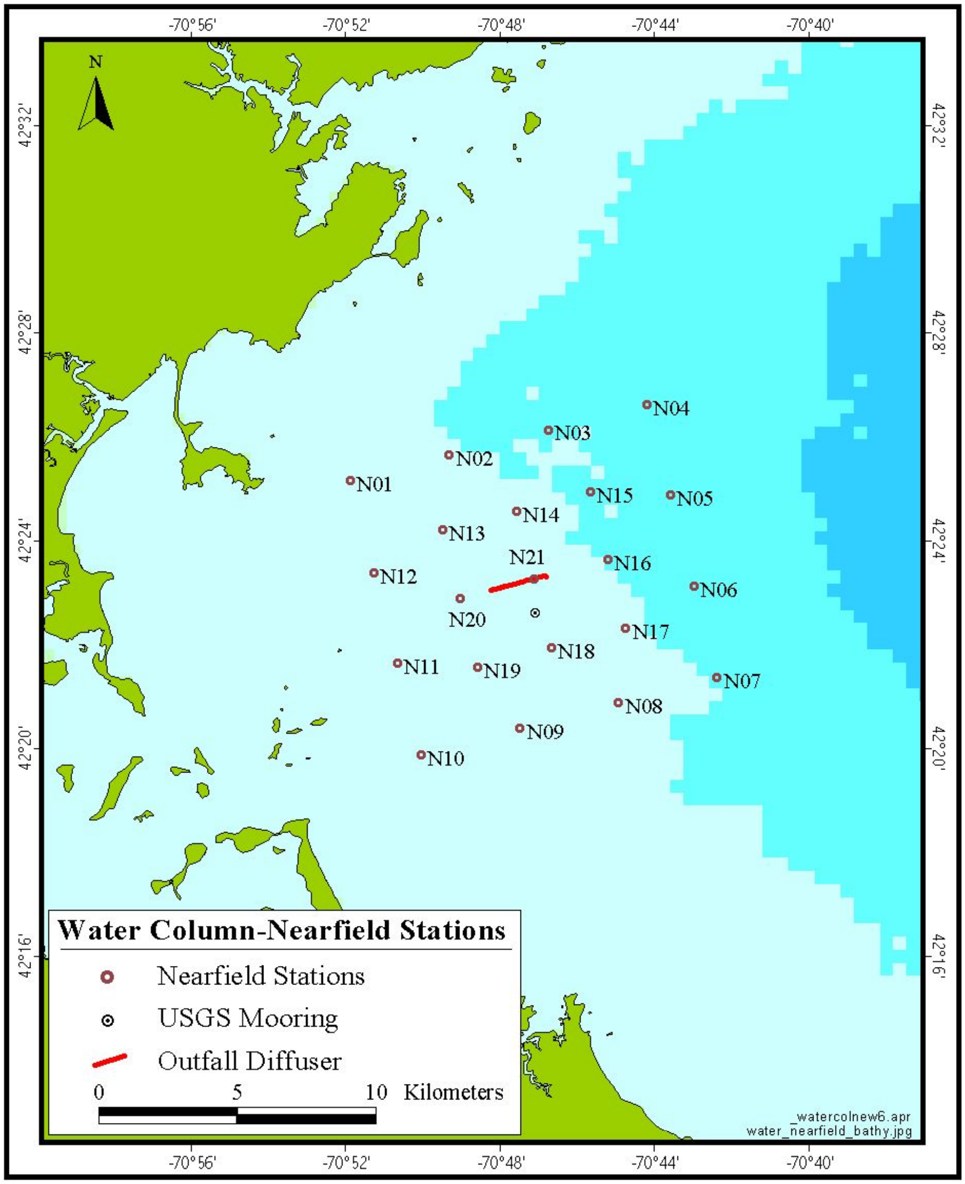

Figure 3-2. Nearfield sampling stations

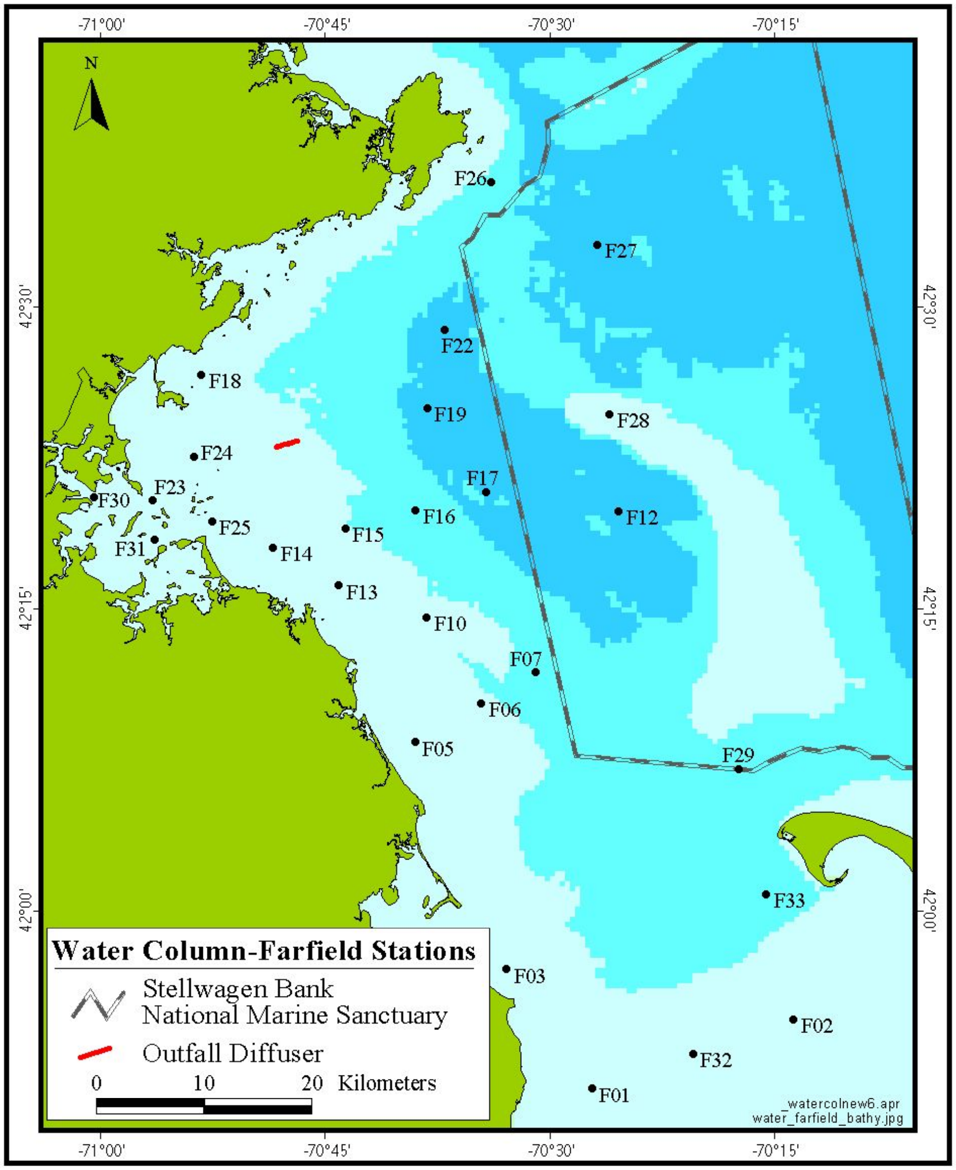

Figure 3-3. Farfield sampling stations

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 the effluent are expected (Figure 3-2). Farfield surveys assess differences across the bays and seasonal changes over a large area (Figure 3-3). Five stations mark the boundary of the monitoring area and are in or near the Stellwagen Bank National Marine Sanctuary. During 2000, 17 surveys were conducted, including six surveys of farfield stations. Twelve of those surveys, including five that sampled farfield stations, were conducted before the Massachusetts Bay outfall came on line. Samples were taken from 48 stations in Boston Harbor, Massachusetts Bay, and Cape Cod Bay.

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

The continuous recording component of the program captures temporal variations in water quality between nearfield water quality surveys. Remote sensing captures spatial variations in water quality on a regional scale.

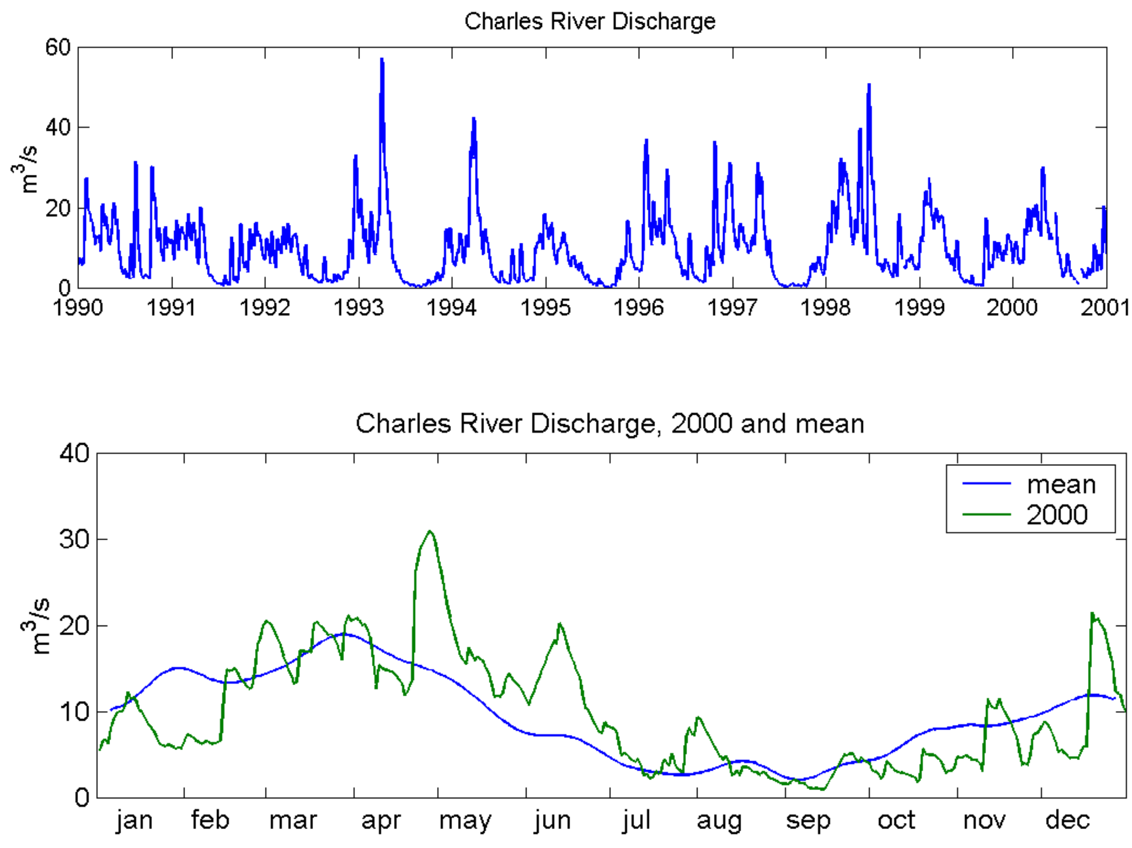

Figure 3-4. Charles River discharge, 1990-2000, and 2000 discharge compared to the historic mean

Results

Physical Conditions

Overall, the weather in Boston in 2000 was typical. After a warm March, the rest of the year was slightly cooler than average. The spring, particularly June, was wet, with 4 inches of rain falling on one day, June 6. July continued to be cool and rainy. The fall was slightly drier than average, with two 10-day rain-free stretches in October and November.

Wind stresses were also typical. Downwelling conditions persisted during the spring. The upwelling conditions typical during the summer were somewhat less strong than average. Downwelling conditions in October were stronger than usual. Average wind speeds were typical, and there were no extreme wind-stress events.

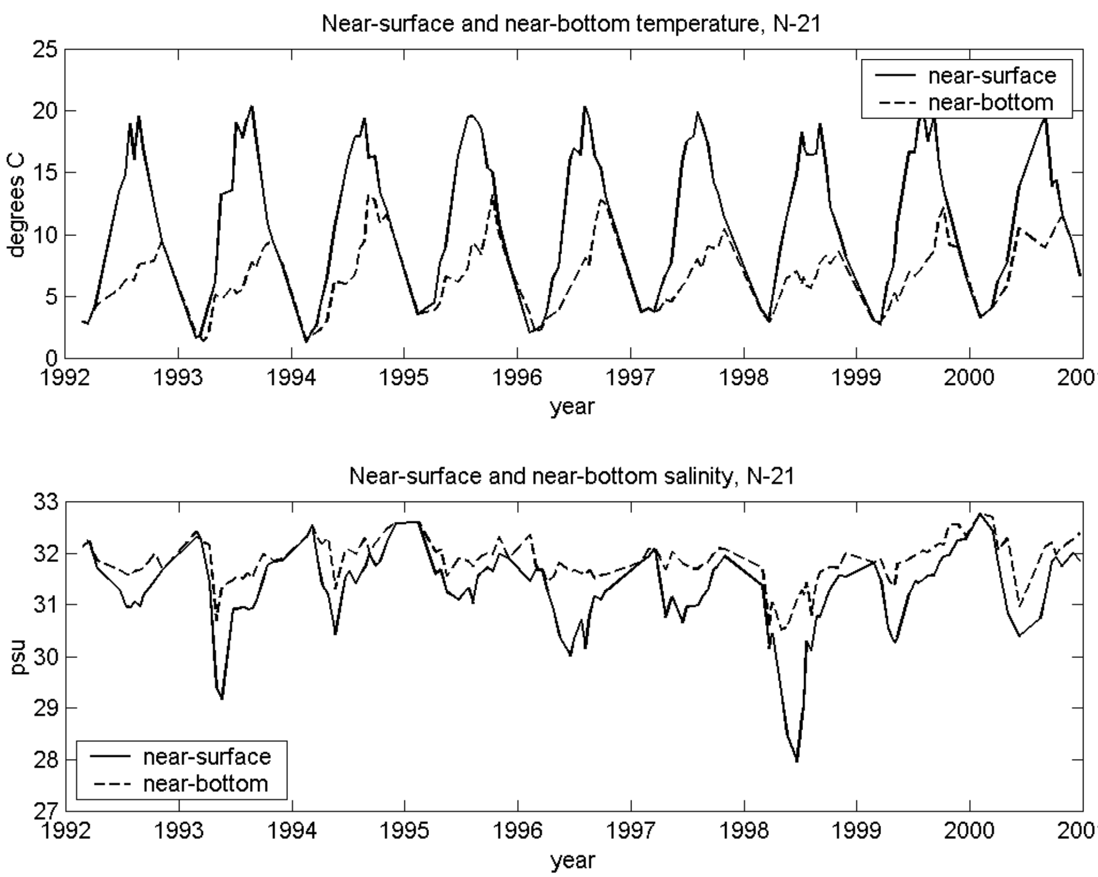

Figure 3-5. Surface and bottom temperature and salinity, 1992-2000

Water temperatures followed a typical pattern in the surface and at the bottom (Figure 3-5), except that bottom waters were warm in June, following the major storm. There was no dramatic decline in temperatures in the fall.

Similar to 1999, which was a drought year, surface and bottom salinities were typical (Figure 3-5). Conditions resulted in a typical annual pattern of water stratification in 2000. Stratification was largely controlled by water temperature rather than salinity through August. The stratification pattern was broken, not by an intense hurricane season, but by gradual seasonal changes during late August through mid-September.

Water Quality

The nutrient cycles for 2000 were typical for the baseline-monitoring period. Nitrate concentrations were high during the winter and decreased sharply between February and March with spring blooms of diatoms and the flagellate *Phaeocystis pouchetii*. By April, surface nitrate concentrations in the nearfield had been depleted. Increased nitrate concentrations occurred at mid-depth in late August and early September, as stratification broke down or as a new water mass entered the area.

Phosphate concentrations also followed a typical pattern, similar to nitrate. There was also a marked decline in silicate concentrations in February and March, coincident with the increase in diatoms, which have cell walls made of silica. By April, however, diatom populations were shrinking, and silicate concentrations increased, remaining elevated through the summer. Silicate concentrations declined again during a fall phytoplankton bloom, but did not reach record low concentrations.

The sharp drop in nitrate concentrations during the spring of 2000 was similar to decreases observed in 1992, 1994, and 1996, when spring blooms rapidly depleted nutrient concentrations. The year was in contrast to 1998 and 1999, when nutrient levels remained elevated well into the spring. In 1998, no spring bloom occurred, and concentrations of nitrate remained high through May. During the fall of 2000, breakdown of stratified conditions apparently increased nutrient availability, leading to a fall bloom. Similar situations occurred during 1993, 1995, and 1999. In other years, when mixing was delayed, surface waters remained depleted and no blooms occurred.

From 1997 through 2000, there was a slight increase in concentrations of dissolved inorganic nitrogen in the nearfield (Figure 3-6). Nitrate concentrations followed a normal seasonal pattern. However, there was an increase in ammonia levels in Boston Harbor. Ammonia in the western nearfield also increased, correlated with increased concentrations in

Boston Harbor. This apparently resulted from an increase in flow from the Deer Island treatment plant's harbor outfalls following diversion of south system flow to Deer Island and also from the treatment process. Secondary treatment breaks down organic wastes, decreasing total nitrogen but increasing ammonia concentrations in the effluent.

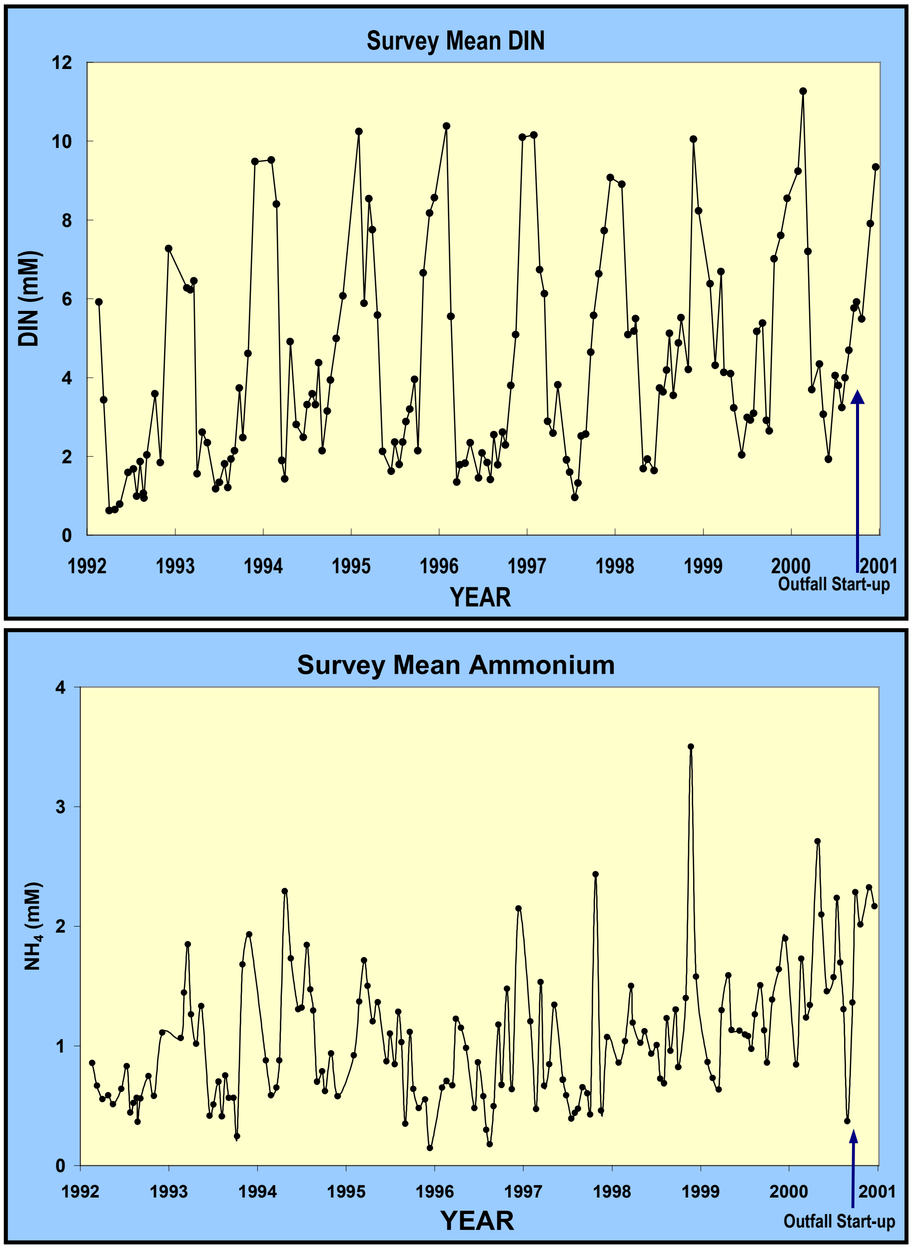

Figure 3-6. Survey mean dissolved inorganic nitrogen and ammonia in the nearfield, 1992-2000

Chlorophyll levels increased from 1998 through 2000 (Figure 3-7). The mean chlorophyll concentration in the nearfield during February through April 2000 was 5.03 µg/l, greater than any winter/spring mean obtained during the baseline period. Winter/spring chlorophyll levels for 1992, 1994, 1996, and 1999, when spring blooms also occurred, averaged only about 2 µg/l. The summer and fall mean chlorophyll levels in the nearfield were also higher in 2000 than in any other year of the baseline period. An extended fall bloom resulted in a mean chlorophyll concentration of 5.69 µg/l. Previous years means had ranged from 1.31 µg/l in 1997 to 5.45 µg/l in 1999. (Quality assurance reviews in 2000 detected analytical errors in chlorophyll measurements during 1998-2000, and data for those years were reevaluated. Two data quality problems were identified: a degraded standard, which had been used to calibrate samples from late September and October 2000, and impurity of the standard, which may have affected all data from 1998. The data have been corrected.)

The high chlorophyll levels occurred not only in the nearfield, but throughout the region. Boston Harbor, the boundary stations, Cape Cod Bay, the coastal stations, and the offshore stations also had annual mean levels that were higher in 2000 than in any baseline year.

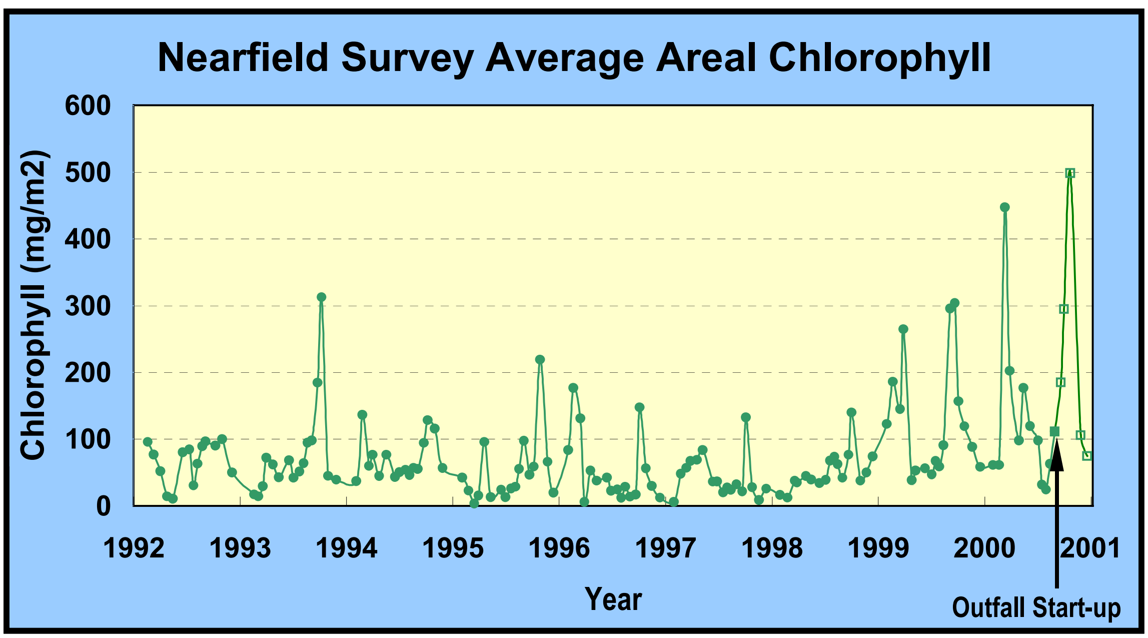

Figure 3-7. Survey areal mean chlorophyll concentrations in the nearfield, 1992-2000

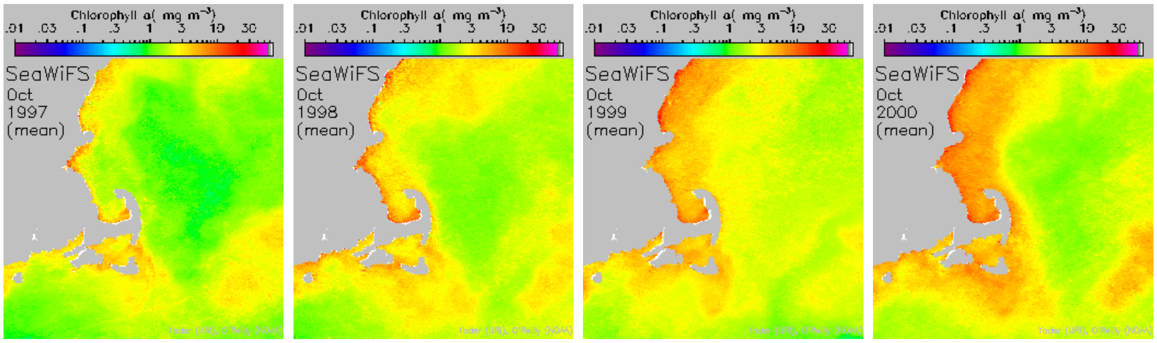

Figure 3-8. Satellite data show an increasing trend in fall chlorophyll levels in Massachusetts Bay, Cape Cod Bay, south of Cape Cod, and in the Gulf of Maine (J. Yoder, URI, J.O'Reilly, NOAA). October 2000 is in the discharge-monitoring period (see Section 6).

Interpretation of MWRA chlorophyll data is aided by results from the Sea-viewing Wide Field-of-view Sensor (SeaWiFS) Project, which is part of the National Air and Space Administration (NASA) mission to view earth from space to better understand it as a system. SeaWiFS provides satellite images using sensors that detect the subtle changes in ocean color that signify the presence of phytoplankton.

SeaWiFS images from the autumns of 1997-2000 depict a region-wide, steady increase in chlorophyll concentrations (Figure 3-8). The reasons for this widespread increase are unknown. Some scientists have suggested that the North Atlantic oscillation, region-wide shifts in water masses, may be responsible for cyclic variation in nutrient levels. Regardless of the explanation, the images graphically demonstrate that Massachusetts Bay is part of a larger system, that increases in fall phytoplankton biomass have been occurring steadily throughout the late baseline monitoring period, and that any exceedances of water-column thresholds must be evaluated in a regional context.

Dissolved oxygen concentrations in the nearfield were not unusually low in 2000 (Figure 3-9). The annual minimum percent saturation was less than 80%, but within the baseline range. Concentrations in bottom waters were about one percent higher in Stellwagen Basin than in the nearfield. Rates of decline in dissolved oxygen concentrations were typical for the period, both in the nearfield and in Stellwagen Basin, although low levels were reached somewhat earlier than usual. The early decline may have resulted from the large amount of organic matter produced by the spring algal blooms.

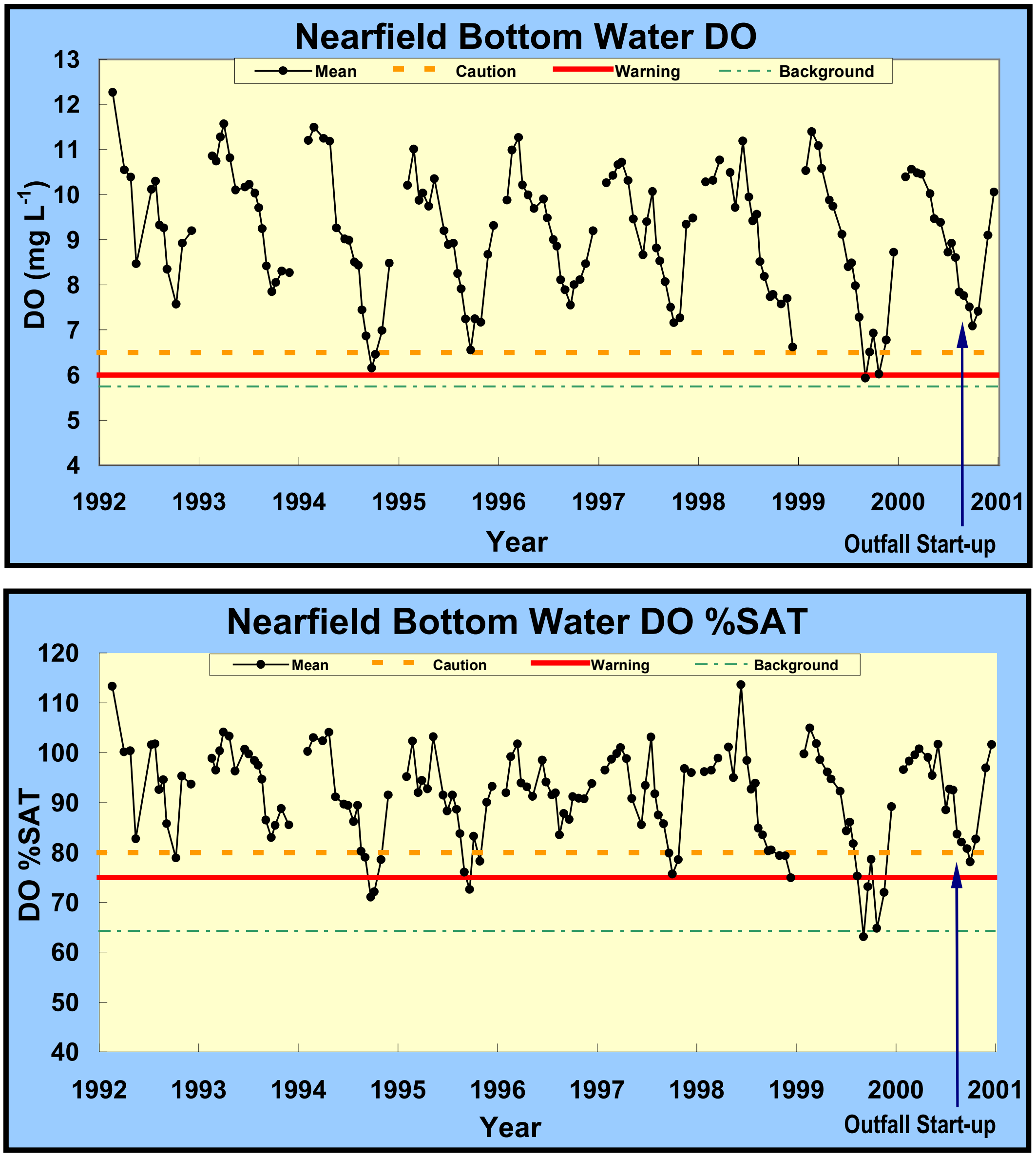

Figure 3-9. Survey mean dissolved oxygen concentrations and percent saturation in the nearfield, 1992-2000

Phytoplankton Communities

Phytoplankton abundance in 2000 was variable and low from February through early March. In late March and April, there was a system-wide bloom of *Phaeocystis pouchetii*, the undesirable, although not toxic, flagellate. Total phytoplankton abundance declined with the end of the bloom in May, but subsequently increased in June and July. Over the year, the magnitude and trends in phytoplankton abundance were similar in the nearfield and the farfield. Although *Phaeocystis* abundance was the highest measured in the baseline period, the year was similar to other years with spring *Phaeocystis* blooms (Figure 3-10; Libby *et al.* 2001).

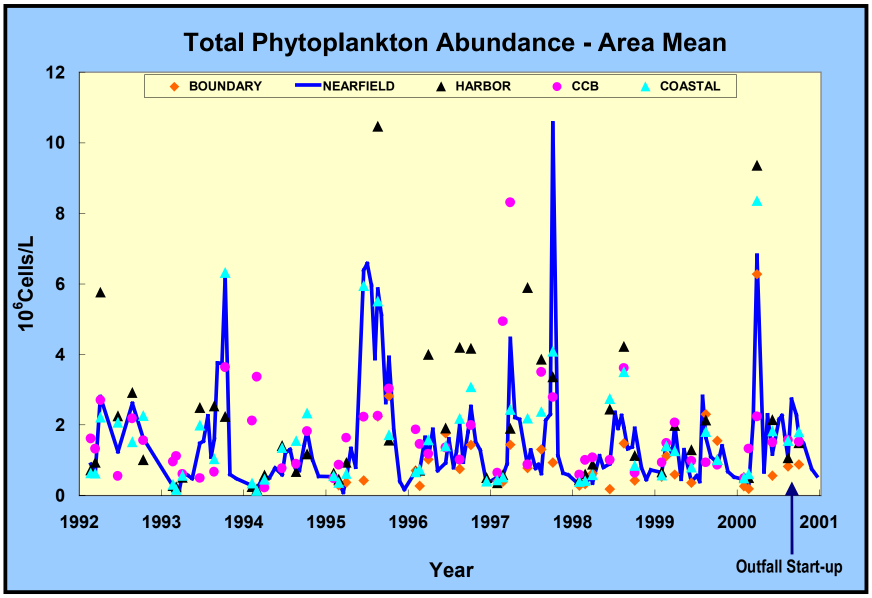

Figure 3-10. Survey mean phytoplankton abundance, 1992-2000

The assemblages of phytoplankton species were also typical for the baseline period. Except for the *Phaeocystis* bloom, unidentified microflagellates and centric diatoms dominated the first part of the year. Microflagellates, cryptomonads, and the diatom *Leptocylindrus danicus* dominated the latter part of the year.

Throughout the baseline period, microflagellates have numerically dominated whole-water samples throughout the year and have been more abundant during the summer than the winter. Diatoms, including *Chaetoceras debilis, C. socialis*, *Thalassiosira nordenskioldii*, and *T. rotula* are also abundant in the winter. During some years, such as 2000, *Phaeocystis* blooms during the spring. In other years, diatoms, the dinoflagellate *Heterocapsa rotundatum*, and cryptomonads dominate during the spring. During the summer, when microflagellates are at peak abundance, cryptomonads and the diatoms *Skeletonema costatum*, *Leptocylindrus danicus*, *Rhizosolenia delicatula*, *Cerataulina pelagica*, and several small species in the genus *Chaetoceros* are present. Crypotomonads, gymnodinoid dinoflagellates, and diatoms, including *Asterionellopsis glacialis*, *Rhizosolenia delicatula*, *Skeletonema costatum*, *Leptocylindrus danicus*, *L. minimus*, are abundant in the fall (Figure 3-7; Libby *et al.* 2001).

Outbursts of single-species blooms have occurred several times throughout the baseline period. *Phaeocystis* blooms occurred in 1992, 1994, 1997, and 2000. There was a bloom of the diatom *Asterionellopsis glacialis* in the fall of 1993, and there have been periodic summer and fall outbursts of *Ceratium* spp. These blooms have been intermittent but dramatic.

Occurrence of potentially toxic nuisance species was rare during 2000, as it has been for most of the baseline period. The dinoflagellate *Alexandrium tamarense*, the cause of PSP or red tide, was recorded only sporadically through the year, although Maine saw its greatest incidence of PSP toxicity in more than 10 years, and some toxicity was measured on the North Shore. The diatoms *Pseudo-nitzschia* spp. were also recorded only sporadically and in lower numbers than in 1999.

A. tamarense has been recorded in trace but not abundant amounts throughout the baseline period. The frequency of sampling by the general MWRA program may not be appropriate for monitoring this toxin-producing species; programs that target *A. tamarense* during the red-tide season tend to record higher abundances.

Consequently, MWRA also evaluates data from a targeted program directed by Donald M. Anderson at the Woods Hole Oceanographic Institution. *A. tamarense* blooms are thought to originate from seedbeds to the north of Massachusetts Bay and be transported southward by currents. These blooms only occasionally reach Massachusetts Bay when northeast winds cause downwelling conditions and press the Maine coastal current along the shoreline (Figure 3-11, Anderson *et al.* in press). The southwest winds and upwelling conditions that predominated during the summer of 2000 were not conducive to the presence of *A. tamarense* in Massachusetts Bay.

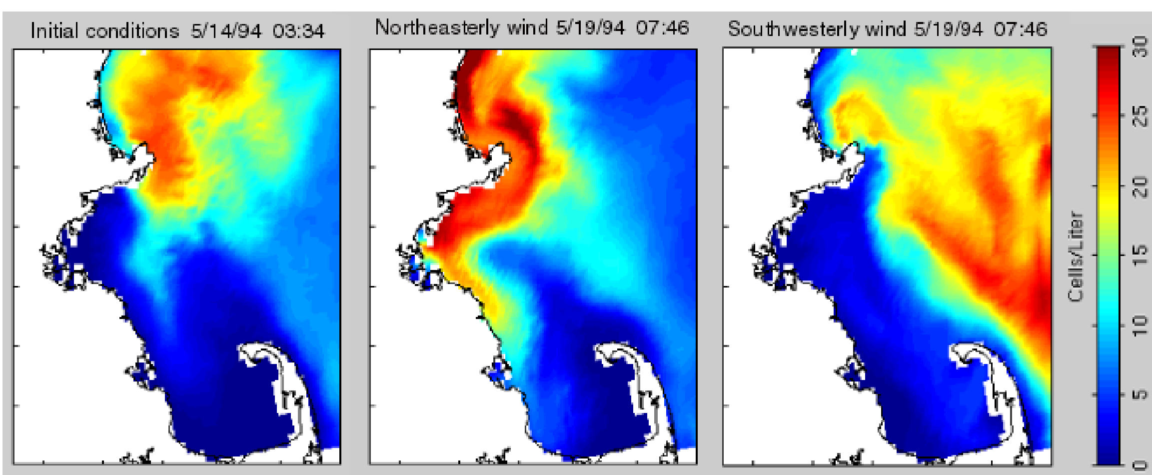

Figure 3-11. Model results indicate that A. tamarense *blooms originate to the north of Massachusetts Bay and are only transported into the bay when winds are from the northeast (Anderson* et al. *in press). The first panel depicts initial conditions, with a bloom occurring north of Massachusetts Bay. The second panel shows conditions five days later if there are northeast winds. The third panel shows conditions five days later if there are southwest winds.*

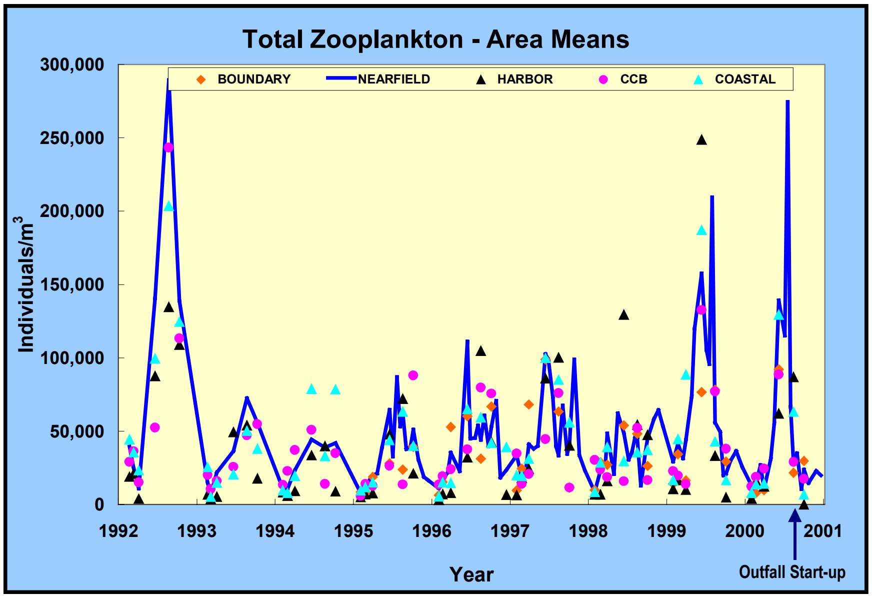

Figure 3-12. Survey mean zooplankton abundance, 1992-2000

Zooplankton Communities

Abundance of zooplankton was high in 2000 (Libby *et al.* 2001; Figure 3-12). Abundance steadily increased from February through July. In the nearfield, total counts in June were among the highest measured in the baseline period, partially due to the presence of planktonic bivalve larvae, which comprised up to 64% of the total individuals at some stations. Total abundances began to decline in early August.

Overall, zooplankton assemblages were similar in the nearfield and the farfield. From February through May, communities were dominated by juvenile copepods, including the small species *Oithona similis*, and the larger species *Pseudocalanus* spp. and *Calanus finmarchicus*. Barnacle larvae were common in April. Bivalve veligers began to be common in the nearfield in May, and in June they dominated many samples. Copepod nauplii and copepodites remained common throughout the year.

The copepods *Acartia* spp. (*Acartia hudsonica* and *Acartia tonsa*), which are typically abundant in Boston Harbor but which were unusually sparse in 1999, rebounded in 2000. Their decline and rebound gave further credence to the theory that these species were affected by the high salinities noted during a drought in 1999. *Acartia* spp. was once thought to be responsive to nutrient loading and therefore a good indicator species for the monitoring program. That relationship has been in doubt for several years; data from the literature, supported by baseline-monitoring data have indicated that salinity rather than nutrient loading limits *Acartia* spp. abundance.

One major event for zooplankton communities, decimation of Boston Harbor zooplankton populations by the ctenophore *Mnemiopsis leidii*, occurred in the fall. Ctenophores are gelatinous carnivores that feed voraciously on copepods and other zooplankton. Normally thought to occur only south of Cape Cod, *Mnemiopsis* had never been noticed in the harbor-and-outfall monitoring program. In 2000, *Mnemiopsis* became abundant in the harbor and adjacent coastal regions in October. Zooplankton populations plummeted, as they have in other coastal areas when ctenophores are present. Overgrazing of the zooplankton populations may have contributed to the fall phytoplankton bloom in the harbor and the coastal area.

Contingency Plan Thresholds

Threshold parameters for water-column monitoring include minimum dissolved oxygen concentrations and percent saturation in nearfield and Stellwagen Bank bottom waters, dissolved oxygen depletion rate in nearfield bottom waters, chlorophyll levels, abundance of nuisance algal species, geographic extent of PSP toxin, and initial dilution (Table 3-1). Baseline monitoring was completed for the water column thresholds at the end of August 2000. Those data were used to calculate the threshold values described in the contingency plan, as revised in May 2001.

Fall 2000 marked the end of the baseline period, completing the data set for MWRA to calculate the threshold values that will be used to compare monitoring results to baseline conditions. Those parameters include background levels for dissolved oxygen concentrations and percent saturation in bottom waters of the nearfield and Stellwagen Basin, oxygen depletion rate, annual and seasonal chlorophyll levels in the nearfield, and seasonal abundance for the nuisance algae *Phaeocystis* and *Pseudo-nitzschia*.

In 1997, Outfall Monitoring Task Force recommended deleting bottom dissolved oxygen saturation as a threshold parameter, because baseline conditions frequently fell below the thresholds that had been fixed by state standards, both in the nearfield and in Stellwagen Basin. EPA and MADEP declined to accept this recommendation but in 2001 suggested adding the phrase "unless background conditions are lower" to the descriptions of both dissolved oxygen concentration and dissolved oxygen saturation, bringing the threshold into closer conformity with the state standard. MWRA has calculated those background conditions as follows: 5.75 mg/l dissolved oxygen in the nearfield. 6.2 mg/l dissolved oxygen in Stellwagen Basin, 64.3% saturation in the nearfield, and 66.3% saturation in Stellwagen Basin.

Table 3-1. Contingency Plan threshold values for water column monitoring

Location/ Parameter	Specific Parameter	Baseline	Caution Level	Warning Level
Bottom water nearfield	Dissolved oxygen concentration	Background 5th percentile 5.75 mg/l	Lower than 6.5 mg/l for any survey (June-October) unless background conditions are lower	Lower than 6.0 mg/l for any survey (June-October) unless background conditions are lower
	Dissolved oxygen percent saturation	Background 5th percentile 64.3%	Lower than 80% for any survey (June-October) unless background conditions are lower	Lower than 75% for any survey (June-October) unless background conditions are lower
Bottom water Stellwagen Basin	Dissolved oxygen concentration	Background 5th percentile 6.2 mg/l	Lower than 6.5 mg/l for any survey (June-October) unless background conditions are lower	Lower than 6.0 mg/l for any survey (June-October) unless background conditions are lower
	Dissolved oxygen percent saturation	Background 5th percentile 66.3%	Lower than 80% for any survey (June-October) unless background conditions are lower	Lower than 75% for any survey (June-October) unless background conditions are lower
Bottom water nearfield	DO depletion rate (June-October)	0.0244 mg/l/d	0.037 mg/l/d	0.049 mg/l/d
Chlorophyll nearfield	Annual	71 mg/m^2	107 mg/m^2	143 mg/m^2
	Winter/spring	81 mgml^2	182 mg/m^2	None
	Summer	51 mg/m^2	80 mg/m^2	None
	Autumn	90 mg/m^2	161 mg/m^2	None
Nuisance algae nearfield *Phaeocystis pouchetii*	Winter/spring	470,000 cells/l	2,020,000 cells/l	None
	Summer	7.2 cells/l	334 cells/l	None
	Autumn	300 cells/l	2,370 cells/l	None
Nuisance algae nearfield *Pseudonitzschia*	Winter/spring	6,200 cells/l	21,000 cells/l	None
	Summer	13,000 cells/l	38,000 cells/l	None
	Autumn	9,700 cells/l	24,600 cells/l	None
Nuisance algae nearfield *Alexandrium tamarense*	Any nearfield sample	Baseline maximum = 163 cells/l	100 cells/l	None
Farfield	PSP toxin extent	Never observed at certain southern Mass. Bay stations	New incidence	None
Plume*	Initial dilution	Not applicable	None	Effluent dilution less than 70:1

* 70:1 is the dilution used by EPA as the basis for MWRA's NPDES permit, to be certified by a dye dilution study in 2001

Chlorophyll threshold values are based on areal measurements, integrating data from 0.5-m depth intervals, rather than on the volume measurements that are typically used to discuss conditions on a finer scale. Had the thresholds been in place, fall chlorophyll concentrations for 1999 would have exceeded the fall caution threshold of 161 mg/m^2. Likewise, fall

2000 values exceeded the caution threshold. (Fall 2000 was not part of the baseline and is discussed further in Section 6, Outfall Monitoring.) However, both the 1999 and 2000 exceedances are important, because they reflect a general increase in fall chlorophyll levels that was recorded since 1998 throughout the region. Preliminary data indicate that the spring 2001 nearfield average chlorophyll concentration was well within the threshold.

In 2001, EPA and MADEP established an interim threshold of 100 cells/liter in any sample for *Alexandrium tamarense,* noting that the maximum count prior to the outfall startup was 163 cells/l. Paralytic shellfish poisoning toxicity is not generally observed until cell counts reach more than 300 cells/l.

MWRA also uses data from a Massachusetts Department of Marine Fisheries (DMF) monitoring program, which addresses extent of paralytic shellfish poison toxicity in the area. The program traditionally has been conducted from early April through November and has involved sampling of shellfish, primarily blue mussels, from 16 primary stations and, if significant toxin is measured at the primary sites, 47 secondary stations. PSP toxin was not detected in bay waters in 2000.

4. Sea Floor Baseline

Background

This section presents results of sea floor monitoring for the year 2000, focusing on the completion of the baseline period, which ended on September 6, 2000. Data from September through December are actually in the discharge-monitoring period and are discussed in more detail in Section 6, Outfall Monitoring.

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 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 meters high, with crests covered by gravel and boulders. Long-term sinks for fine-grained sediments include Boston Harbor, Cape Cod Bay, and Stellwagen Basin (USGS 1997a, 1998).

Sediment transport in the region occurs primarily during storms. Typically, waves during storms with winds from the northeast resuspend sediments, which are transported by shallow currents from western Massachusetts Bay toward Cape Cod Bay and by deeper currents to Stellwagen Basin, where they are likely to remain. Cape Cod Bay is partially 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

Within Boston Harbor, studies of the sediments are documenting recovery following the cessation of sludge discharge, improvements to CSO systems, and improved sewage effluent treatment. Conversely, relocating the outfall has introduced concerns about potential effects on the offshore sea floor. Concern is focused on three issues: eutrophication and related low levels of dissolved oxygen, accumulation of toxic contaminants in depositional areas, and smothering of animals by particulate matter.

If transfer of the nutrient loads to offshore were to cause eutrophication, depressed levels of dissolved oxygen could profoundly affect bottom communities. Increasing the amount of particles and organic matter to the bottom could disrupt normal benthic community structure in the vicinity of the discharge. 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 and in Cape Cod Bay and Stellwagen Basin. Similarly, concentrations of particulate matter are expected to be low, but there remains some concern that bottom communities near the outfall could be affected by deposition.

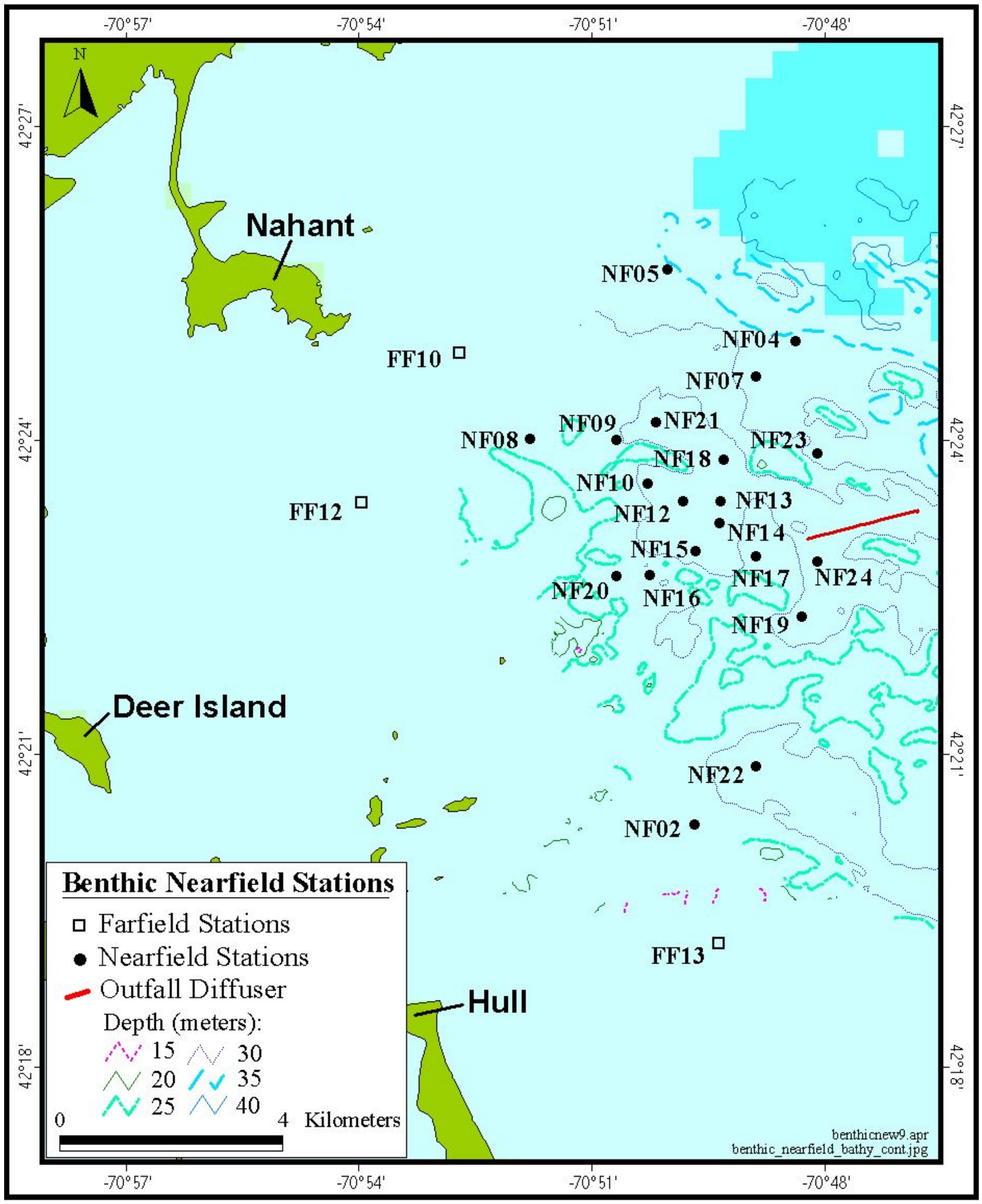

Figure 4-1. Locations of nearfield soft-bottom stations (NF12 and NF17 are also sampled by USGS)

Monitoring Design

Sea floor monitoring includes several components: measurements of contaminant concentrations and other chemistry parameters in sediments, sediment-profile imaging to provide a rapid assessment of potential effects, studies of nearfield and farfield soft-bottom communities (sampling sites in Figures 4-1, 4-2), and study of hard-bottom communities (sampling sites in Figure 4-3).

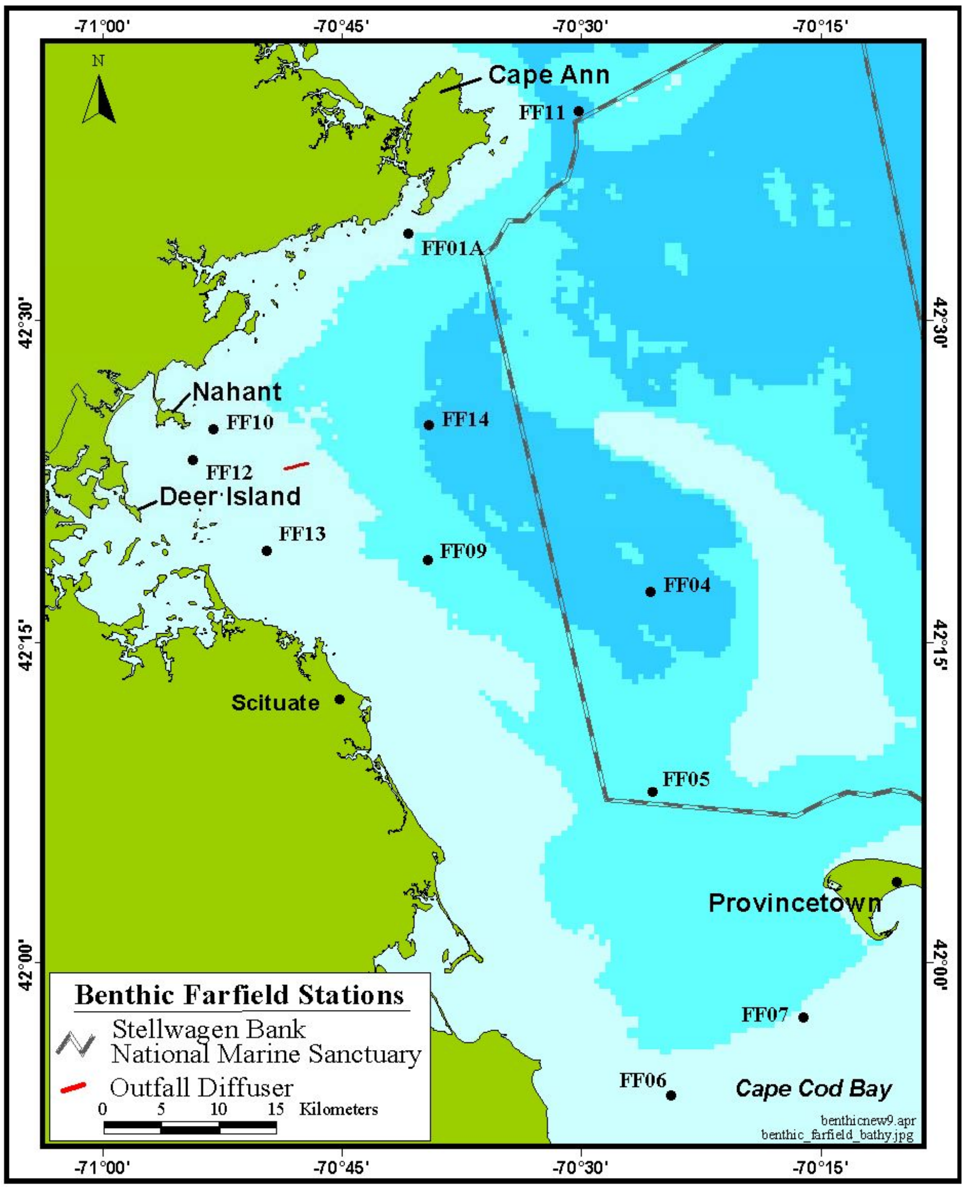

Figure 4-2. Locations of farfield soft-bottom stations

In addition to MWRA's outfall monitoring, long-term studies of sediment transport and contaminant levels in Boston Harbor, Massachusetts Bay, and Cape Cod Bay are conducted by USGS. Since 1977, USGS has periodically sampled four stations within Boston Harbor, and since 1989 they have taken sediment cores three times a year from two stations, one sandy and one muddy, near the Massachusetts Bay outfall (USGS 1997b; Figure 4-1).

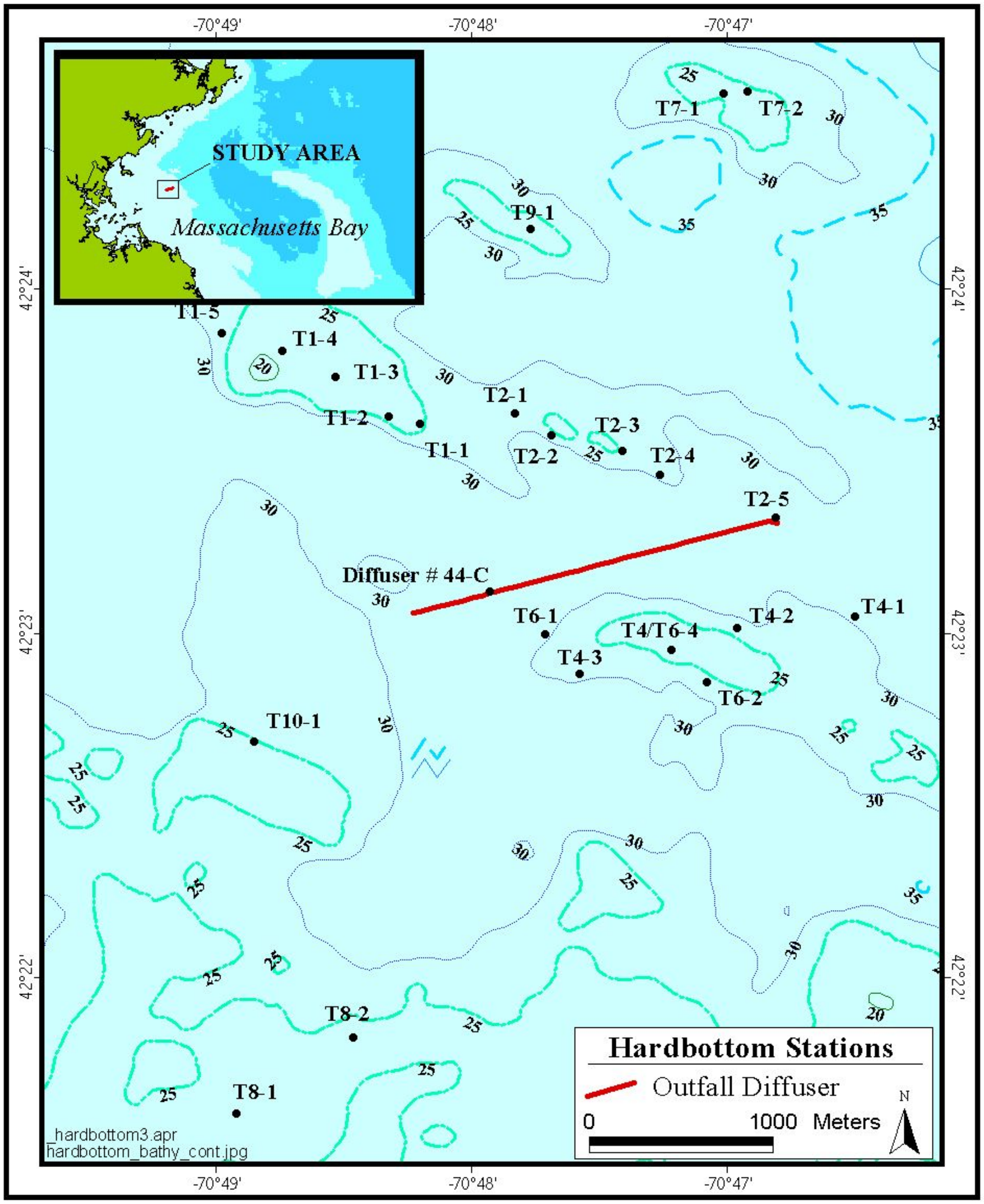

Figure 4-3. Locations of hard-bottom transects

Because concentrations were consistently low, the MWRA baseline sediment-contaminant studies were considered adequate after 1995. However, when outfall start-up was delayed, additional sampling was conducted. In 1998, a "special contaminant study" was resumed at four stations. The stations included in this study were selected because they have a high percentage of fine-grained material, with those percentages remaining stable during the monitoring period. They have high concentrations of total organic carbon (TOC) and are located in the zone of effluent particle deposition predicted by the Bays Eutrophication Model. Should it occur, data from these stations would provide early indications of any contaminant build-up.

Prior to the startup of the outfall, the stations were sampled once per year, in August. Starting in late 2000, because the outfall began operation, they are being sampled three times per year, in April, August, and October. (Results from the October 2000 survey are discussed in Section 6, Outfall Monitoring.) Samples are 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 three farfield, western Massachusetts Bay, 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 at to which oxygen penetrates, known as the oxidation-reduction potential discontinuity (RPD). Later, complete analyses of films provide information on prism penetration, surface relief, apparent color RPD depth, sediment grain size, sediment layering, fauna and structures, and successional stage of the soft-bottom animal communities.

Nearfield and farfield soft-bottom surveys are also conducted in August. Sampling of 23 nearfield and western Massachusetts Bay stations is designed to provide spatial coverage and local detail about the fauna in depositional areas located within eight kilometers of the diffusers. Farfield sampling of eight additional stations in Massachusetts and Cape Cod bays contributes reference data on soft-bottom habitats. Samples are analyzed for community parameters, *Clostridium perfringens* spores, sediment grain size, TOC content, and contaminant concentrations.

While most studies of benthic communities, including the MWRA monitoring program, focus on the soft bottom areas with finer-grained sediments, such depositional areas are few 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 4-3). Video and still photographs are taken at waypoints along 6 transects, at Diffuser Head #44 of the outfall (which will not be opened), and at Diffuser Head #2. These surveys are conducted annually in June. Photographs are examined for substrate type, amount of sediment drape, and biota.

Results

August 2000 marked the completion of sediment sampling for the baseline period. Baseline monitoring of hard-bottom areas was completed in June 2000.

Sediment Contaminants

Spatial distribution of sediment grain-size patterns and TOC content from sediments taken as part of the special contaminant study and the soft-bottom community surveys remained stable in 2000, with no substantial change from 1992 through 2000 (Kropp *et al.* 2001). Within the nearfield (including farfield stations inshore from the outfall site), TOC was slightly elevated but within the historic range.

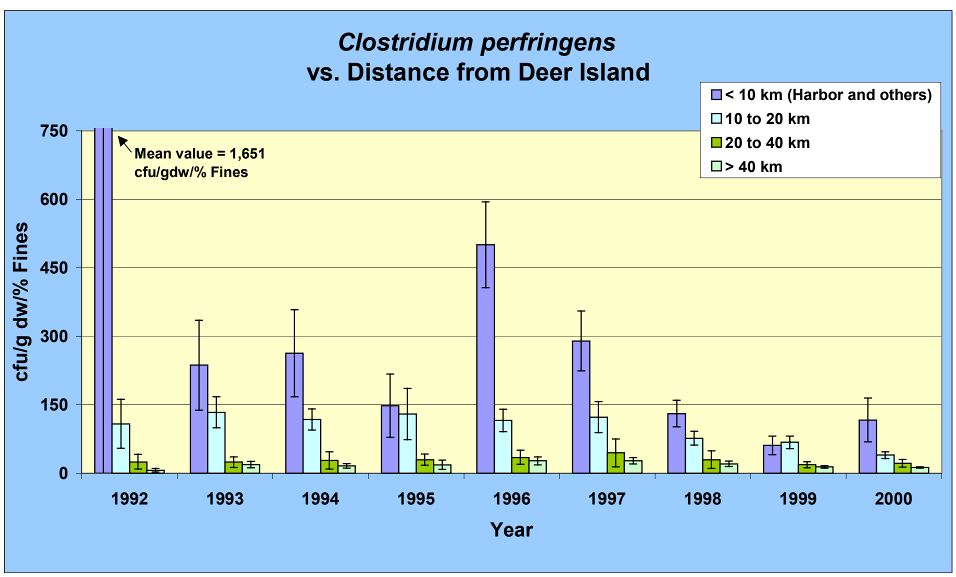

Figure 4-4. There is a gradient of decreasing C. perfringens spores with distance from Deer Island and a decrease at Deer Island since the mid 1990s. Data are normalized to percent fine-grained particles.

Concentrations of organic and inorganic contaminants in sediments sampled during 2000 remained very low, well below established EPA or NOAA guidelines. Concentrations of organic contaminants and some metals (mercury, silver, copper, and cadmium) were, as in previous years, lower in the farfield than in the nearfield. Concentrations of lead and chromium were similar in both regions.

During the early 1990s, USGS studies documented a decrease in concentrations of *Clostridium perfringens* spores with increasing distance from Boston Harbor (Parmenter and Bothner 1993). Analysis of MWRA baseline data from 1992 through 2000 found a similar pattern, consistent with the USGS findings (Figure 4-4). This pattern has been thought to reflect inshore sewage effluent discharge—concentrations of the sewage indicator decreased with increasing distance from Deer Island.

Storms can also affect concentrations of contaminants in the sediments (USGS 1997b). Concentrations of silver, *Clostridium perfringens* spores, inventories of natural radioisotopes, and sediment texture in samples from Massachusetts Bay stations changed abruptly between surveys conducted during October of 1992 and February of 1993. USGS attributes these changes to a December 1992 storm, which probably transported near-shore sediments to the offshore. Sediment-trap studies currently underway may provide better information on the effects of short-term events on concentrations of contaminants within the sediments.

Figure 4-5. Typical sediment profile image

Sediment Profile Imaging

Baseline sediment-profile imaging surveys were conducted in 1992, 1995, and 1997-2000 (Kropp *et al.* 2001). The surveys have focused on areas with fine-grained sediments, and for most of the monitoring period, most sampling stations have had fine sand to silty-fine sand as the dominant sediment type (Figures 4-5, 4-6). In 2000, some coarser sediments were found. The smallest sediment size at Station FF10, located just off Nahant, was gravel, and the finest sediments at several nearfield stations were sands. Bedforms, surface depositional patterns typically associated with high energy, sandy conditions, were noted at six stations. These findings indicate that in 2000, storms resuspended and transported sediments from at least some stations. However, homogeneous, fine-grained sediments were also found, particularly northwest and south of the outfall.

Assessment of the apparent RPD at many stations has often suffered from shallow penetration of the prism, particularly at stations with coarser sediments. In 2000, no image could be made at the gravel-and-pebble bottom at Station FF10. At the sandy stations, no images penetrated deeply enough to see the RPD layer. After accounting for these difficulties, the grand average depth to the RPD layer was unchanged from 1999 (Figure 4-6). Over the course of the entire baseline period, the RPD layer depth was shallower in 1997 and 1998, compared to the preceding and succeeding years.

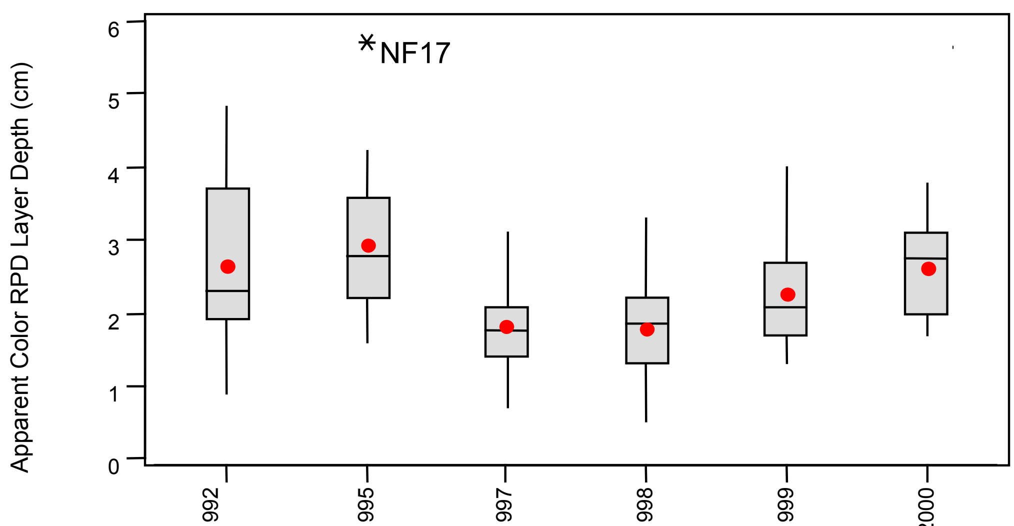

Figure 4-6. Apparent color RPD layer depth for all data from nearfield stations, including those for which the prism did not penetrate deeply enough. (Center bar is median, dot is mean, box is interquartile range, and whiskers are total range of the station data.)

Biologically, in 1992, 1995, and 1997, pioneering or "Stage I" communities prevailed in the nearfield. Stage II fauna became more prevalent in 1998-2000. Data from 1997 were collected later than in other years, and there is some evidence that the increasing trend in importance of biological processes may have begun in 1995. In 2000, the sediment surfaces continued to be dominated by biogenic structures and organism activity. Stations with fine-grained sediments had high densities of polychaete tubes, and the stations with coarser sediments were draped with fine sediments and covered with tubes, sponges, and hydroid-like organisms.

Soft-bottom Communities

Soft-bottom benthic communities have been distinguished throughout the monitoring program by their patchiness. Among individual nearfield samples collected in 2000, infaunal abundance varied four-fold (Kropp *et al.* 2001). As in previous years, annelid worms were the most abundant higher-level taxon at both nearfield and farfield stations, accounting for more than 80% of the fauna at 15 nearfield stations. Crustaceans and mollusks were the next most abundant fauna.

In the nearfield, the polychaete *Prionospio steenstrupi* was the most common organism at 16 stations. Other polychaetes that ranked as most common included *Dipolydora socialis, Exogone verugera*, *Mediomastus californiensis*, and *Exogone hebes*. Common amphipod crustaceans included *Crassicorophium crassicorne* and *Unciola inermis*. The most common mollusks were the northern dwarf-cockle *Cerastoderma pinnulatum* and the nutclam *Nucula delphinodonta*. Common polychaetes in the farfield included *Prionospio steenstrupi*, *Cossura longocirrata*, *Euchone incolor*, and *Spio limicola*. Multivariate analyses indicated that the grouping by which stations can be sorted was very similar to previous years. As in previous years, the grouping reflected sediment type and biogenic activity as the major factors structuring the communities.

Annual measurements of community parameters have shown somewhat similar patterns in the nearfield and farfield (Figure 4-7). In the nearfield, the baseline-monitoring years can be divided into two periods: the early years from 1992-1996 when the infaunal community was in flux and the later years when the community has remained relatively constant. The changing communities in the early years are thought to result from the severe winter storm in 1992. The effects of the storm were evident in the two community parameters that are measured directly, total abundance of organisms and total number of species, and in one of the calculated indices, log-series alpha. Two other indices, Shannon diversity, and Pielou's evenness, did not detect any change from the storm, and these measures may also prove less likely to detect any potential effect of the outfall.

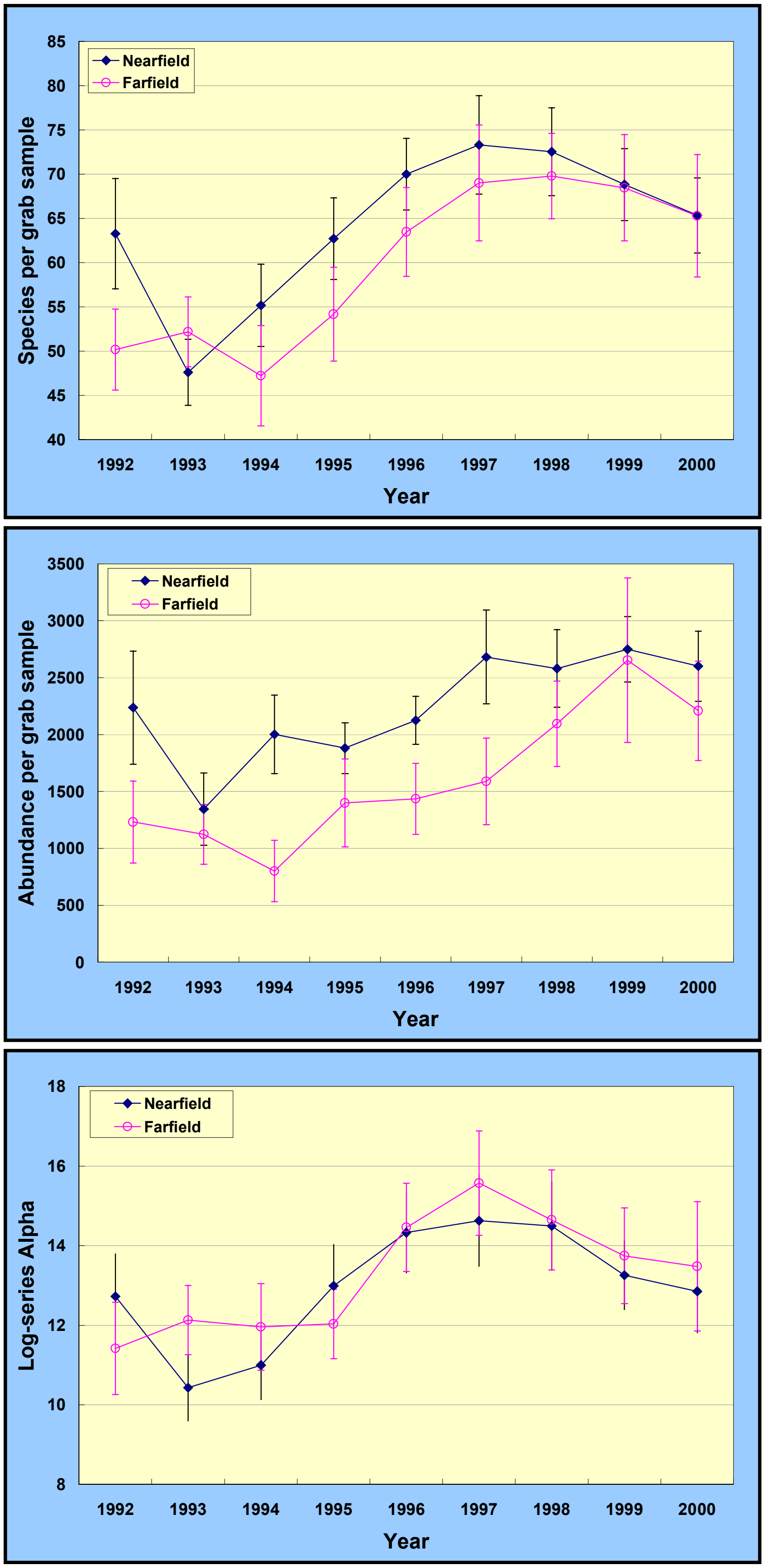

Figure 4-7. Community parameters for soft-bottom communities. Nearfield includes three western Massachusetts Bay farfield stations.

In the farfield, effects of the storm were not apparent. Total abundances were lowest in 1992-1994, increased in 1995-1997, and increased further in 1998-1999. Total number of species was low in 1992-1995, then rose to a peak in 1998. Log-series alpha followed a similar pattern.

Despite the apparent difference in nearfield and farfield response to the 1992 storm, overall patterns in the abundance of species appear to be bay-wide (Figure 4-8). Over all the years of monitoring, the mean number of species found throughout the bay has been quite stable, with a mean of 254 and a coefficient of variation of about eight percent. Despite large changes in species richness per sample, overall variability has been small. Such patterns of large-scale consistency in species richness despite considerable small-scale and year-to-year patchiness have been documented for many plant and animal communities (Brown *et al.* 2001).

Any future substantial change in rate of disappearance or appearance of species could indicate that a change in the Massachusetts Bay system has occurred. Recognizing that a change in species richness could be interpreted as an effect of the outfall, MWRA will continue to compare trends observed in the nearfield with those observed in the farfield.

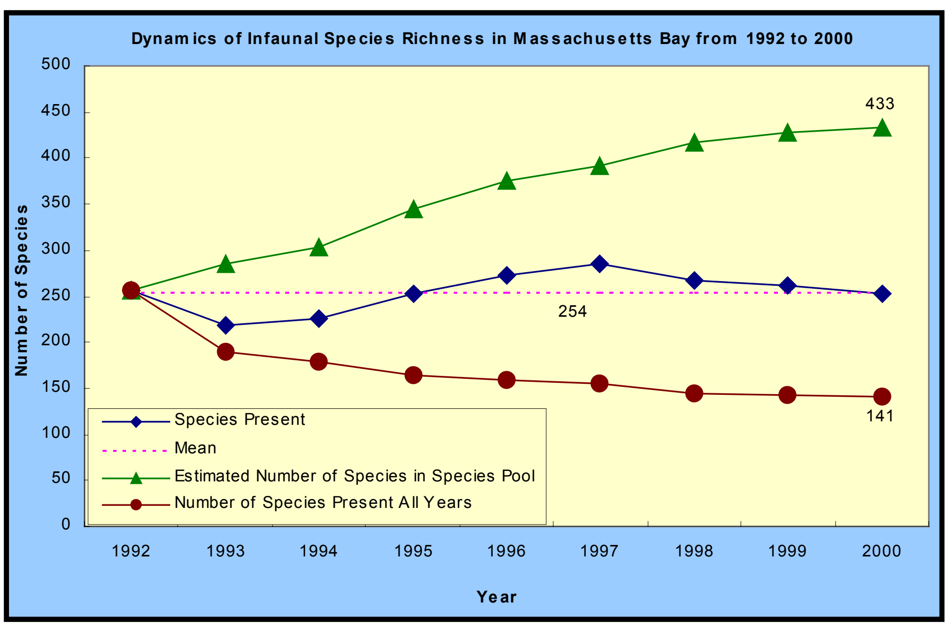

Figure 4-8. Patterns of species abundance in Massachusetts Bay

Hard-bottom Communities

Baseline monitoring of the hard bottom in the vicinity of the outfall has documented locally variable but temporally stable communities (Figure 4-9, Kropp *et al.* 2001). Visibility was poor during the June 2000 survey, due to a high amount of suspended matter in the water column. (June was very rainy, and a northeaster, which dropped 4 inches of rain on Boston, occurred 2-3 weeks before the survey.) Consequently, fewer taxa could be seen clearly in the video and still photography. Nevertheless, the data analysis continues to show the temporally stable pattern that has been observed in past years.

As in previous years, approximately half the organisms seen could be identified to species. Other organisms were grouped into taxa that could be described by general characteristics, such as "orange-tan encrusting." Sixty-five species and grouped taxa were identified in 2000. The most abundant taxon was, as in previous years, coralline algae. Direct collections made in September 2000 confirmed that this taxon is made up of at least 5 species, including *Leptophytum laevae*, *Leptophytum foecundum*, *Phymatolithon laevigatum*, *Phymatolithon lamii*, and *Lithothamnion glaciale*. Other common algae included dulse *Rhodymenia palmata* and a red, filamentous alga *Ptilota serrata*. Shotgun kelp *Agarum cribosum* was very abundant at one waypoint, where it was typically overgrown by an organism that appeared to be a lacy bryozoan.

The most abundant invertebrate was the northern seastar, *Asterias vulgaris*, which was found at all waypoints. Other common invertebrates included an unidentified orange or tan sponge, the horse mussel *Modiolus modiolus*, three species of tunicates, and the blood sea star *Henricia sanguinolenta*. Anemones are especially abundant on the smooth surface of the outfall diffuser that is included in the monitoring. The most common fish was the cunner *Tautogolabrus adspersus*, which was seen at all waypoints.

There was no indication that the amount of sediment drape was greater in 2000 than in prior years, despite the high amounts of particulate matter in the water column that obscured the images. These findings suggest that the particulate matter in the water column was not part of a long-term event, but more likely resulted from runoff and resuspension during the northeaster that occurred 2-3 weeks before the survey.

As in previous years, algae usually dominated the tops of drumlins, while encrusting or attached invertebrates were increasingly dominant on the flanks. Abundance of encrusting coralline algae has been inversely correlated with sediment drape throughout the baseline-monitoring program, percent cover being greatest in areas with the least sediment.

This relationship is not surprising, because an encrusting growth form makes organisms susceptible to smothering. Consequently the coralline algae may be good indicators of outfall effects. The overall similarities among the 6 surveys conducted in 1996-2000 indicate that a substantial departure from the baseline should be readily apparent. Should solid material discharged from the outfall accumulate in the vicinity, a marked decrease in the percent cover by coralline algae may be expected. Changes in light penetration or water clarity would also reduce coverage by coralline algae.

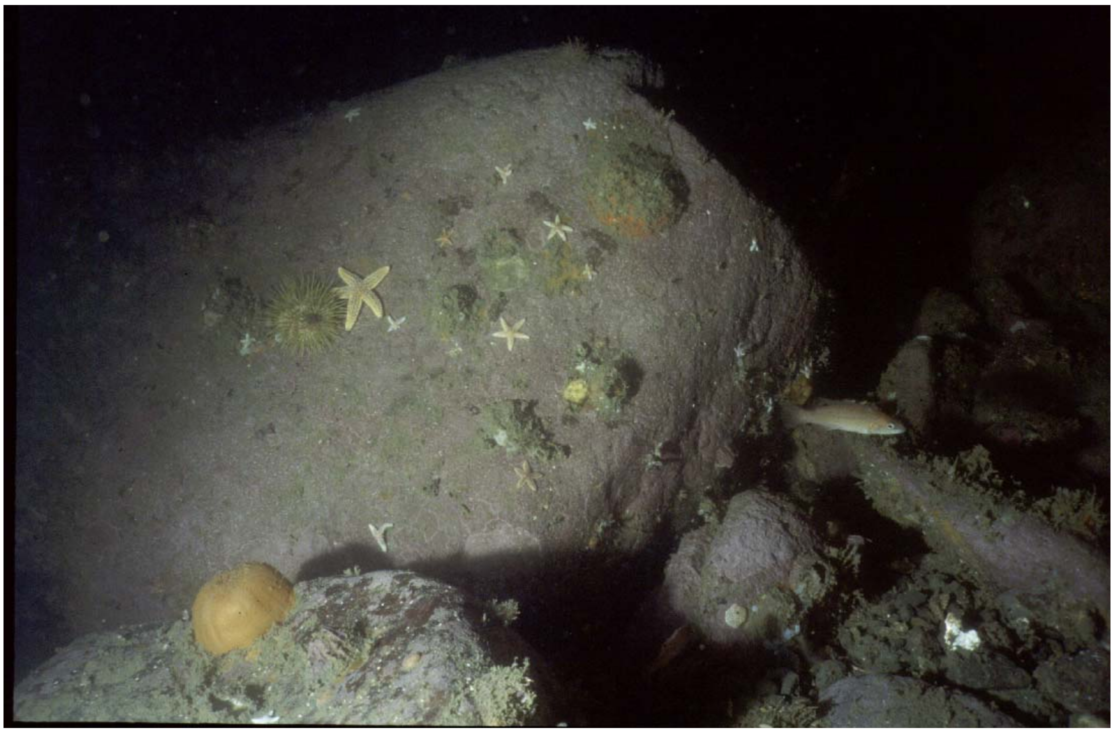

Figure 4-9. Hard-bottom survey photograph from Transect 1, located about 1000 m north of the outfall. Boulder and cobbles with very light sediment dusting and 80% coralline algae cover.

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). Baseline monitoring for these threshold was completed in August 2000. Those data were used to calculate the thresholds as described in the contingency plan.

Table 4-1. Contingency Plan baseline and threshold values for sea floor monitoring

Location	Parameter	Baseline Mean	Caution Level	Warning Level
Sediment toxic contaminants, nearfield	Acenaphthene	30 ppb dry	None	500 ppb dry
	Acenaphylene	48 ppb dry	None	640 ppb dry
	Anthracene	151 ppb dry	None	1100 ppb dry
	Benz(a)pyrene	278 ppb dry	None	1600 ppb dry
	Benzo(a)pyrene	258 ppb dry	None	1600 ppb dry
	Cadmium	0.2 ppm dry	None	9.6 ppm dry
	Chromium	76 ppm dry	None	370 ppm dry
	Chrysene	255 ppb dry	None	2800 ppb dry
	Copper	24 ppm dry	None	270 ppm dry
	Dibenzo(a,h)anthracene	37 ppb dry	None	260 ppb dry
	Fluoranthene	558 ppb dry	None	5100 ppb dry
	Fluorene	50 ppb dry	None	540 ppb dry
	Lead	44 ppm dry	None	218 ppm dry
	Mercury	0.24 ppm dry	None	0.71 ppm dry
	Naphthalene	70 ppb dry	None	2100 ppb dry
	Nickel	17 ppm dry	None	51.6 ppb dry
	p,p’-DDE	0.8 ppb dry	None	27 ppm dry
	Phenanthrene	349 ppb dry	None	1500 ppb dry
	Pyrene	516 ppb dry	None	2600 ppb dry
	Silver	0.6 ppm dry	None	3.7 ppm dry
	Total DDTs	3.5 ppb dry	None	46.1 ppb dry
	Total HMWPAH	3559 ppb dry	None	9600 ppb dry
	Total LMWPAH	1639 ppb dry	None	3160 ppb dry
	Total PAH	5199 ppb dry	None	44792 ppb dry
	Total PCBs	17 ppb dry	None	180 ppb dry
	Zinc	61 ppm dry	None	410 ppm dry
Sediments, nearfield	RPD depth	2.36 cm	1.18 cm	None
Benthic diversity, nearfield	Species per sample	64.52	<47.95 or >81.09	None
	Fisher’s log-series alpha	13.00	<10.13 or >15.58	None
	Shannon diversity	3.67	<3.32 or >4.02	None
	Pielou’s evenness	0.62	<0.56 or >0.67	None
Species composition, nearfield	Percent opportunists	0.75%	10%	25%

With the completion of baseline sediment-profiling images, it is clear that the number of sampling stations included in the program is adequate to readily detect a caution level of decline in the RPD depth to half of its baseline level. Levels measured have ranged from 1.73 cm in 1998 to 3.02 measured in 1995. None of these measurements approached the caution level of a lessening of the RPD by half.

The caution level for changes in species diversity has been set by the 2001 revision of the contingency plan as “appreciable change” from the baseline. Also in 2001, OMSAP further defined that threshold as the 2.5th and 97.5th percentiles of four baseline measurements: total species, Fisher's log-series alpha, Shannon diversity, and Pielou's evenness. None of the thresholds would have been crossed during the baseline period.

Caution and warning levels have also been set for the percentage of the infaunal community that is made up of species known to be "opportunists," that is, species that are found in environments that have been subjected to sudden change. MWRA recognizes seven species—three amphipods in the genus *Ampelisca* and three polychaetes and one bivalve—as opportunists of potential concern. Over the baseline period, mean percent occurrence of these species has ranged from 0.31 to 1.11% in the nearfield and from 0.10 to 1.00% in the farfield.

5. Fish and Shellfish Baseline

Background

This section presents the results of fish and shellfish monitoring for the year 2000. It marks the end of the baseline period, which ended when the Massachusetts Bay outfall began operation in September 2000.

Fisheries

The fish and shellfish industry is an important part of the regional identity and economy of Massachusetts. During 1999, commercial landings in Massachusetts totaled almost 200 million pounds, valued at more than $260 million (NMFS fisheries statistics for the most recent year for which data are available). More than 25% of the total value was attributed to the lobster fishery. Flounders, including winter flounder, made up almost 10% of the total value of the fishery. Although many shellfish beds are closed due to coastal bacterial contamination, the fishery for oysters and clams remains important to the region. The annual Massachusetts aquaculture fishery is valued at $5-10 million.

Recreational fishing is also important in coastal Massachusetts. There are approximately 240,000 recreational anglers living within Massachusetts coastal counties, and almost 3 million “angler trips” were taken in Massachusetts during 2000. Striped bass, bluefish, mackerel, and cod are the most popular sports fisheries within the Massachusetts territorial sea (NMFS recreational fisheries data for 2000), and flounders are also popular.

Environmental Concerns

One concern about relocating sewage effluent offshore, into relatively clean waters, is that contaminants could adversely affect resource species, either through direct damage to the fishery stocks or by contamination of the fish, lobster, and other shellfish, rendering them unfit for human consumption. Because many toxic contaminants adhere to particles, animals that live on the bottom, in contact with sediments, and 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, subtler, abnormalities in flounder, lobster, or other bottom-dwelling animals. Shellfish that feed by filtering suspended matter from large volumes of water are also potential bioaccumulators of toxic contaminants. These shellfish are themselves resource species, and are also prey to other fisheries species. Consumption of these animals by predators could result in transferring contaminants up the food chain and ultimately to humans.

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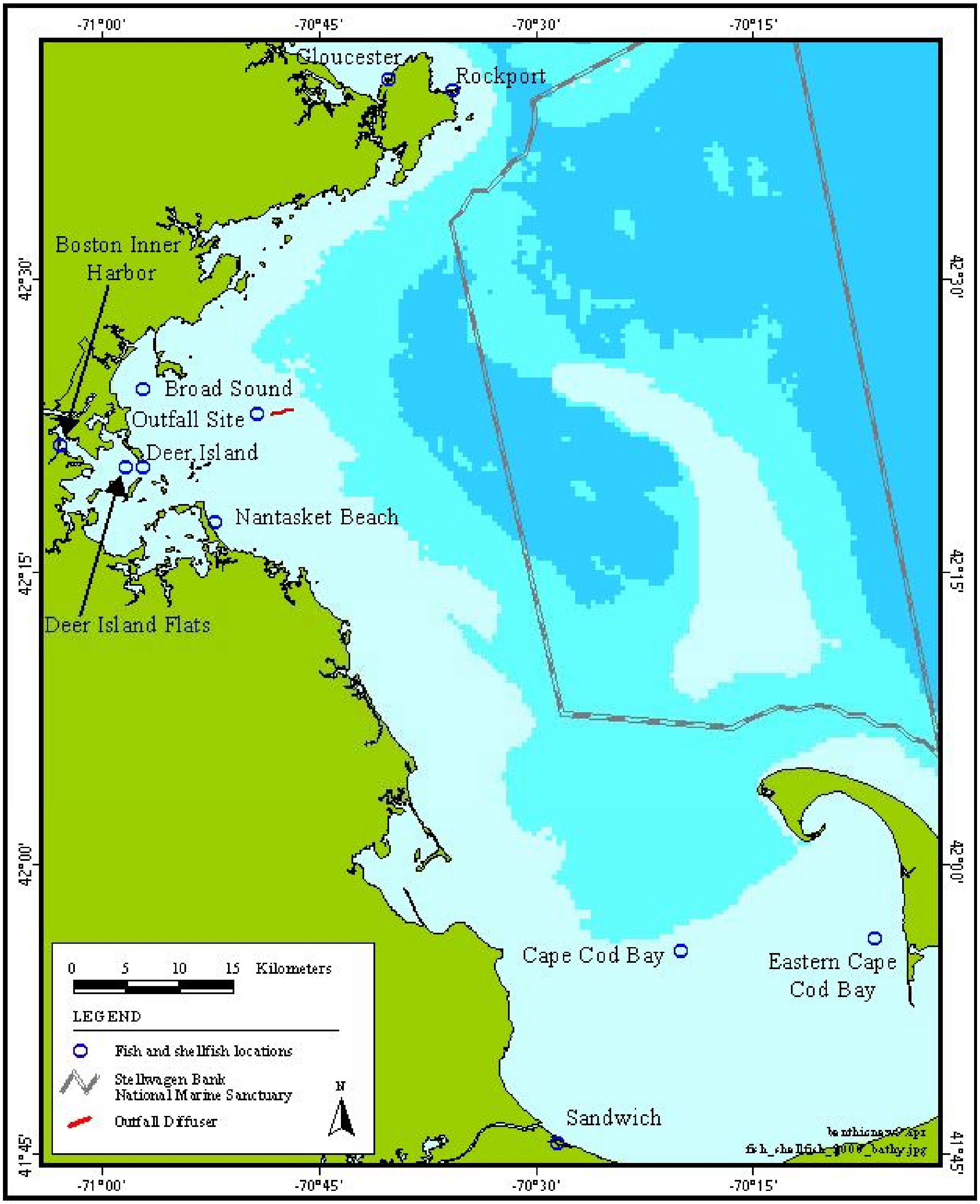

Figure 5-1. Sampling areas for fish and shellfish monitoring. Flounder are taken from Deer Island Flats, Broad Sound, off Nantasket Beach, the outfall site, and eastern Cape Cod Bay. Lobsters are taken from Deer Island Flats, the outfall site, and eastern Cape Cod Bay. In 2000, mussel arrays were deployed at Boston Inner Harbor, Deer Island, and the outfall site.

Monitoring Design

The monitoring program focuses on three indicator species: winter flounder, lobster, and blue mussel (Figure 5-1). Winter flounder and lobster are important resource species in the region. The blue mussel is also a fishery species and, when deployed in caged arrays, is a common biomonitoring organism.

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 five locations to obtain specimens for age determination, gross examination of health, and liver histology: Deer Island Flats, Broad Sound, off Nantasket Beach, the outfall site, and eastern Cape Cod Bay. Livers are examined to quantify three types of vacuolation (centrotubular, tubular, and focal, representing increasing severity), microphage aggregation, biliary duct proliferation, and neoplasia or tumors. These histology parameters have been associated with chronic exposure to contaminants.

Chemical analyses of winter flounder tissues from Deer Island Flats, the outfall site, and Cape Cod Bay are made to determine tissue burden and to evaluate whether contaminant burdens approach human health consumption limits. Chemical analyses of composite samples of fillets and livers include PCBs, pesticides, mercury, and lipids. Liver samples are also analyzed for PAHs, lead, silver, cadmium, copper, nickel, zinc, and lipids.

Lobsters live on a variety of surfaces within the region, including mud, sand, gravel, and rock outcrops. Commercial lobstermen collect lobsters for the monitoring program, with on-board scientists verifying the sampling locations. Lobsters are taken from Deer Island Flats, the area near the new outfall, and eastern Cape Cod Bay to determine specimen health and tissue contaminant burden. Chemical analyses are performed on composite samples. Meat (from the tail and claw) and hepatopancreas are analyzed for lipids, 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. Until 2000, mussels were collected from reference sites in Gloucester and Sandwich. Gloucester mussels provided a reference for organic contaminant analyses, and Sandwich mussels provided a reference for inorganic contaminants. Beginning in 2000, a new reference area, with low levels of both organic and inorganic contaminants, was identified in Rockport.

Mussels have been deployed in replicate arrays at as many as five sites, including the Boston Inner Harbor, Deer Island, Quincy Bay, the outfall site, and Cape Cod Bay. In 2000, arrays were deployed at Boston Inner Harbor, Deer Island, and the outfall site. After a minimum deployment of 40 days or a preferred deployment of 60 days, chemical analyses are performed on composite samples of mussel tissue. Tissues are analyzed for PCBs, pesticides, PAHs, mercury, and lead.

Results

Winter Flounder

Fifty sexually mature (4-5 years old) winter flounder were taken from four of the sampling sites in April 2000 (Lefkovitz *et al.* 2001). Only 26 fish were taken from Deer Island Flats, and high winds precluded additional sampling. Each of the fish was examined for physical characteristics. Fifteen fish from Deer Island Flats, the outfall site, and eastern Cape Cod Bay were designated for chemical analyses. All fish were used for histological analyses.

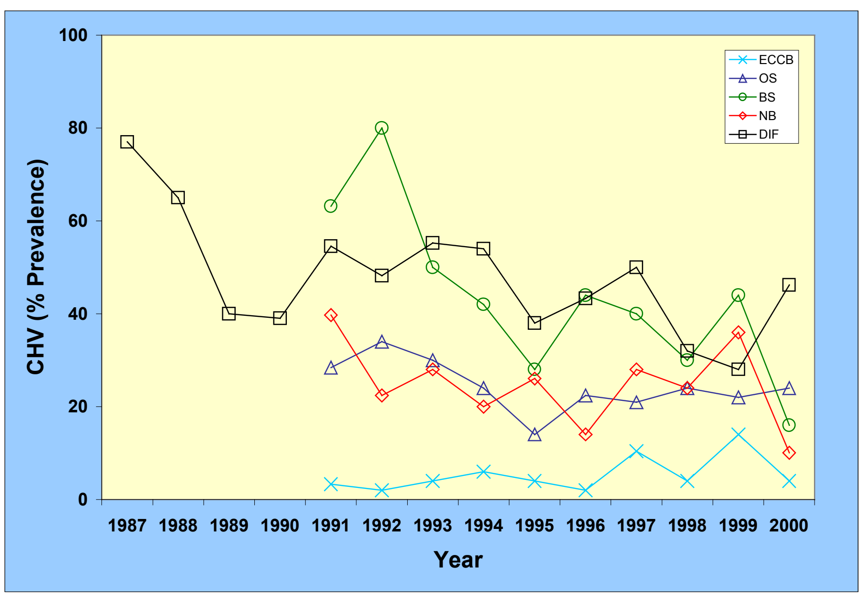

Figure 5-2. Prevalence of centrotubular hydropic vacuolation (CHV)

Overall, the fish appeared healthy, without the severe fin erosion that was prevalent in fish from Deer Island Flats in the mid- to late-1980s. Tumors were absent. As in previous years, the milder centrotubular hydropic vacuolation (CHV) was the most common form of vacuolation.

CHV prevalence at Deer Island Flats was higher than in 1999 (Figure 5-2), possibly because the 1999 Deer Island fish were collected in May rather than in April. As in previous years, there were no obvious relationships between age or length and lesion presence, indicating that differences among sampling areas are indicative of differences in environmental conditions.

Overall, body burdens of organic contaminants in edible tissues were similar to burdens in previous years (Figure 5-3). Total PCB and DDT (not shown) concentrations appear to have declined in fish from Deer Island Flats since 1995. Mercury concentrations in flounder fillets have been variable at all sites.

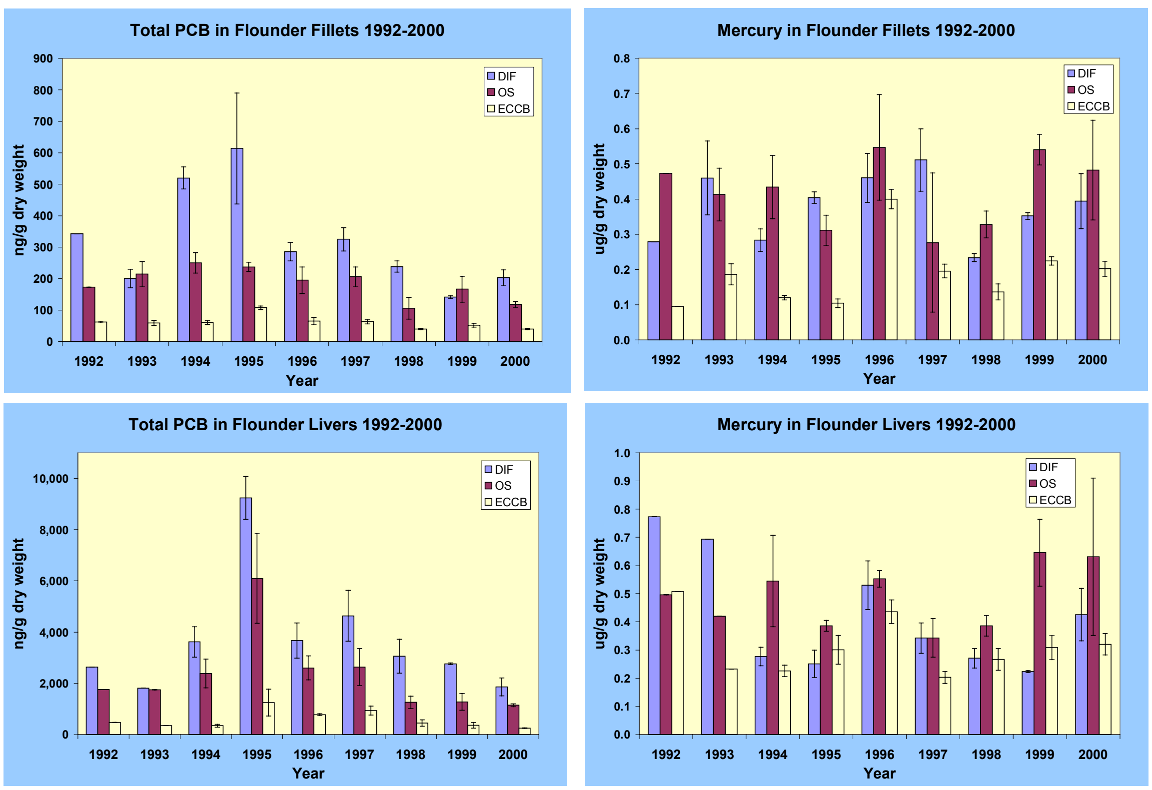

Figure 5-3. Concentrations of representative contaminants in flounder fillets and livers (DIF = Deer Island Flats, OS = Outfall Site, and ECCB = Eastern Cape Cod Bay)

Concentrations of organic contaminants in flounder livers were comparable to or lower than concentrations measured in prior years, and generally similar to 1999 measurements. Over all the years of sampling, concentrations of organic compounds have been highest in fish from Deer Island Flats and lowest in those from eastern Cape Cod Bay. Metals concentrations have been highest at the outfall site and eastern Cape Cod Bay. At the outfall site, concentrations of lead, mercury, cadmium, copper, and silver (only mercury shown) were at the upper end of the historical range. The concentration of lead in flounder livers from Deer Island Flats was the highest measured during the baseline period.

Lobster

Fifteen lobsters were taken from each sampling location during July and August (Lefkovitz *et al.* 2001). The lobsters were approximately the same weight and size at all sites. Mostly males were found at eastern Cape Cod Bay. Females predominated at Deer Island Flats and the outfall site. No gross abnormalities were noted in any of the lobsters collected during the survey. As in previous years, contaminant concentrations in lobster meat were low. The highest concentrations of most organic contaminants in tail and claw meat were found in lobsters taken from Deer Island Flats, and the lowest concentrations were found in lobsters taken from eastern Cape Cod Bay (Figure 5-4). Following a different pattern, mercury concentrations were highest in samples taken at the outfall site and lowest in those from Cape Cod Bay. This pattern has also been consistent throughout the baseline-monitoring period. Concentrations of mercury in the claw and tail meat were within the historical range.

The inter-regional pattern of organic contaminant burdens in lobster hepatopancreas was the same in 2000 as in prior years, with the highest concentrations in lobsters from Deer Island Flats. Overall, concentrations of organic compounds, including total PCBs and DDTs (not shown), were similar to or lower than those found in 1999, reversing a trend of increases during the 1990s. Total PAHs appear to have declined throughout the baseline period, although in 2000, levels were higher than those measured in 1998 and 1999 in lobsters from Deer Island Flats and the outfall site.

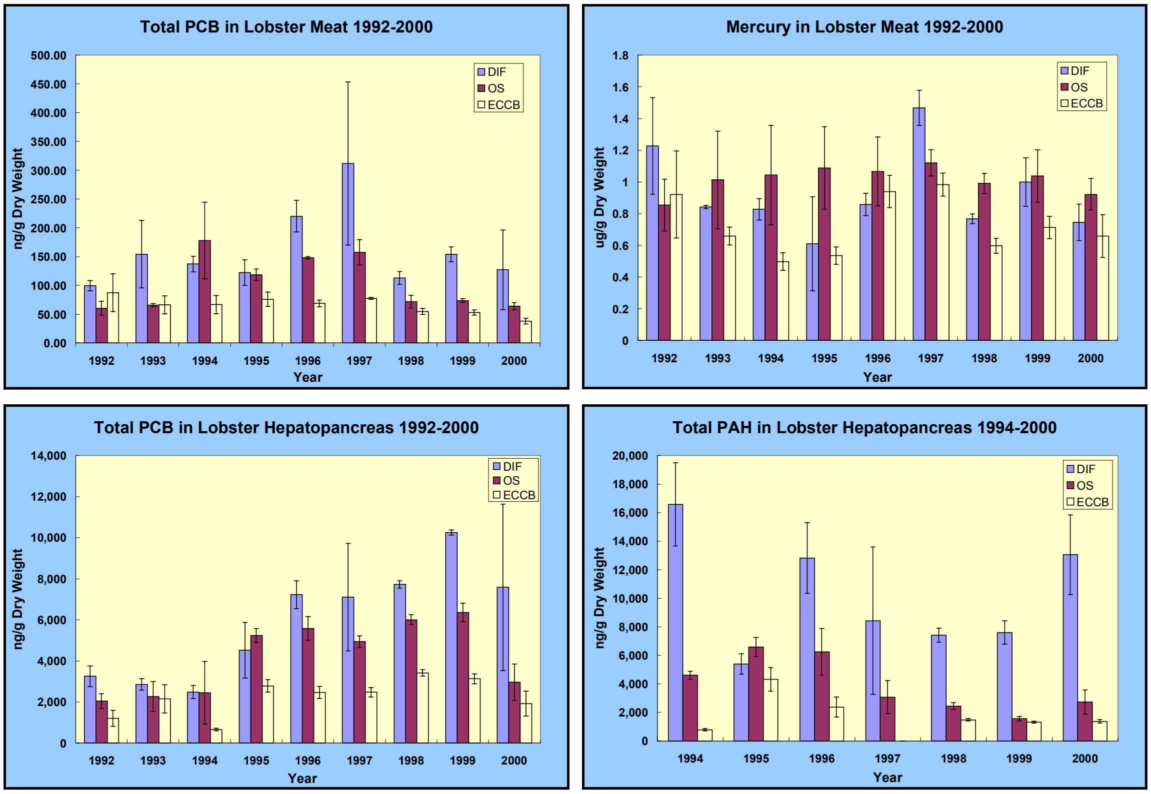

Figure 5-4. Concentrations of representative contaminants in lobster meat and hepatopancreas (DIF = Deer Island Flats, OS = Outfall Site, and ECCB = Eastern Cape Cod Bay)

MWRA investigated the causes of the apparent increases in organic contaminant concentrations observed during the 1990s and determined that they did not result from an analytical artifact caused by co-elution encountered during the PCB and pesticide analyses. The study of the industry-standard analytical methods showed that the methods may provide overestimates of PCB concentrations. However, those errors are not sufficient to explain the observed increases. The increases may reflect later collection of lobsters than in earlier years. The lobsters taken in the summer and fall may have spent a longer period inshore, while those taken in the spring may have just arrived from deeper water. A 1999 drought may also have contributed to the high concentrations during that year, if lobsters followed the salt wedge upstream into more contaminated areas and then moved back downstream before they were caught. A special study evaluating these data will be completed during 2001.

Historically, concentrations of metals in lobster hepatopancreas have been more variable than concentrations of organic contaminants, with concentrations often as high or higher in animals from the outfall site and eastern Cape Cod Bay as in those from Deer Island Flats. In 2000, concentrations of all inorganic contaminants except zinc were similar or lower than those measured in 1999. Silver concentrations were notably lower than those found in 1998 and 1999 (data not shown).

Blue Mussel

Full mussel arrays were recovered after 40 and 60 days (Lefkovitz *et al.* 2001). Survival was high, ranging from 96 to 99% after 60 days, among all mussel arrays recovered.

As in previous years, contaminant burdens were highest in mussels deployed in the Inner Harbor (Figure 5-5). Overall, contaminant concentrations were low in mussels from Rockport and the outfall site, moderate in mussels deployed at Deer Island, and high in mussels deployed in the Inner Harbor. Mercury and lead concentrations were within the historical range, but slightly higher than the very low 1998 and 1999 concentrations. PCB concentrations were also within the historical range (the reference station mussels had the lowest levels of total PCBs recorded during the program). Pesticide and PAH concentrations (not shown) were also low.

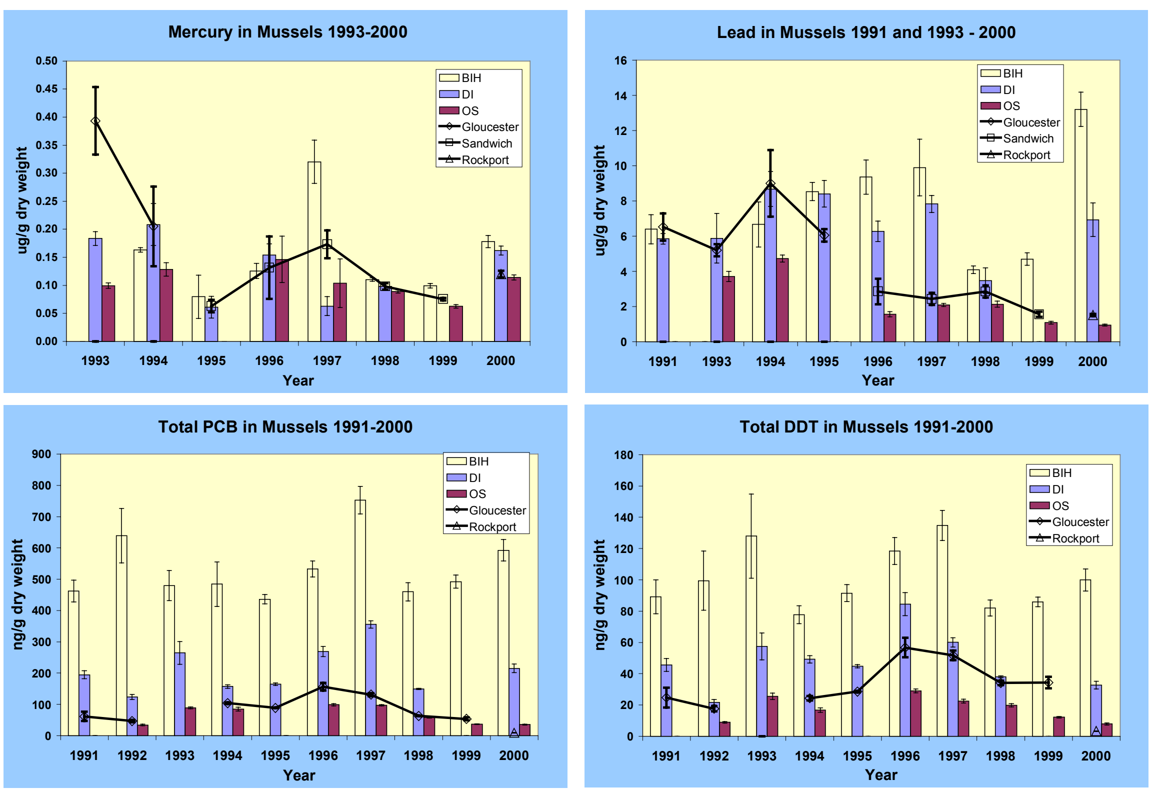

Figure 5-5. Concentrations of representative contaminants in mussels (BIH = Boston Inner Harbor, DI = Deer Island, and OS = Outfall Site)

Contingency Plan Thresholds

Threshold parameters for fish and shellfish monitoring include levels of toxic contaminants in flounder, lobster, and mussels and liver disease in flounder (Table 5-1). Some thresholds are based on U.S. Food and Drug Administration (FDA) limits for maximum concentrations of specific contaminants in edible portions of fish and fishery products. Others are based on the baseline monitoring, which was completed in August 2000. Those data were used to calculate thresholds, as described in the contingency plan.

Table 5-1. Contingency plan baseline and threshold values for fish and shellfish monitoring

Parameter Type/ Location	Parameter	Baseline	Caution Level	Warning Level
Flounder tissue nearfield	PCB	0.033 ppm	1 ppm wet weight	1.6 ppm wet weight
	Mercury	0.074 ppm	0.5 ppm wet weight	0.8 ppm wet weight
	Chlordane	242 ppb lipid	484 ppb lipid	None
	Dieldrin	63.7 ppb lipid	127 ppb lipid	None
	DDT	775.9 ppb lipid	1552 ppb lipid	None
Flounder nearfield	Liver disease (CHV)	24.4%	44.9%	None
Lobster tissue nearfield	PCB	0.015 ppm	1 ppm wet weight	1.6 ppm wet weight
	Mercury	0.148 ppm	0.5 ppm wet weight	0.8 ppm wet weight
	Chlordane	75 ppb lipid	150 ppb lipid	None
	Dieldrin	161 ppb lipid	322 ppb lipid	None
	DDT	341.3 ppb lipid	683 ppb lipid	None
Mussel tissue nearfield	PCB	0.011 ppm	1 ppm wet weight	1.6 ppm wet weight
	Lead	0.415 ppm	2 ppm wet weight	3 ppm wet weight
	Mercury	0.019 ppm	0.5 ppm wet weight	0.8 ppm wet weight
	Chlordane	102.3 ppb lipid	205 ppb lipid	None
	Dieldrin	25 ppb lipid	50 ppb lipid	None
	DDT	241.7 ppb lipid	483 ppb lipid	None
	PAH	1080 ppb lipid	2160 ppb lipid	None

6. Outfall Monitoring

The Massachusetts Bay outfall was commissioned on September 6, 2000, marking the beginning of outfall monitoring (see Figure 6-1). This section covers the period of September 6 through December 31, 2000.

When the outfall began operation on September 6, the water column was stratified and a fall phytoplankton bloom was underway. Plume-tracking studies began immediately. Other studies that were conducted by the end of 2000 included water-column surveys, a sediment-contaminant survey, and a nutrient-cycling study.

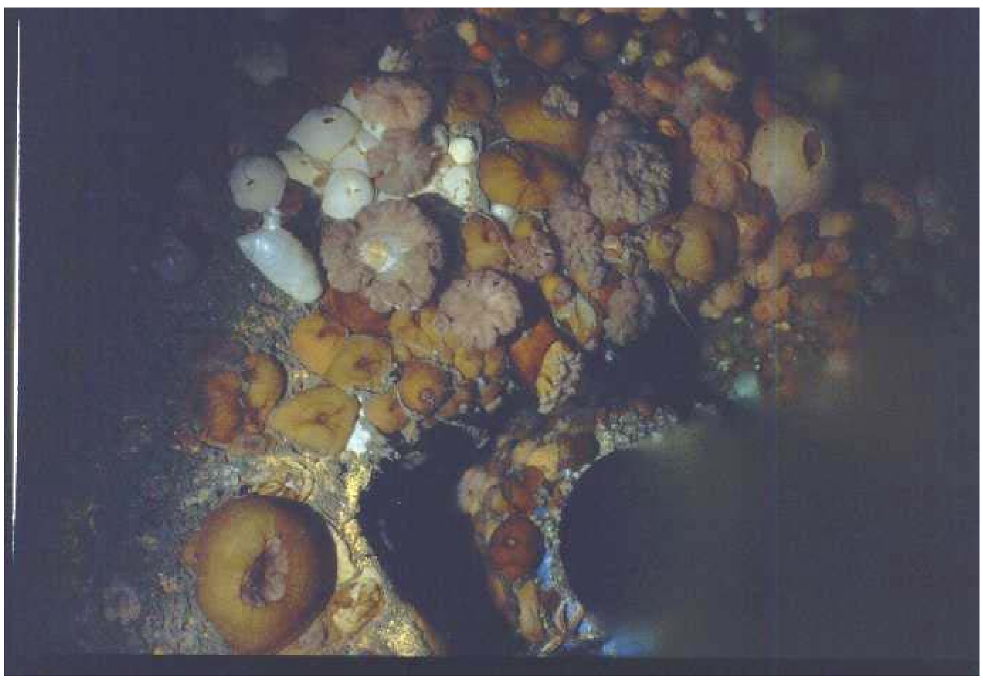

Figure 6-1. Outfall discharge photographed in June 2001. The discharging plume is located in the lower right.

Plume Observations

A preliminary plume-tracking survey was conducted in late September 2000. The survey focused on the area immediately around the outfall. Its objectives were to provide early information on initial plume dilution and to examine the spatial variability in salinity structure. The information on salinity structure was necessary for planning the more extensive plume-tracking exercises scheduled for 2001. The survey used an *in situ* sensor package that measures conductivity, temperature, depth, water clarity, and altitude above the sea floor. The package can be operated at a constant depth, to collect vertical profiles, or as a "towyo," that is, in a vertically undulating pattern.

The water column was strongly stratified during the plume-tracking exercise. The sensors readily detected the plume beneath the pycnocline and moving to the north. The survey found ammonia to be a particularly good plume tracer (Figure 6-2). Lowered salinity also proved to be a good plume indicator, and is likely to provide adequate sensitivity to see plume dilutions of up to 100 or higher.

Only minimal data were available to define the mixing zone. Those data suggested that initial dilution was large, as had been expected, and that it occurred in close proximity to the diffusers, less than 50 m horizontally and vertically. Continued dilution beyond the hydraulic mixing zone was probably gradual.

The preliminary data provided initial assurances that plume behavior matched model predictions. As predicted by the model, no effluent was detected at the surface while the pycnocline remained strong. Later in the year, after the pycnocline had broken down, photographic evidence and information from water quality surveys indicated that effluent did reach the surface, also as predicted by the model.

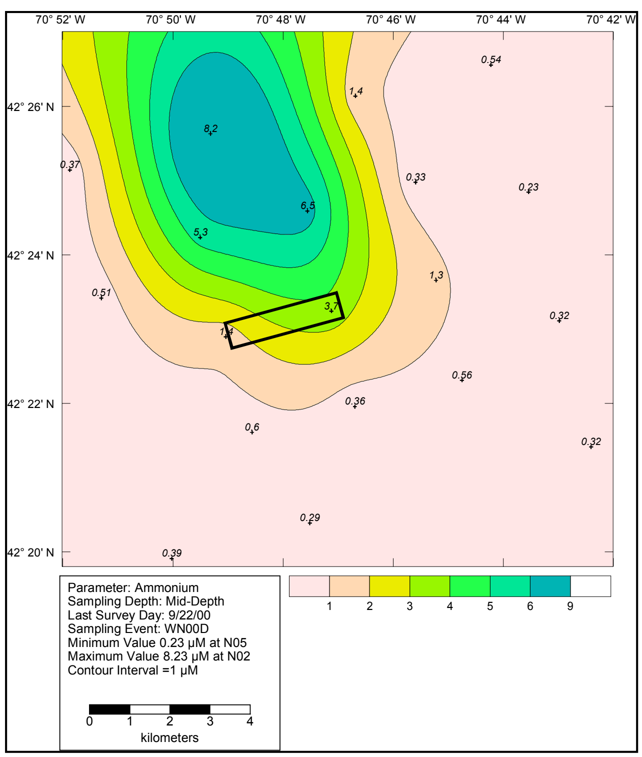

Figure 6-2. Horizontal contour of NH_4 at the pycnocline. The rectangle represents the location of the diffuser.

Water-Column Observations

Water quality surveys indicated that following initiation of discharge at the new outfall, high and variable concentrations of ammonia occurred at Station N21, which is located along the outfall diffuser. In the effluent, ammonia concentrations remained relatively constant from September through December. Although ammonia is used biologically and therefore is not a conservative tracer, it is a useful tracer of the effluent plume in the nearfield. The transfer of effluent from the harbor to the bay had a clear signature on ammonia concentrations in the nearfield (Libby *et al.* 2001).

On September 1, prior to outfall start-up, ammonia concentrations were relatively low throughout the nearfield. By late September, concentrations clearly indicated that effluent was present. In early October, data indicated that the plume was trapped beneath the pycnocline, but by late October and for the remainder of the year, it appeared that ammonia concentrations were elevated over the entire water column in the nearfield. (These elevated concentrations were much lower than the ammonia concentrations seen in Boston Harbor when the discharge was located in the harbor.)

Using ammonia as a tracer, the monitoring data showed an areal pattern that was similar to what had been predicted by the computer model of outfall dilution (Figure 6-3). Monitoring data matched outfall dilution predictions for before and after the discharge began. Data also matched the model predictions for depth distribution (not shown).

Chlorophyll levels were already elevated in the nearfield (Figure 6-4, top) and throughout the region when the outfall began operation. Concentrations were higher in October than in September, but there was no indication that these increases could be attributed to the outfall, because levels were high throughout the monitoring area (See Figure 3-8, p. 31). Preliminary data (Figure 6-4, bottom) suggest that by the winter/spring of 2001, chlorophyll levels had declined to levels lower than 1998 and 1999.

Dissolved oxygen concentrations and percent saturation reached their minima in October, following the outfall start-up. This timing is normal, as oxygen minima are reached just before stratification breaks down in the fall. The survey mean concentration and saturation minima were within the baseline range.

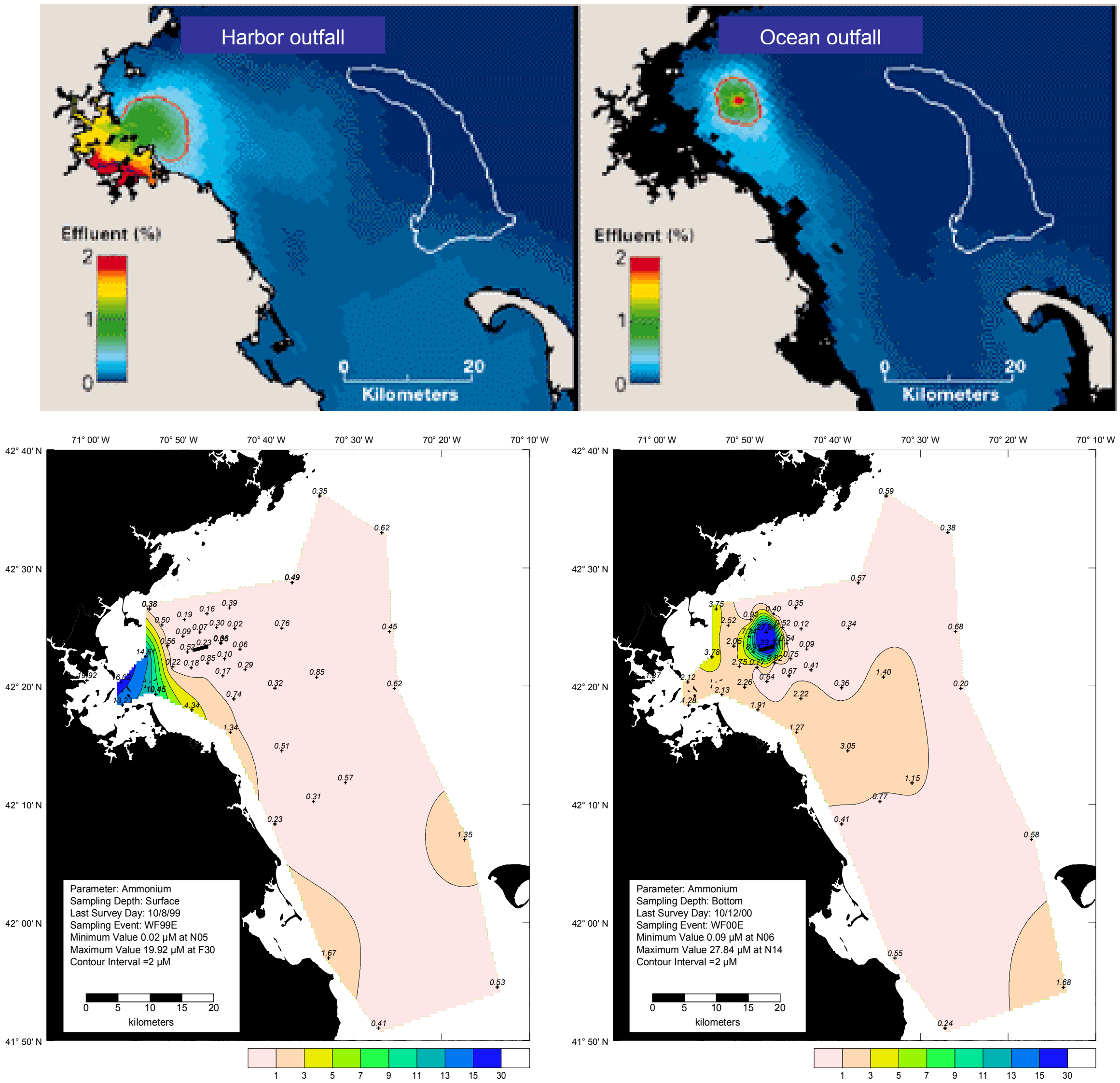

Figure 6-3. Model predictions for effluent dilutions from Deer Island (top left) and Massachusetts Bay (top right) outfalls; measured ammonia concentrations from pre-discharge and post-discharge, October 1999 (bottom left) and October 2000 (bottom right).

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There were no apparent shifts in phytoplankton abundance or community composition following the outfall start-up. A fall bloom was underway, and assemblages included abundant large, chain-forming diatoms, such as were present during the baseline-sampling years. No blooms of harmful or nuisance species occurred.

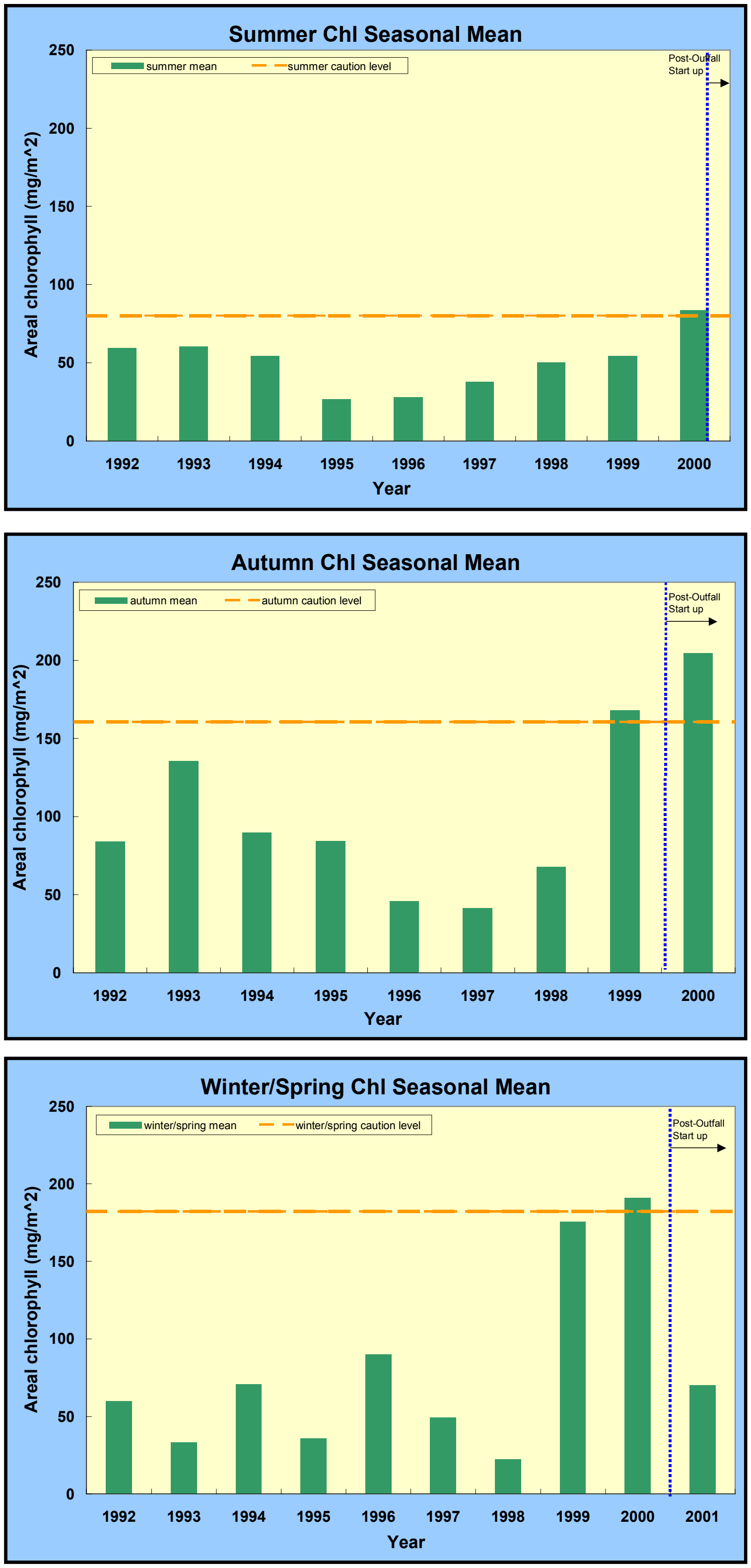

Figure 6-4. Seasonal chlorophyll levels, 1992-winter/spring 2001

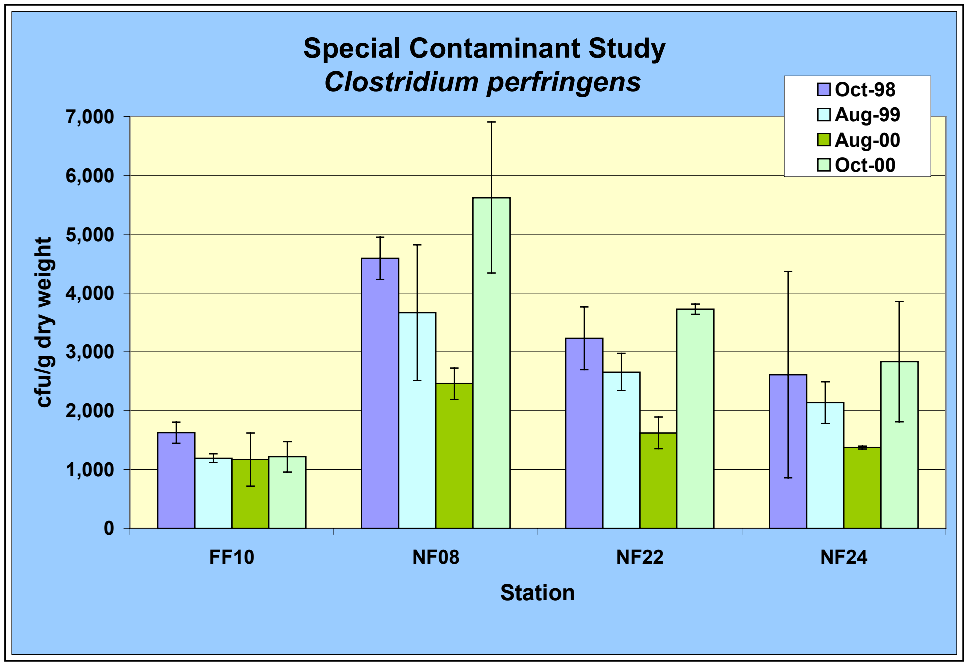

Figure 6-5. Clostridium perfringens *spore density at special contaminant study stations*

Sediment Contaminants

A sediment-contaminant survey was conducted in the fall of 2000 after the outfall came on line. Three replicate samples from each of the four special contaminant study stations were collected and analyzed for TOC, grain size, *Clostridium perfringens* spores, and organic and inorganic contaminants. Concentrations of TOC measured post discharge were similar to those measured prior to start-up of the outfall. At the three nearfield stations, concentrations of spores of the sewage tracer bacterium *Clostridium perfringens* were about twice as high in October as they had been in August, although the values were not significantly different from the baseline average. Concentrations were similar to those measured in October 1998 (Figure 6-5). Concentrations of organic and inorganic contaminants were similar to those measured prior to the outfall coming on line.

Benthic Flux

MWRA has conducted studies to study benthic nutrient cycling and oxygen dynamics in Massachusetts Bay (see Section 7, Special Studies). One survey was conducted in late August, just before the outfall began operation, and the final survey of 2000 took place after the outfall began discharging to Massachusetts Bay (Tucker *et al.* 2001).

As would be expected from such a short interval, none of the measurements made at that time indicated a change in benthic processes. Typically, sediments are thought to integrate effects of multiple stresses, so any effects would be detected after a longer time.

Contingency Plan Threshold Results

Because the outfall did not begin operation until September, most ambient contingency plan thresholds were not applicable in 2000 (Table 6-1).

MWRA reported three exceedances of ambient caution thresholds for the period that the outfall was in operation. All three exceedances occurred in the water column. They included dissolved oxygen percent saturation in the nearfield and in Stellwagen Basin, and autumn nearfield chlorophyll.

Dissolved Oxygen Percent Saturation

In October 2000, dissolved oxygen percent saturation fell below the caution level of 80% in the nearfield and in Stellwagen Basin. Therefore, the regulatory agencies, OMSAP, and the public were notified. Dissolved oxygen concentrations remained well above the standards.

Subsequently, the thresholds related to dissolved oxygen were modified. In April 2001, EPA and MADEP suggested adding the phrase "unless background conditions are lower" to the thresholds. This addition makes the thresholds more consistent with the state water quality standard, which was the intended basis for the thresholds. MWRA calculated background using methodology suggested by EPA and those thresholds have been implemented on an interim basis. Now, the threshold will be exceeded if an observed value crosses both the original threshold and the background values. Neither percent saturation nor dissolved oxygen concentration have fallen below the background levels since the outfall start-up in September 2000. Figure 6-6 shows the fluctuations of bottom dissolved oxygen percent saturation, along with the threshold and background levels, since the start of monitoring in 1992.

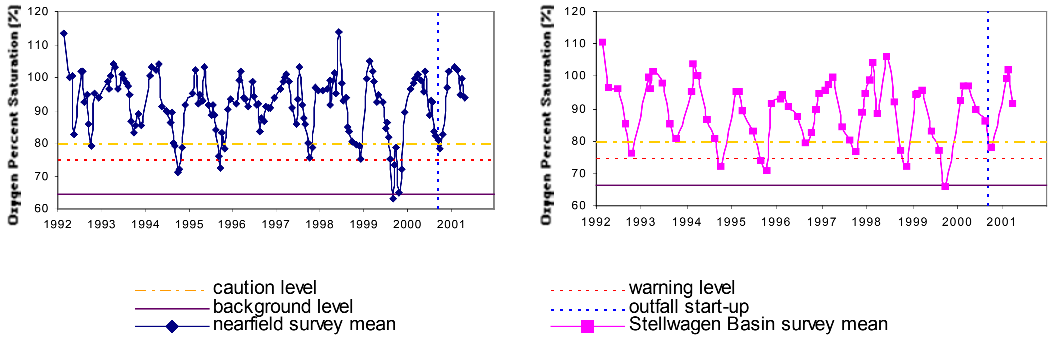

Figure 6-6. Patterns of percent saturation in bottom water dissolved oxygen for the nearfield (left) and Stellwagen Basin (right). Values often fell below the state standards for percent saturation but rarely fell below the background levels.

Nearfield Chlorophyll Autumn 2000

The fall 2000 average chlorophyll level was 212 mg/m^2, which exceeded the seasonal caution level of 161 mg/m^2, triggering notification of EPA, MADEP, OMSAP, and the public (see Figure 6-4). In reviewing the data, MWRA determined that the high values for chlorophyll in the fall were independent of the effluent outfall and instead reflected a large-scale region-wide occurrence, which began prior to the outfall beginning operation.

Increased algal levels were first noted in early September, before the outfall went on line. Satellite imagery confirmed that there was a region-wide algal bloom that ranged from New Jersey to the Bay of Fundy (see Figure 3-8 in Section 3, Water Column Baseline). The monitoring team closely followed the progress of this bloom throughout the fall, winter, and following spring.

Throughout this period, there were no unusual elevations of nuisance algal species; the diatoms making up the fall 2000 bloom were members of the normal coastal plankton community. There were no effects on dissolved oxygen concentrations. In fact, concentrations of dissolved oxygen in the water column were somewhat higher than usual. Benthic chlorophyll levels, which would indicate whether large amounts of algae were settling to the bottom, were normal. Benthic respiration, which would indicate if an unusual amount of oxygen were being used if excess algae were being broken down in the sediments, was also normal. Particulate organic carbon and phytoplankton cell counts peaked in early September (before the outfall went on line), remaining at moderate levels through late October, then declining to low, winter levels. The fall 2000 particulate organic carbon levels and phytoplankton abundances were well within the range observed throughout baseline sampling.

The spring 2001 nearfield average chlorophyll concentration was 78 mg/m^2, well within the contingency plan threshold of 182 mg/m^2. In summary, all evidence suggests that the fall 2000 threshold exceedance was part of a region-wide pattern of elevated chlorophyll levels, independent of the MWRA outfall and that there were no immediate adverse effects from the fall bloom.

Table 6-1. Contingency plan thresholds and threshold testing results for 2000 ambient discharge monitoring (Results for 2000 effluent discharge monitoring are in Table 2-2.)

Parameter	Background or Baseline	Caution Level	Warning Level	September 6 – December 31, 2000 Results
Water Column Thresholds				
Nearfield bottom water, dissolved oxygen concentration	5.75 mg/l	6.5 mg/l	6.0 mg/l	Not exceeded 7.1 mg/l
Stellwagen Basin bottom water, dissolved oxygen concentration	6.2 mg/l	6.5 mg/l	6.0 mg/l	Not exceeded 7.3 mg/l
Nearfield bottom water, dissolved oxygen saturation	64.3%	80%	75%	Caution Level exceeded 78%
Stellwagen Basin, dissolved oxygen saturation	66.3%	80%	75%	Caution Level exceeded 78%
Nearfield bottom water, dissolved oxygen depletion rate	0.0244 mg/l/d	0.037 mg/l/d	0.049 mg/l/d	Not applicable
Nearfield chlorophyll, annual	71 mg/m^2	107 mg/m^2	143 mg/m^2	Not applicable
Nearfield chlorophyll, winter/spring	81 mg/m^2	182 mg/m^2	None	Not applicable
Nearfield chlorophyll, summer	51 mg/m^2	80 mg/m^2	None	Not applicable
Nearfield chlorophyll, autumn	90 mg/m^2	161 mg/m^2	None	Caution Level exceeded 212 mg/m^2
Nearfield *Phaeocystis*, winter/spring	470,000 cells/l	2,020,000 cells/l	None	Not applicable
Nearfield *Phaeocystis*, summer	7.2 cells/l	334 cells/l	None	Not applicable
Nearfield *Phaeocystis*, autumn	300 cells/l	2,370 cells/l	None	Not exceeded 0 cells/l

Parameter	Background or Baseline	Caution Level	Warning Level	September 6 – December 31, 2000 Results
Nearfield *Pseudonitzschia*, winter/spring	6,200 cells/l	21,000 cells/l	None	Not applicable
Nearfield *Pseudonitzschia*, summer	13,000 cells/l	38,000 cells/l	None	Not applicable
Nearfield *Pseudonitzschia*, autumn	9,700 cells/l	24,600 cells/l	None	Not exceeded 12,600 cells/l
Nearfield *Alexandrium*	Maximum = 163 cells/l	100 cells/l	None	Not exceeded No *Alexandrium* present
Farfield PSP toxin extent	Never observed at certain southern Mass Bay stations	New incidence	None	Not exceeded No PSP in Mass. Bay
Plume initial dilution	None	None	Less than predicted	Not applicable
Sediment Thresholds				
Nearfield, sediment depth of redox discontinuity	2.36 cm	1.18 cm	None	Not applicable
acenaphthene	30 ppb dry	none	500 ppb dry	Not applicable
acenaphthylene	48 ppb dry	none	640 ppb dry	Not applicable
anthracene	151 ppb dry	none	1100 ppb dry	Not applicable
benz(a)anthracene	278 ppb dry	none	1600 ppb dry	Not applicable
benzo(a)pyrene	258 ppb dry	none	1600 ppb dry	Not applicable
cadmium	0.2 ppm dry	none	9.6 ppm dry	Not applicable
chromium	76 ppm dry	none	370 ppb dry	Not applicable
chrysene	255 ppb dry	none	2800 ppb dry	Not applicable
copper	24 ppm dry	none	270 ppm dry	Not applicable
dibenzo(a,h)anthracene	37 ppb dry	none	260 ppb dry	Not applicable
fluoranthene	558 ppb dry	none	5100 ppb dry	Not applicable
fluorene	50 ppb dry	none	540 ppb dry	Not applicable
lead	44 ppm dry	none	218 ppm dry	Not applicable
mercury	0.24 ppm dry	none	0.71 ppm dry	Not applicable
naphthalene	70 ppb dry	none	2100 ppb dry	Not applicable
nickel	17 ppm dry	none	51.6 ppm dry	Not applicable
p,p'-DDE	0.8 ppb dry	none	27 ppb dry	Not applicable

Parameter	Background or Baseline	Caution Level	Warning Level	September 6 – December 31, 2000 Results
phenanthrene	349 ppb dry	none	1500 ppb dry	Not applicable
pyrene	516 ppb dry	none	2600 ppb dry	Not applicable
silver	0.6 ppm dry	none	3.7 ppm dry	Not applicable
total DDTs	3.5 ppb dry	none	46.1 ppb dry	Not applicable
total HMWPAH	3559 ppb dry	none	9600 ppb dry	Not applicable
total LMWPAH	1639 ppb dry	none	3160 ppb dry	Not applicable
total PAH	5199 ppb dry	none	44,792 ppb dry	Not applicable
total PCBs	17 ppb dry	none	180 ppb dry	Not applicable
zinc	61 ppm dry	none	410 ppm dry	Not applicable
Nearfield benthos, species per sample	64.52	<47.95 or >81.09	None	Not applicable
Nearfield benthos, Fisher's log-series alpha	13.00	<10.13 or >15.88	None	Not applicable
Nearfield benthos, Shannon diversity	3.67	<3.32 or >4.02	None	Not applicable
Nearfield benthos, Pielou's evenness	0.62	<0.56 or >0.67	None	Not applicable
Nearfield benthos, opportunists	0.75%	10%	25%	Not applicable
Fish and Shellfish				
Nearfield flounder, PCB	0.033 ppm wet	1 ppm wet	1.6 ppm wet	Not applicable
Nearfield flounder, mercury	0.074 ppm wet	0.5 ppm wet	0.8 ppm wet	Not applicable
Nearfield flounder, chlordane	242 ppb lipid	484 ppb lipid	None	Not applicable
Nearfield flounder, dieldrin	63.7 ppb lipid	127 ppb/g lipid	None	Not applicable
Nearfield flounder, DDT	775.9 ppb lipid	1552 ppb lipid	None	Not applicable
Nearfield flounder, liver disease	24.4%	44.9%	None	Not applicable
Nearfield lobster, PCB	0.015 ppm wet	1 ppm wet	1.6 ppm wet	Not applicable
Nearfield lobster, mercury	0.148 ppm wet	0.5 ppm wet	0.8 ppm wet	Not applicable
Nearfield lobster, chlordane	75 ppb lipid	150 ppb lipid	None	Not applicable
Nearfield lobster, dieldrin	161 ppb lipid	322 ppb lipid	None	Not applicable
Nearfield lobster, DDT	341.3 ppb lipid	683 ppb lipid	None	Not applicable
Nearfield mussel, PCB	0.011 ppm wet	1 ppm wet	None	Not applicable
Nearfield mussel, lead	0.415 ppm wet	2 ppm wet	3 ppm wet	Not applicable

Parameter	Background or Baseline	Caution Level	Warning Level	September 6 – December 31, 2000 Results
Nearfield mussel, mercury	0.019 ppm wet	0.5 ppm wet	0.8 ppm wet	Not applicable
Nearfield mussel, chlordane	102.3 ppb lipid	205 ppb lipid	None	Not applicable
Nearfield mussel, dieldrin	25 ppb lipid	50 ppb lipid	None	Not applicable
Nearfield mussel, DDT	241.7 ppb lipid	483 ppb lipid	None	Not applicable
Nearfield mussel, PAH	1080 ppb lipid	2160 ppb lipid	None	Not applicable

7. Special Studies

Background

Besides monitoring the effluent and the water column, sea floor, and fish and shellfish in Massachusetts Bay and the surrounding area, MWRA conducts special studies in response to specific permit requirements, scientific questions, and public concerns. For example, MWRA has an ongoing study of Boston Harbor, which in 2000, documented the first changes in water quality following diversion of the effluent from the harbor to Massachusetts Bay. MWRA is also monitoring bacterial water quality in Massachusetts Bay, has ongoing studies of nutrient cycling in the harbor and the bay, and makes observations of marine mammals during water column and other surveys.

Water Quality in Boston Harbor

Over the past decade, MWRA has been documenting the effects on Boston Harbor due to source reduction and facilities upgrades, including ending of sludge discharges, transfer of all effluent to Deer Island for secondary treatment, implementation of plans to control CSOs, and finally, in 2000, ending effluent discharges to the harbor. MWRA efforts have included monitoring water quality at the former outfalls and at other locations in the harbor. Monitoring within the harbor has focused on three issues: eutrophication, water clarity, and effluent indicator bacteria. The focus on eutrophication has included measurements of nutrient concentrations, algal quantity, and dissolved oxygen concentration.

From 1998 through August 2000, monitoring within the harbor focused on the effects of the upgrade to secondary treatment at Deer Island and then the transfer of Nut Island flows through this upgraded facility. During this period, there was a large reduction in ammonia concentrations (Figure 7-1) and a large increase in water clarity, as measured by Secchi disk depth (Figure 7-2) at the former Nut Island outfalls and elsewhere in the southern portion of the harbor. Some increase in ammonia levels were observed off Deer Island, due to the increased loads, but the same area showed an improvement in water clarity, because of the improved solids removal at Deer Island.

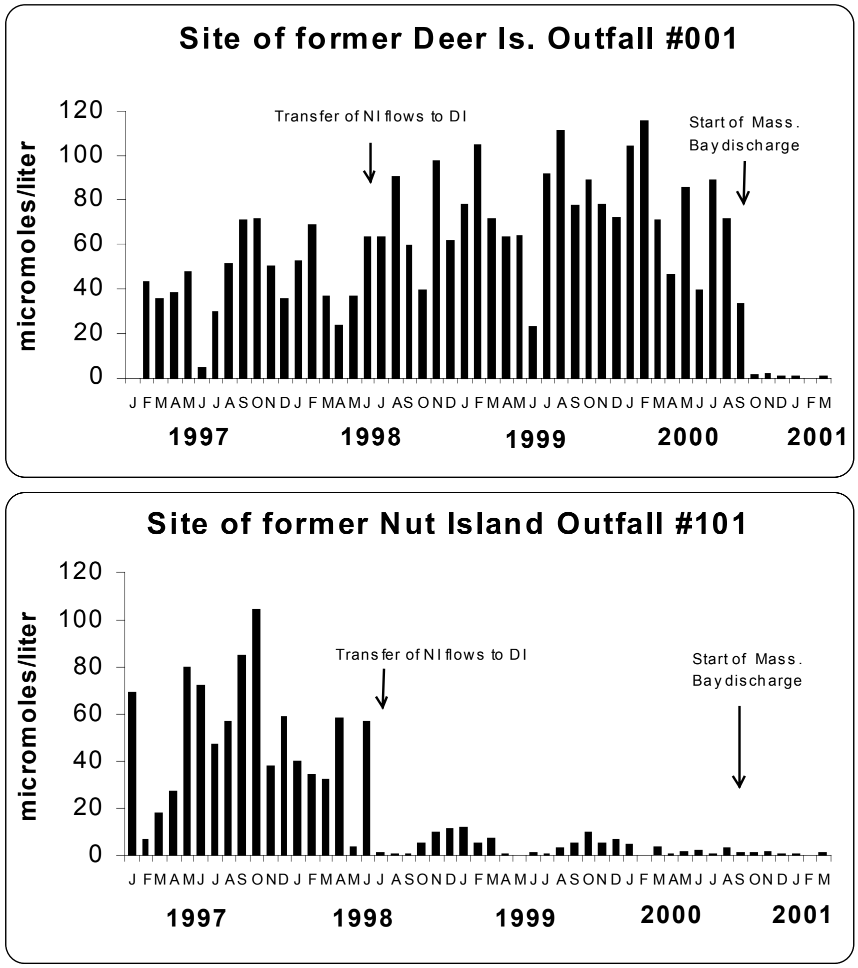

Figure 7-1. Ammonia levels in waters in the vicinity of the Deer Island and Nut Island outfalls

During the last four months of 2000, monitoring focused on the changes resulting from the end of discharge from Deer Island. Within days of closing the harbor outfall, improvements in water quality were apparent. Ammonia concentrations decreased and water clarity increased in the vicinity of the former outfall.

By the end of 2000, improvements in water quality were detectable at stations further away from the former harbor outfalls. These improvements included reductions in nitrogen concentrations, including ammonia, reductions in phosphorus concentrations, and improved water clarity. Drops in ammonia concentrations were detected even at the former Nut Island site (Figure 7-1). MWRA expects that further improvements will be detected in 2001.

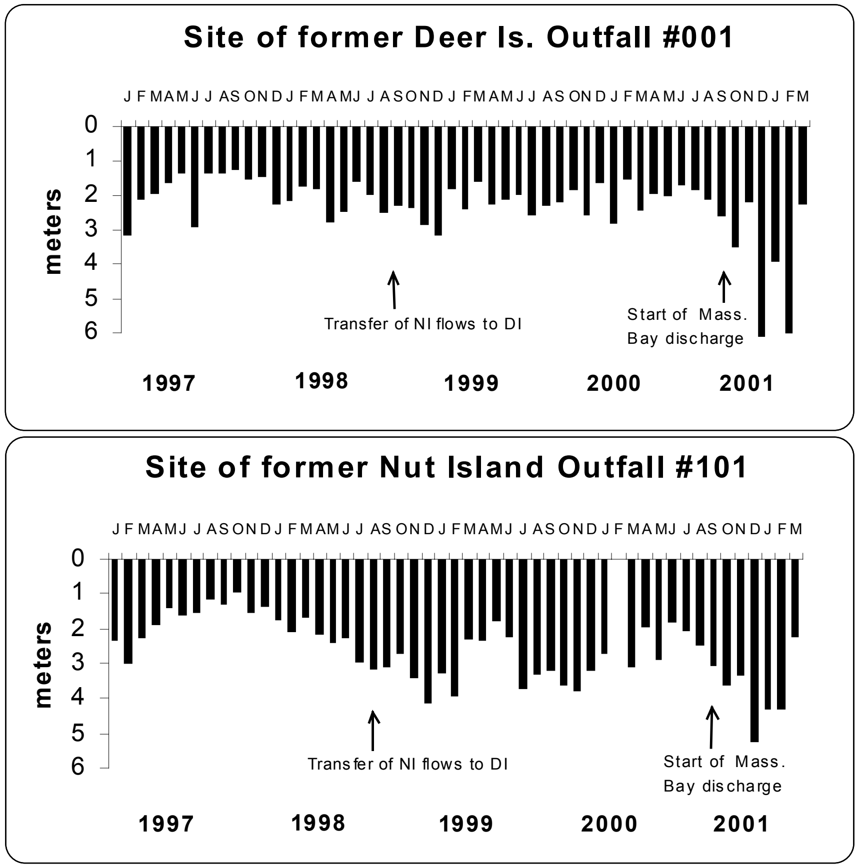

Figure 7-2. Secchi disk depths in waters in the vicinity of the Deer Island and Nut Island outfalls

Massachusetts Bay Bacteria Monitoring

MWRA monitors bacterial water quality near the new outfall and at other locations in Massachusetts Bay (Figure 7-3) under a "Monitoring and Notification Agreement" included in a memorandum of understanding (MOU) between MWRA and the Massachusetts Division of Marine Fisheries (DMF). The purpose of the monitoring is to assure that the operation of the outfall does not adversely affect shellfish-growing waters. Results of the studies will also be used by DMF to identify areas in Massachusetts Bay suitable for shellfish harvesting. The monitoring involves collection of water from the surface and beneath the pycnocline at twelve locations in the bay. Samples are collected during periods of stratification, and are analyzed for fecal coliform bacteria and another sewage indicator, *Enterococcus*. Fecal coliform bacteria are used by the FDA as an indicator for classifying shellfish-growing areas. *Enterococcus* is the EPA-preferred indicator of public health risk in marine waters used for recreation. Surveys are conducted monthly: three baseline surveys were performed between 1999 and September 2000, and the first post-discharge survey was conducted in October 2000.

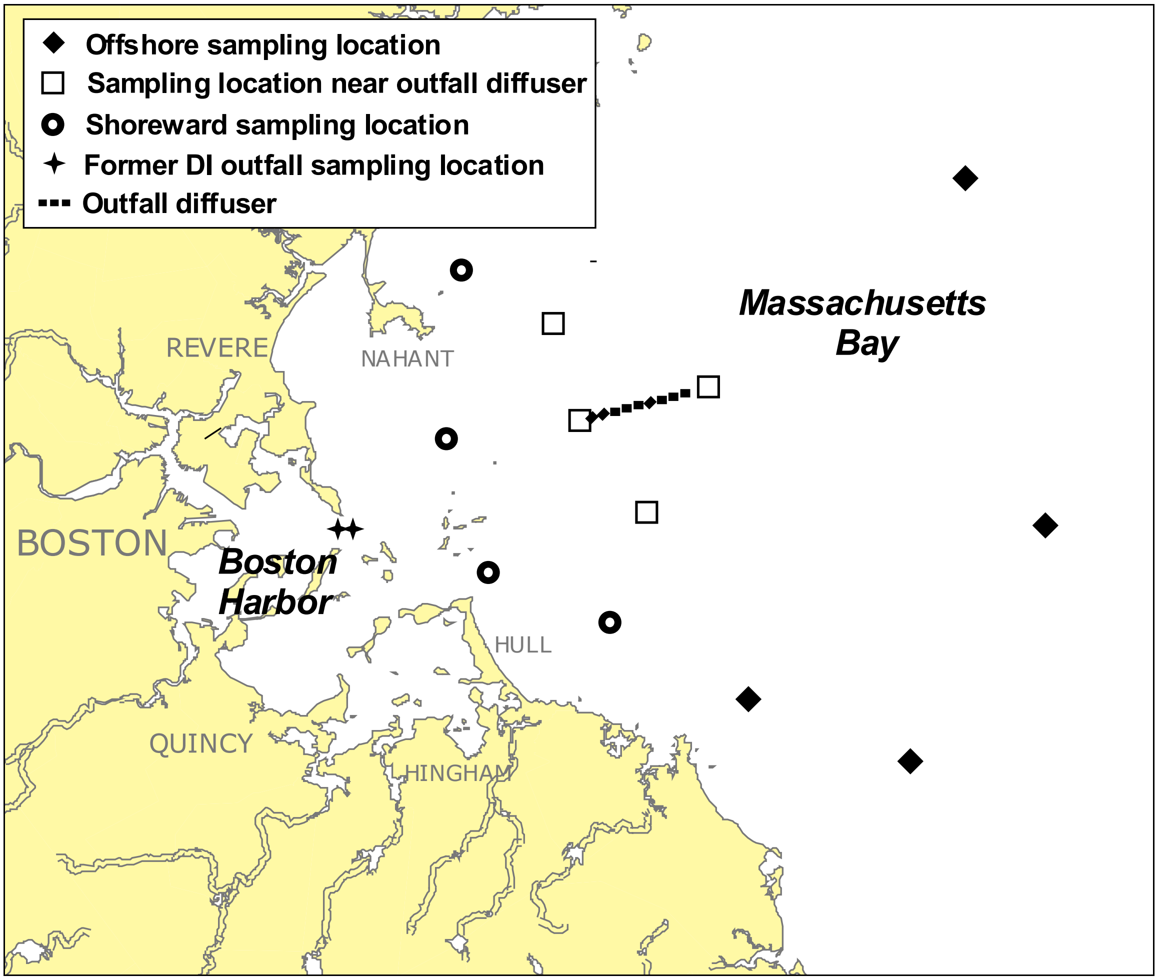

Figure 7-3. Locations of bacteria monitoring stations

Fecal coliform counts in Massachusetts Bay have remained low following the opening of the new outfall (Table 7-1). Many samples had counts that were below detection limits; those samples were assigned the value of the detection limit, 2 colonies/100 ml. Mean number of colonies increased slightly at stations near the outfall diffusers and shoreward; no changes were found offshore.

As with fecal coliform counts, *Enterococcus* counts have been very low in Massachusetts Bay (Table 7-2). As with fecal coliform bacteria, counts for many samples were below detection limits and were assigned a value of 1 colony/100 ml, the detection limit. Geometric means have increased slightly following the commissioning of the outfall; only stations near the outfall diffuser have shown any change.

Table 7-1. Fecal coliform bacteria counts from the Boston Harbor outfall location and Massachusetts Bay. Water quality standard in Massachusetts Bay is ≤200 colonies per 100 ml. Unrestricted shellfishing standard is ≤14 colonies per 100 ml.

	Geometric mean fecal coliform counts (colonies/ 100 ml)			
	Former (Harbor) Outfall	Massachusetts Bay		
		Near Outfall Diffuser	Shoreward	Offshore
Before outfall opening	8.6	2.0	2.1	2.0
After outfall opening	5.9	2.2	2.3	2.0

Table 7-2. Entercoccus *bacteria counts from the Boston Harbor outfall location and from Massachusetts Bay. Swimming standard for Massachusetts beaches is ≤35 colonies/ 100 ml.*

	Geometric mean *Enterococcus* counts (colonies/ 100 ml)			
	Former (Harbor) Outfall	Massachusetts Bay		
		Near Outfall Diffuser	Shoreward	Offshore
Before outfall opening	6.8	1.0	1.2	1.0
After outfall opening	5.3	1.1	1.2	1.0

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. Denitrification, a process that converts nitrate to gaseous forms of nitrogen, causes nitrogen to be lost to the atmosphere. Consequently, when an offshore outfall was planned, scientists were concerned about a possible increase in nitrogen loads. If denitrification rates were high within the harbor, then moving the outfall into deeper waters with lower denitrification rates might increase the nitrogen load to the region.

MWRA has conducted studies of benthic nutrient cycling within Boston Harbor since 1992. In 2000, 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, also in the southern harbor (Tucker *et al.* 2001). Results of the studies have shown that denitrification rates within the harbor are high, as had been predicted. However, the studies have also shown that little of the nutrient inputs to the harbor are cycled through the sediments and lost to the system.

Consequently, moving the outfall offshore is unlikely to affect the total nitrogen load to the bay.

The studies have also documented recovery of the harbor since the cessation of sludge disposal in 1991. For the first years after sludge inputs ceased, rates of respiration and nutrient flux were extremely high at the former disposal site. Rates have decreased since 1998.

MWRA also conducts studies of nutrient cycling and oxygen dynamics in Massachusetts Bay. Studies conducted in 2000 marked the completion of baseline studies and the first measurements to be made after the outfall began operation. Studies were conducted at three stations near the new outfall and at one station in Stellwagen Basin. As was expected after such a brief period, no changes were detected following start-up of the outfall. Further, if the outfall plume continues to act as predicted by model calculations, no detectable changes are expected in the future (see Section 6, Outfall Monitoring).

Marine Mammal Observations

Several endangered or threatened species of whales and turtles regularly visit Massachusetts and Cape Cod bays, including the right, humpback, finback, sei, and blue whales. Species that are not endangered or threatened include the minke whale, harbor porpoise, gray seal, harbor seal, and several kinds of dolphins.

Since 1995, MWRA has included endangered species observers on monitoring surveys. In 2000, observers were included on 23 surveys (McLeod *et al.* 2001). Besides providing monitoring data, presence of trained marine mammal observers addresses a request by NMFS that MWRA provide observational data and minimize the chances of collision of its survey vessels with a right whale.

During these surveys, 55 individual whales, 11 Atlantic white-sided dolphins, 21 pilot whales, and more than 50 unidentified dolphins were sighted by the observers or other members of the survey team (Figure 7-4). Included in the sightings were 29 humpback whales, 4 finback whales, and 3 minke whales. Other whales could not be identified to species. No right whales were observed in 2000. Forty-seven of the sightings were within the boundaries of the Stellwagen Bank National Marine Sanctuary, and two minke whales were seen in the nearfield.

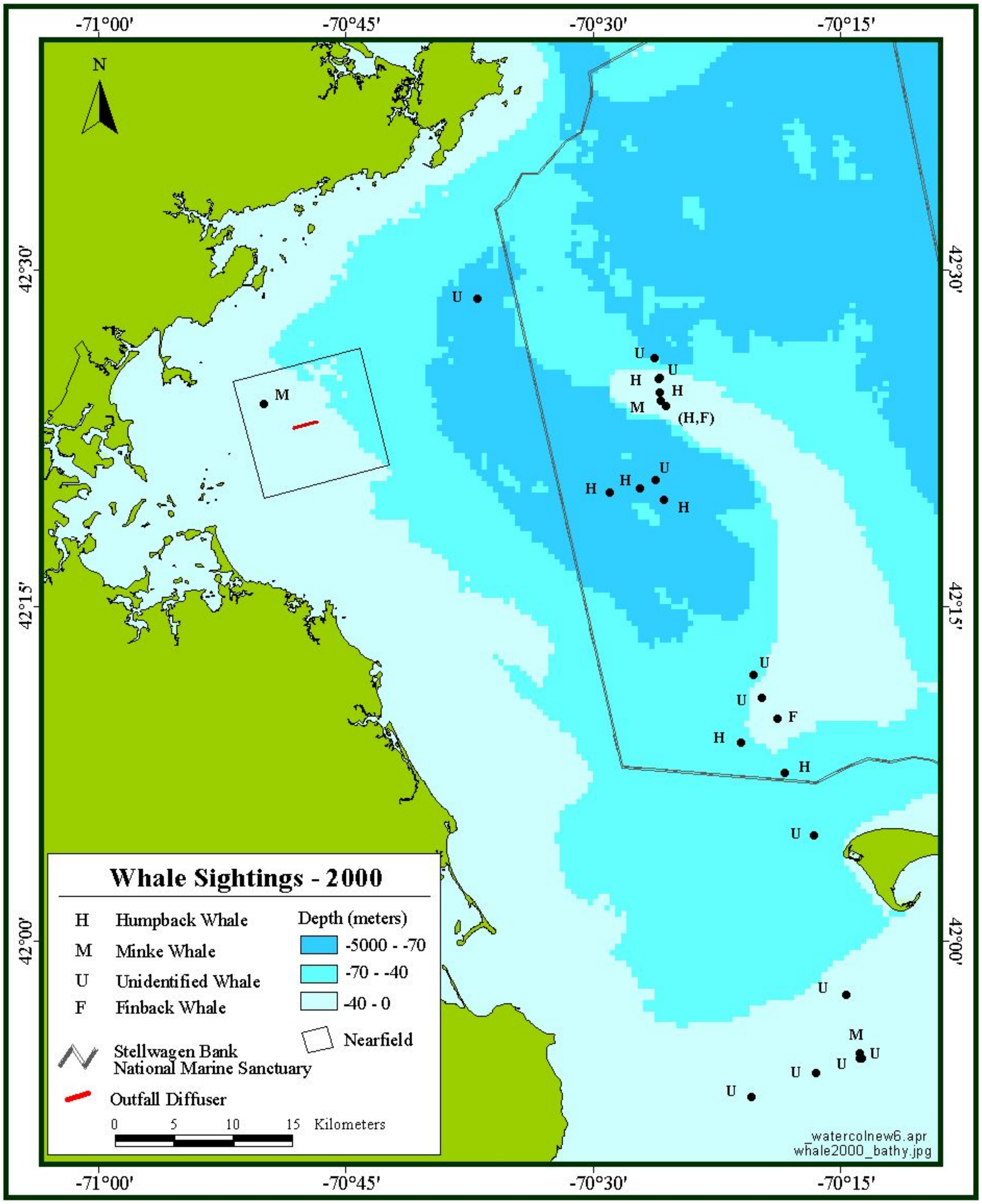

Figure 7-4. Whale sightings during 2000

The data from these surveys are difficult to interpret, because whale populations are known to fluctuate between years, and the observations are opportunistic, tied to surveys with other missions, rather than systematic and specifically designed to inventory mammal populations. In general, however, observations in 2000 were similar to those in 1998 and

1999. For example, 28 large baleen whales were sighted in 1998, 27 in 1999, and 31 in 2000.

General observations of large baleen whales in the Stellwagen Bank area indicated that only a few humpback and fin whales used the area in May (noted by the Whale Center of New England and reported in McLeod *et al.* 2001). Whales were abundant over the southern flank of Stellwagen Bank from June through September, and over the entire area in October. An unusual observation was that two juvenile humpback whales spent a week within a mile of the coast, between Nahant and Boston, even entering Boston Harbor. One of these whales remained near the coast through December, entering and feeding in Salem, Beverly, and Gloucester harbors.

8. Stellwagen Bank National Marine Sanctuary

The Gerry E. Studds Stellwagen Bank National Marine Sanctuary comprises 842 square miles of area located at the boundary of Massachusetts Bay and the Gulf of Maine. It is approximately 25 miles east of Boston, 3 miles north of Provincetown, and 3 miles south of Gloucester. The most prominent feature within the sanctuary is Stellwagen Bank, a sand-and-gravel plateau, with water depths of about 65 feet. The bank rises about 165 feet above Stellwagen Basin to its west. Currents from the Gulf of Maine and Stellwagen Basin create a rich habitat for marine life. Stellwagen Bank is popular as a fishing ground and for whale-watching excursions.

The sanctuary is currently revising its 1993 management plan. Scoping comments made public in January 2000 listed eleven issues of concern (Table 8-1).

Table 8-1. Issues of concern for the Stellwagen Bank National Marine Sanctuary

Management Plan Issues
Ship strikes of whales and other whale-ship interactions
Whale watching
Research
Education and outreach
Marine conservation zones
Fishing activity
Mariculture
Effects of MWRA discharge
Extension of the sanctuary boundaries
Enforcement of sanctuary regulations
Installation of submerged cables or pipelines within sanctuary boundaries

A preliminary draft plan addressing all the concerns is planned for 2001. Meanwhile, the MWRA permit recognizes the concerns about possible effects of the outfall on the sanctuary and requires an annual report of those possible effects.

The plume-tracking exercises that began after the outfall began operation in 2000 provided an early indication that the plume was rapidly diluted and behaved as predicted by the transport and dilution models. During those first studies, the plume moved towards the north rather than towards the sanctuary, and dilution of approximately 1:100 occurred in close proximity to the diffusers, <5 m horizontally and vertically. These preliminary measurements provided an initial assurance that the outfall will not affect the waters of the sanctuary. More extensive measurements will be reported in the coming years.

MWRA's regular water-column and sea-floor monitoring programs include stations in and near the sanctuary. Five water-column stations, including four within the sanctuary and one just outside the northern border are considered "boundary" stations, that is, they mark the boundary between Massachusetts Bay and the Gulf of Maine. These stations are important to MWRA, not just because of their location within a marine sanctuary, but also because water column processes within Massachusetts Bay are largely driven by the processes in wider region of the Gulf of Maine. Eight water-column stations located just inshore from the sanctuary are considered "offshore" stations by the MWRA program. Two sea-floor stations are within the sanctuary, and two additional stations are inshore from the sanctuary but in waters of similar depths and with similar sediments as those found within the sanctuary bounds.

Baseline water-column sampling has indicated that the stations within the sanctuary are healthy and similar to other farfield stations. Nutrient levels at boundary stations are consistently with the same range as the nearfield Figure 8-1). Annual mean chlorophyll concentrations were elevated at the boundary stations in 2000, as they were in other regions, but as in other years, they did not differ significantly from the nearfield or other offshore stations (Figure 8-2).

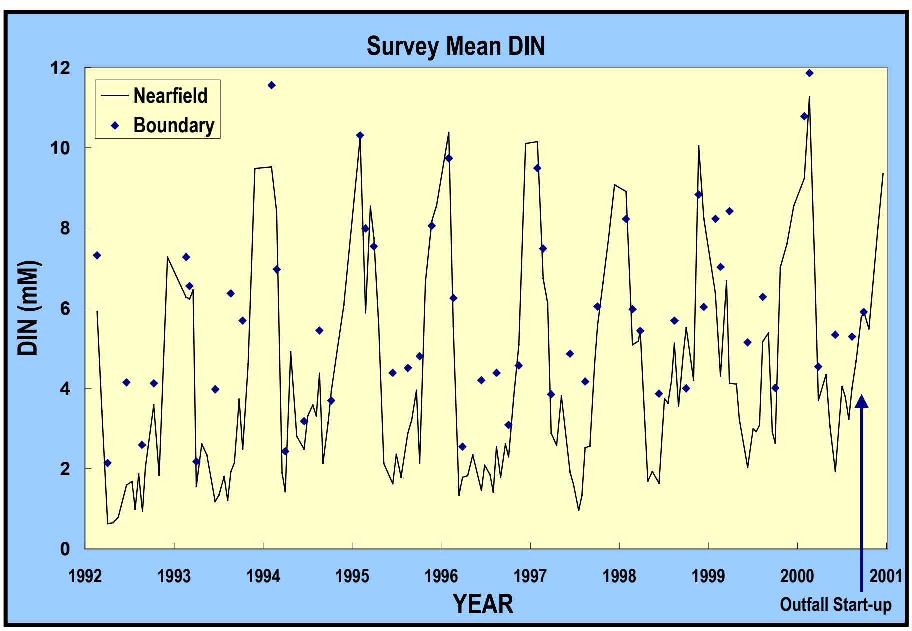

Figure 8-1. Survey mean dissolved inorganic nitrogen in the nearfield and at the boundary in the Stellwagen Bank National Marine Sanctuary

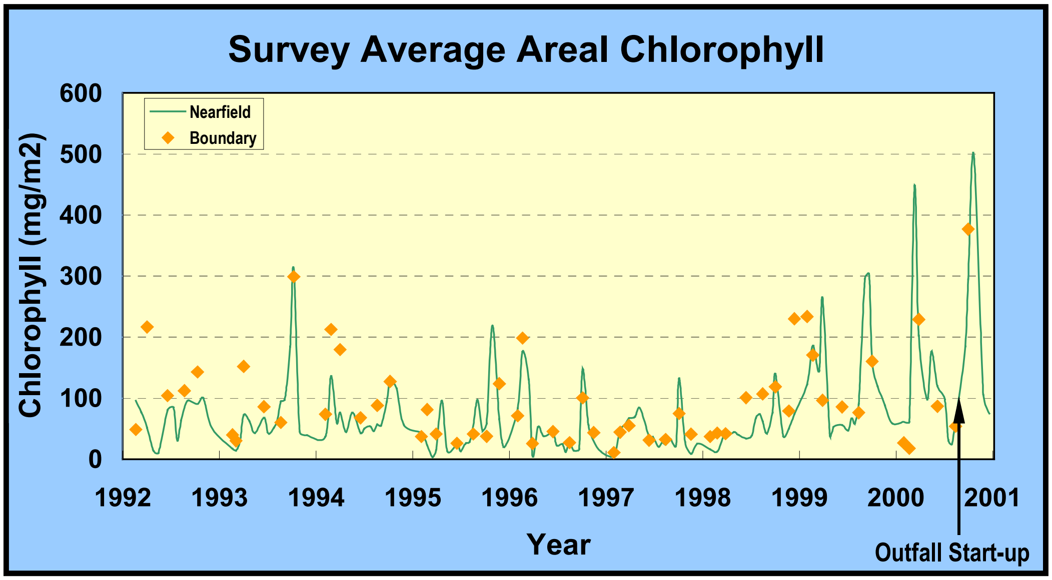

Figure 8-2. Survey mean areal chlorophyll levels in the nearfield and at the boundary in the Stellwagen Bank National Marine Sanctuary

The annual survey mean concentration of dissolved oxygen was 7.3 mg/l, slightly higher than the nearfield value, as is typical. Levels were within the range for dissolved oxygen concentrations in the baseline-sampling period (Figure 8-3). Percent oxygen saturation fell below 80% but was well above the background value.

In 2000, assemblages found in whole-water phytoplankton samples taken from the boundary area were very similar to those of other farfield stations and to nearfield stations, with the April *Phaeocystis* bloom being the most noticeable event in all geographic regions. Zooplankton assemblages were also similar for boundary, other farfield, and nearfield stations. The limited data collected after the outfall began operation in 2000 have provided no indication that effluent is transported to the sanctuary in concentrations that would adversely affect productivity or plankton communities.

Sea-floor studies for 2000 were completed prior to the outfall coming on line. In future years, MWRA will be able to evaluate possible effects of the outfall on the sanctuary by analyzing data from the two stations that are included within its borders and from another two stations in similar locations. During the baseline period, these four stations (FF04, FF05, FF11, and FF14) have had similar benthic communities, dominated by annelids. Multivariate analysis of infauna data from all farfield stations indicated that these four stations were similar enough to be considered one of four farfield “groups.” The other three groups could be defined by their location, depth, and sediment type and included (1) northern, shallow stations, (2) Cape Cod bay, shallow stations, and (3) stations with coarse sediments.

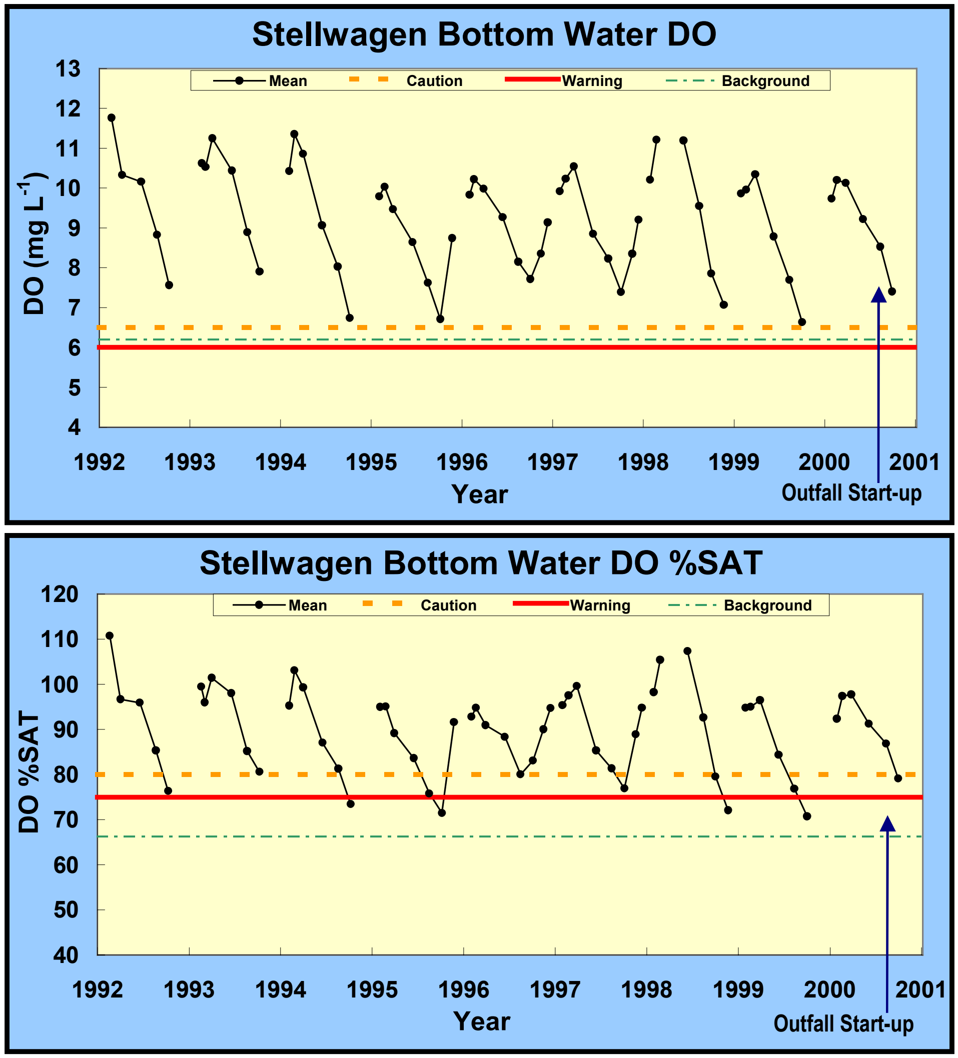

Figure 8-3. Survey mean dissolved oxygen concentrations and percent saturation in Stellwagen Basin, 1992-2000

The Stellwagen Basin and other deep stations have shown less similarity with respect to contaminant levels. The two offshore stations outside the sanctuary tend to be defined by slightly elevated levels of total PAHs, while slightly elevated levels of metals defined one of the stations within the sanctuary, and the other station did not align more closely with either group.

The bacteria monitoring that MWRA carries out in Massachusetts Bay includes two offshore stations located just shoreward from the sanctuary. Data from these stations showed no increase of fecal coliform or *Enterococcus* bacteria after the outfall opened (see Tables 7-1 and 7-2 in Section 7, Special Studies). Ongoing monitoring of these stations will provide an additional means of determining whether the outfall has any effect on the sanctuary.

One major concern of the sanctuary is for the whales that migrate through it and that feed within its boundaries. The sanctuary draws as many as one million whale watchers each year. As expected, most of the whales observed during MWRA surveys (discussed in Section 7, Special Studies) were seen in the sanctuary. Only a few humpback and fin whales used the Stellwagen Bank area in May (noted by the Whale Center of New England and reported in MacLeod *et al.* 2001). Whales were abundant over the southern flank of Stellwagen Bank from June through September, and over the entire area in October.

References

Anderson DM, Signell RP, McGillicuddy D. In press. Modeling toxic *Alexandrium* dynamics in the Gulf of Maine: progress to date. Ho KC, Wang ZD (eds.) Prevention and Management of Harmful Algal Blooms in the South China Sea. Hong Kong: Open University of Hong Kong School of Science and Technology.

Brown JH, Morgan Ernst SK, Parody JM, Haskell JP. 2001. Regulation of diversity: maintenance of species richness in changing environments. *Oecologia* 126:321-332.

EPA. 1988. Boston Harbor Wastewater Conveyance System. Supplemental Environmental Impact Statement (SEIS). Boston: Environmental Protection Agency Region 1.

Gayla DP, Bleiler J, Hickey K. 1996. Outfall monitoring overview report: 1994. Boston: Massachusetts Water Resources Authority. Report ENQUAD 1996-04. 50p.

Gayla DP, Zavistoski R, Williams I, Connor MS, Mickelson M, Keay K, Hall M, Cibik S, Sung W, Mitchell D, Blake J, Lieberman J, Wolf S, Hilbig B, Bleiler J, Hickey K, 1997a. Outfall monitoring overview report: 1995. Boston: Massachusetts Water Resources Authority. Report ENQUAD 1997-02. 61p.

Gayla DP, Zavistoski R, Maciolek N, Sung W, Cibik S, Mitchell D, Connor MS, Mickelson M, Keay K, Hall M, Blake J, Sullivan K, Hickey K. 1997b. Outfall monitoring overview report: 1996. Boston: Massachusetts Water Resources Authority. Report ENQUAD 1997-08. 57p.

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

Geyer WR, Signell RP, Anderson DM, Keafer BP. In preparation. The freshwater transport and dynamics of the Western Maine Coastal Current.

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 1999-14. 62p.

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

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 1995-8. 403p.

Kropp RK, Diaz RJ, Hecker B, Dahlen D, Boyle JD, Abramson SL, Emsbo-Mattingly S. 2001. 2000 outfall benthic monitoring report. Boston: Massachusetts Water Resources Authority. Report ENQUAD 2001-11. Draft.

Lefkovitz L, Abramson S., Field J. 2001. 2000 annual fish and shellfish report. Boston: Massachusetts Water Resources Authority. Report ENQUAD 2001-20. 143p.

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 1995-12. 37p.

Libby PS, Hunt CD, McLeod LA, Geyer WR, Keller AA, Oviatt CA. Turner JT. 2001. 2000 annual water column monitoring report. Boston: Massachusetts Water Resources Authority. Draft.

Long ER, MacDonald DD, Smith, SL Calder FD. 1995. Incidence of adverse biological effects within ranges of chemical concentrations in marine and estuarine sediments. *Environmental Management* 19:81-97.

Long ER, Morgan LG. 1991. Potential for Biological Effects of Sediment-sorbed Contaminants Tested in the National Status and Trends Program. U.S. Department of Commerce, National Oceanic and Atmospheric Administration. NOAA Technical Memorandum NOS OMA 52. 175 p.

McLeod LA. 2001. Summary of marine mammal observations during 2000 surveys. Boston: Massachusetts Water Resources Authority. Report ENQUAD 2000-01. 11p.

MWRA. 1991. Massachusetts Water Resources Authority effluent outfall monitoring plan: Phase I baseline studies. Boston: Massachusetts Water Resources Authority. Report ENQUAD ms-02. 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. Massachusetts Water Resources Authority contingency plan. Boston: Massachusetts Water Resources Authority. Report ENQUAD ms-069. 41p.

MWRA. 2001. Massachusetts Water Resources Authority contingency plan revision 1. Boston: Massachusetts Water Resources Authority. Report ENQUAD ms-071. 47 p.

Parmenter CM, Bothner MH. 1993. The distribution of *Clostridium perfringens*, a sewage indicator, in sediments of coastal Massachusetts. US Geologic Survey Open File Report 93-8.

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 1996-06. 22p.

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 1997-05. 32p.

Rex AC. 2000. The state of Boston Harbor 1997-1998: beyond the Boston Harbor project. Boston: Massachusetts Water Resources Authority. Report ENQUAD 2000-05. 24p.

Taylor DI. 2000. Inter-island transfer and water quality changes in the North Harbor and South Harbor regions of Boston Harbor, Massachusetts. Boston: Massachusetts Water Resources Authority. 2000-13.

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

Trulli HR, Coniaris C, Carroll SR, editors. 2000. Outfall Monitoring Science Advisory Panel technical workshop 1999 [CD-ROM]. Boston: Massachusetts Water Resources Authority. Report ENQUAD ms-57.

Tucker J, Giblin AE, Hopkinson CS Jr., Vasiliou D. 2001. Benthic nutrient cycling in Boston Harbor and Massachusetts Bay: 2000 annual report. Boston: Massachusetts Water Resources Authority. Report ENQUAD 2001-07.

USGS. 1997a. 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 1997b. Metals concentrations in sediments of Boston Harbor and Massachusetts Bay document environmental change. Woods Hole: U.S. Geological Survey. USGS Fact Sheet 150-97. 4p.

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.

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

Werme C, Hunt CD. 2000. 1999 Outfall monitoring overview. Boston: Massachusetts Water Resources Authority. Report ENQUAD 2000-14. 72p.

List of Acronyms

BEM	Bays Eutrophication Model
BIH	Boston Inner Harbor
BOD	Biochemical oxygen demand
cBOD	Carbonaceous biochemical oxygen demand
CCB	Cape Cod Bay
CD-ROM	Compact disk
CHV	Centrotubular hydropic vacuolation
C-NOEC	No observable effect concentration
CSO	Combined sewer overflow
DI	Deer Island
DIF	Deer Island Flats
DMF	Massachusetts Division of Marine Fisheries
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
MEG	Model Evaluation Group
MGD	Million gallons per day
MOU	Memorandum of understanding
MWRA	Massachusetts Water Resources Authority
NASA	National Air and Space Administration
NMFS	National Marine Fisheries Service
NPDES	National Pollutant Discharge Elimination System
OMSAP	Outfall Monitoring Science Advisory Panel
OMTF	Outfall Monitoring Task Force
OS	Outfall site
PAH	Polycyclic aromatic hydrocarbon
PCB	Polychlorinated biphenyl
PIAC	Public Interest Advisory Committee
RPD	Redox potential discontinuity
PSP	Paralytic shellfish poisoning
SeaWiFS	Sea-viewing Wide Field-of-view Sensor
SEIS	Supplemental Environmental Impact Statement
USGS	U.S. Geological Survey
TCR	Total chlorine residual
TOC	Total organic carbon
TSS	Total suspended solids
WHOI	Woods Hole Oceanographic Institution

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