2004 outfall monitoring overview

Massachusetts Water Resources Authority

Environmental Quality Department
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2004
Outfall Monitoring Overview

submitted to

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Summary

During 2004, the fourth full year of discharge from the Massachusetts Bay outfall, the Deer Island Treatment Plant operated as designed, with no detectable negative effects on the ecosystem of Massachusetts and Cape Cod bays. Total loads of many parameters measured within the effluent, including solids and metals, remain low.

After nine years of baseline monitoring and four years of post-discharge monitoring, the Massachusetts Water Resources Authority (MWRA) has been able to answer many of the questions that were posed when the program began (Table 1). As expected, monitoring has been able to detect minimal environmental responses in the immediate vicinity of the outfall. However, overall conditions within the bays have not changed from the baseline.

There were three Contingency Plan exceedances during the year (Table 2). On one day in April, the daily mean effluent fecal coliform bacteria count was slightly higher than the permit allowance. This excursion took place during a period of rough weather, so no field measurements could be taken; however, the rough weather also increased mixing, minimizing a chance for any environmental effect. As in 2002 and 2003, summer concentrations of the nuisance algal species *Phaeocystis pouchetii* exceeded the caution level. In 2004, the winter/spring concentration of *Phaeocystis pouchetii* also exceeded the caution level. As in 2002 and 2003, the wide geographical extent of the bloom suggests that regional processes, rather than the outfall, have been responsible for increasing frequency of *Phaeocystis* blooms.

As in other years, no effects of the outfall on the Stellwagen Bank National Marine Sanctuary have been detected. Plume tracking, water column, and sea floor studies suggested that no effects of the outfall on the sanctuary were likely.

During 2004, MWRA implemented several changes to the monitoring program, following a revised monitoring plan, which focuses on the potential for long-term chronic effects. Effluent monitoring remained unchanged. Nearfield water column sampling was reduced from 17 surveys of 21 stations to 12 surveys of 7 stations. Soft-bottom sampling began a rotation, in which approximately half the stations were sampled for identification and enumeration of animals, with the remainder of the stations to be sampled and analyzed in alternate years. Fish and shellfish sampling also began a rotation, in which samples will be analyzed for chemical constituents once every three years. These measurements of chemical constituents were not made during 2004.

Table 1. Summary of monitoring questions and status as of the end of 2004

Monitoring Question	Status
Do effluent pathogens exceed the permit limits?	Pathogenic viruses detectable in the final effluent but at very low numbers: secondary treatment effectively removes pathogens.
Does acute or chronic toxicity of effluent exceed the permit limit?	General compliance with permit limits.
Do effluent contaminant concentrations exceed permit limits?	Compliance with permit limits. Discharges of priority pollutants well below SEIS predictions and in most cases meet receiving water quality criteria even before dilution.
Do conventional pollutants in the effluent exceed permit limits?	General compliance: discharges of solids and BOD have decreased by 80% compared to the old treatment plant.
What are the concentrations of contaminants in the influent and effluent and their associated variability?	High removal by treatment system with consistently low concentrations since secondary treatment brought on line.
Do levels of contaminants in water outside the mixing zone exceed water quality standards?	Water quality standards not exceeded, confirmed by plume studies conducted in 2001 and ongoing effluent monitoring.
Are pathogens transported to shellfish beds at levels that might affect shellfish consumer health?	Dilution is sufficient for pathogens to reach background concentrations before reaching shellfish beds, confirmed by plume studies conducted in 2001. Indicator bacteria surveys and adverse condition surveys in Massachusetts Bay did not detect appreciable levels of indicator bacteria in the region of the outfall.
Are pathogens transported to beaches at levels that might affect swimmer health?	Dilution is sufficient for pathogens to reach background concentrations before reaching beaches, confirmed by plume studies conducted in 2001. Pathogen surveys and adverse condition surveys in Massachusetts Bay did not detect appreciable levels of indicator bacteria in the region of the outfall.
Has the clarity and/or color of the water around the outfall changed?	Although clarity and color have not changed, there are occasional observations of tiny bits of grease, similar to samples collected at the treatment plant.
Has the amount of floatable debris around the outfall changed?	Floatable debris of concern is rare in the effluent. Signs of effluent can occasionally be detected in the field.
Are the model estimates of short-term (less than 1 day) effluent dilution and transport accurate?	Model estimates accurate, confirmed by plume studies conducted in 2001.
What are the nearfield and farfield water circulation patterns?	Flow is controlled by general circulation in the Gulf of Maine, affected by tides and local wind. Bottom currents around the outfall can flow in any direction with no mean flow.
What is the farfield fate of dissolved, conservative, or long-lived effluent constituents?	Changes in farfield concentrations of salinity and dissolved components not detected within tens of meters of outfall and not observed in farfield water or sediments.
Have nutrient concentrations changed in the water near the outfall; have they changed at farfield stations in Massachusetts Bay or Cape Cod Bay, and, if so, are they correlated with changes in the nearfield?	Changes consistent with model predictions. The effluent signature is clearly observed in the vicinity or the outfall but is diluted over a few days and 10s of kilometers.
Do the concentrations (or percent saturation) of dissolved oxygen in the water column meet the state water quality standards?	Conditions unchanged from background.

Monitoring Question	Status
Have the concentrations (or percent saturation) of dissolved oxygen in the vicinity of the outfall or at selected farfield stations in Massachusetts Bay or Cape Cod Bay changed relative to pre-discharge baseline or a reference area? If so, can changes be correlated with effluent or ambient water nutrient concentrations, or can farfield changes be correlated with nearfield changes?	Conditions not changed from background.
Has the phytoplankton biomass changed in the vicinity of the outfall or at selected farfield stations in Massachusetts Bay or Cape Cod Bay, and, if so, can these changes be correlated with effluent or ambient water nutrient concentrations, or can farfield changes be correlated with nearfield changes?	No substantial change detected.
Have the phytoplankton production rates changed in the vicinity of the outfall or at selected farfield stations, and, if so, can these changes be correlated with effluent or ambient water nutrient concentrations, or can farfield changes be correlated with nearfield changes?	Timing of the fall blooms in the nearfield appears to be different, but this change may not be associated with the discharge. Productivity patterns in Boston Harbor may be changing, as the area transitions from eutrophic conditions to a more typical coastal regime.
Has the abundance of nuisance or noxious phytoplankton changed in the vicinity of the outfall?	No outfall-related change detected. Frequency of *Phaeocystis* blooms has increased, but the phenomenon is regional in nature.
Has the species composition of phytoplankton or zooplankton changed in the vicinity of the outfall or at selected farfield stations in Massachusetts Bay or Cape Cod Bay? If so, can these changes be correlated with effluent of ambient water nutrient concentrations, or can farfield changes be correlated with nearfield changes?	No change detected.
What is the level of sewage contamination and its spatial distribution in Massachusetts and Cape Cod bays sediments before discharge through the new outfall?	Effects of historic inputs from Boston Harbor and other sources detected.
Has the level of sewage contamination or its spatial distribution in Massachusetts and Cape Cod bays sediments changed after discharge through the new outfall?	Effluent signal detected as *Clostridium perfringens* spores, the most sensitive sewage tracer, within a few kilometers of the outfall.
Has the concentration of contaminants in sediments changed?	No general increase in contaminants. Effluent signal can be detected as silver, a sensitive sewage tracer, in sediment traps and as *Clostridium perfringens* spores in sediments within 2 km of the diffuser.
Has the soft-bottom community changed?	Possible localized change reflected by high number of animals in the nearfield in 2002 (decrease in 2004).
Have the sediments become more anoxic; that is, has the thickness of the sediment oxic layer decreased?	No change in total organic carbon or sediment RPD detected.
Are any benthic community changes correlated with changes in levels of toxic contaminants (or sewage tracers) in sediments?	No change detected.
Has the hard-bottom community changed?	Small increase in sediment drape on hard-bottom surfaces detected at a subset of stations; not yet known whether these changes are related to the outfall.

Monitoring Question	Status
How do the sediment oxygen demand, the flux of nutrients from the sediment to the water column, and denitrification influence the levels of oxygen and nitrogen in the water near the outfall?	Described by baseline monitoring; conditions do not suggest adverse changes have resulted from moving outfall offshore.
Have the rates of these processes changed?	No short-term changes.
Has the level of contaminants in the tissues of fish and shellfish around the outfall changed since discharge began?	No short-term changes in flounder or lobster contaminant body burdens. Detectable increases in PAHs and chlordane in mussels deployed at the outfall. Mercury concentrations in flounder tissue have been elevated in 2003 and 2004.
Do the levels of contaminants in the edible tissue of fish and shellfish around the outfall represent a risk to human health?	No short-term changes that would pose a threat to human health. Regional patterns have persisted since the baseline period, and there appears to be a general long-term downward trend for most contaminant levels.
Are the contaminant levels in fish and shellfish different between the outfall, Boston Harbor, and a reference site?	Differences documented during baseline monitoring. Regional patterns have persisted since the diversion.
Has the incidence of disease and/or abnormalities in fish or shellfish changed?	Blind-side skin lesions found on flounder from western Massachusetts Bay. Appear to be seasonal manifestations, and their cause has not been attributed to the outfall. Long-term downward trend in liver disease.

Table 2. Summary of Contingency Plan thresholds and exceedances as of 2004. (NA = not applicable, ✓ = no exceedance, **C** *= caution level exceedance,* **W** *= warning level exceedance)*

Location/ Parameter Type	Parameter	2000	2001	2002	2003	2004
Effluent						
	pH	**W**	✓	✓	✓	✓
	Fecal coliform bacteria, monthly	✓	✓	✓	✓	✓
	Fecal coliform bacteria, weekly	✓	✓	✓	✓	✓
	Fecal coliform bacteria, daily	✓	**W**	✓	✓	**W**
	Fecal coliform bacteria, 3 consecutive days	✓	✓	✓	✓	✓
	Chlorine residual, daily	**W**	✓	✓	✓	✓
	Chlorine residual, monthly	✓	✓	✓	✓	✓
	Total suspended solids, weekly	✓	✓	**W**	✓	✓
	Total suspended solids, monthly	✓	✓	**W**	✓	✓
	cBOD, weekly	✓	✓	✓	✓	✓
	cBOD, monthly	✓	✓	✓	✓	✓
	Acute toxicity, mysid shrimp	✓	✓	✓	✓	✓
	Acute toxicity, fish	✓	✓	✓	✓	✓
	Chronic toxicity, fish	✓	**W**	✓	✓	✓
	Chronic toxicity, sea urchin	✓	**W**	✓	✓	✓
	PCBs	✓	✓	✓	✓	✓
	Plant performance	✓	✓	✓	✓	✓
	Flow	NA	✓	✓	✓	✓
	Total nitrogen load	NA	✓	✓	✓	✓
	Floatables	NA	NA	NA	NA	NA
	Oil and grease	✓	✓	✓	✓	✓
Water Column						
Nearfield bottom water	Dissolved oxygen concentration	**C**	✓	✓	✓	✓
	Dissolved oxygen saturation	**C**	✓	✓	✓	✓
Stellwagen Basin bottom water	Dissolved oxygen concentration	✓	✓	✓	✓	✓
	Dissolved oxygen saturation	✓	✓	✓	✓	✓
Nearfield bottom water	Dissolved oxygen depletion rate (June-October)	NA	✓	✓	✓	✓
Nearfield chlorophyll	Annual	NA	✓	✓	✓	✓
	Winter/spring	NA	✓	✓	✓	✓
	Summer	NA	✓	✓	✓	✓
	Autumn	**C**	✓	✓	✓	✓

Location/ Parameter Type	Parameter	2000	2001	2002	2003	2004
Nearfield nuisance algae *Phaeocystis pouchetii*	Winter/spring	NA	✓	✓	✓	C
	Summer	NA	✓	C	C	C
	Autumn	✓	✓	✓	✓	✓
Nearfield nuisance algae *Pseudonitzchia*	Winter/spring	NA	✓	✓	✓	✓
	Summer	NA	✓	✓	✓	✓
	Autumn	✓	✓	✓	✓	✓
Nearfield nuisance algae *Alexandrium fundyense*	Any sample	✓	✓	✓	✓	✓
Farfield shellfish	PSP toxin extent	✓	✓	✓	✓	✓
Plume	Initial dilution	NA	✓	Completed		
Sea Floor						
Nearfield sediment	RPD depth	NA	✓	✓	✓	✓
Nearfield benthic diversity	Species per sample	NA	✓	✓	✓	✓
	Fisher's log-series alpha	NA	✓	✓	✓	✓
	Shannon diversity	NA	✓	✓	✓	✓
	Pielou's evenness	NA	✓	✓	✓	✓
Nearfield species composition	Percent opportunists	NA	✓	✓	✓	✓
Fish and Shellfish						
Nearfield flounder tissue	Total PCBs	NA	✓	✓	✓	NA
	Mercury	NA	✓	✓	✓	NA
	Chlordane	NA	✓	✓	✓	NA
	Dieldrin	NA	✓	✓	✓	NA
	Total DDTs	NA	✓	✓	✓	NA
Nearfield flounder	Liver disease (CHV)	NA	✓	✓	✓	✓
Nearfield lobster tissue	Total PCBs	NA	✓	✓	✓	NA
	Mercury	NA	✓	✓	✓	NA
	Chlordane	NA	✓	✓	✓	NA
	Dieldrin	NA	✓	✓	✓	NA
	Total DDTs	NA	✓	✓	✓	NA
Nearfield mussel tissue	Total PCBs	NA	✓	✓	✓	NA
	Lead	NA	✓	✓	✓	NA
	Mercury	NA	✓	✓	✓	NA
	Chlordane	NA	C	C	✓	NA
	Dieldrin	NA	✓	✓	✓	NA
	Total DDTs	NA	✓	✓	✓	NA
	Total PAHs	NA	C	C	C	NA

1. Introduction

Background

For 20 years, the Massachusetts Water Resources Authority (MWRA) has worked to end long-standing violations of the Clean Water Act and to minimize the effects of wastewater discharge on the marine environment. Before MWRA was created in 1985, the Boston metropolitan area discharged both sewage sludge and inadequately treated sewage effluent into the confined waters of Boston Harbor, from outfalls located at Deer Island in the northern part of the harbor and Nut Island, in the southern Quincy Bay. MWRA ended discharge of municipal sludge into northern and southern Boston Harbor in 1991, when sludge from both treatment plants began to be barged to a processing plant in Quincy and made into fertilizer. Steps to minimize effects of effluent discharge have included:

- **Source reduction** to prevent pollutants from entering the waste stream.
- **Improved treatment** before discharge.
- **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 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.

Improved treatment was implemented in a series of steps carried out during 1995-2001. In 1995, a new primary treatment plant at Deer Island was brought on line, and disinfection facilities were completed. (Primary treatment involves removal of solids through settlement and disinfection.) Batteries of secondary treatment (which includes bacterial decomposition as well as settlement and disinfection) went on line in 1997, 1998, and 2001. Also during 1998, discharge from the Nut Island Treatment Plant into Quincy Bay ceased, and all wastewater was conveyed to Deer Island for treatment, ending effluent discharge to the southern part of the harbor.

Better dilution was achieved in 2000, 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).

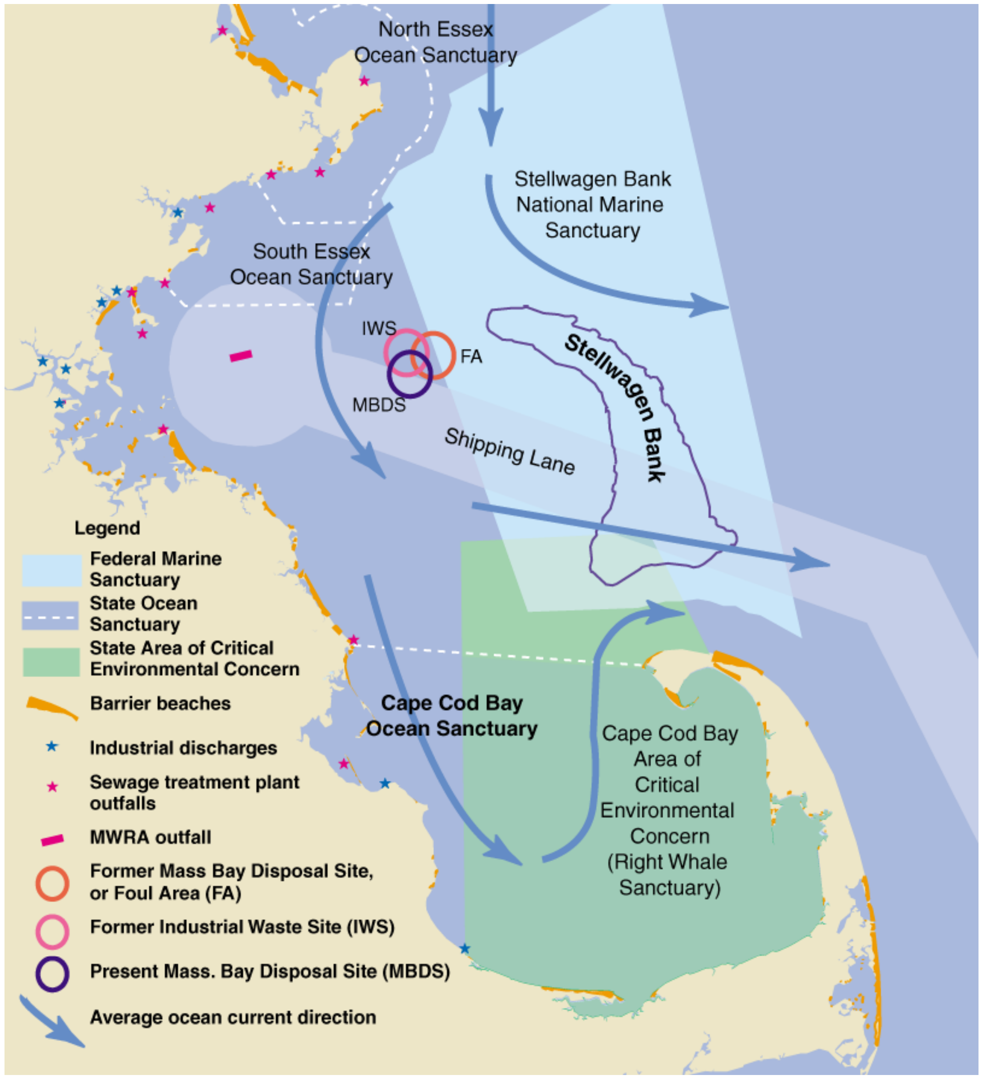


Figure 1-1. Map of Massachusetts and Cape Cod bays

The outfall site was selected because it had a water depth and current patterns that would promote effective dilution, it was the least likely of the alternative sites to affect sensitive resources, and it was feasible to construct an outfall tunnel to the location.

The outfall tunnel is bored through bedrock and has a diffuser system made up of 53 risers, each with five or six open ports, along its final 1.25 miles. Discharge from the diffuser heads is at the sea floor, at water depths of about 100 feet. Initial dilution at the outfall is about five times that of the Boston Harbor outfall, which was shallower, in 50 feet of water. The offshore location of the outfall diffuser ensures that effluent will not reach beaches or shellfish beds within a tidal cycle, even if currents are shoreward.

For many of the components of MWRA's work, there was little or no argument that the project benefited the marine environment and the people of the region. One aspect of the project, moving the effluent outfall from the harbor to Massachusetts Bay, raised some concerns, which were expressed as general, continuing questions:

- Is it safe to eat fish and shellfish?
- Are natural/living resources protected?
- Is it safe to swim?
- Are aesthetics being maintained?

These concerns were recognized by MWRA and by the permit for the outfall issued jointly by the U.S. Environmental Protection Agency (EPA) and the Massachusetts Department of Environmental Protection (MADEP).

Outfall Permit

The permit issued by EPA and MADEP under the National Pollutant Discharge Elimination System (NPDES) became effective on August 9, 2000 and continued until August 9, 2005. (After expiration, MWRA operates under the conditions of the permit until a new permit is issued.) It limits discharges of pollutants and requires reporting on the treatment plant operation and maintenance. The permit requires MWRA to continue its ongoing pollution prevention program and to employ 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 a monitoring plan (MWRA 1991, 1997a, 2004) developed in response to the EPA Supplemental Environmental Impact Statement (SEIS) prepared as part of the outfall-siting process (EPA 1988). It requires that MWRA implement a Contingency Plan (MWRA 1997b, 2001), which identifies relevant environmental quality parameters and thresholds that, if exceeded, would require a response.

In 1998, in anticipation of the permit, EPA and MADEP established an independent panel of scientists to review monitoring data and provide advice on key scientific issues related to the permit. This panel, the Outfall Monitoring Science Advisory Panel (OMSAP, Table 1-1), conducts peer reviews of monitoring reports, evaluates the data, and advises EPA and MADEP on scientific 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. 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 2004
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 Vakalopoulos, MA Department of Environmental Protection (OMSAP staff)
Winifred Donnolly, MA Department of Environmental Protection (staff)

IAAC as of December 2004	**PIAC as of December 2004**
MA Coastal Zone Management	Patty Foley (chair, representative of Save the Harbor/Save the Bay)
Todd Callaghan	Association for the Preservation of Cape Cod
Jan Smith (alternate)	Maggie Geist
MA Department of Environmental Protection	Tara Nye (alternate)
Catherine Coniaris Vakalopoulos	Bays Legal Fund
MA Division of Marine Fisheries	Wayne Bergeron
Jack Schwartz	The Boston Harbor Association
National Marine Fisheries Service	Vivian Li
David Dow	Cape Cod Commission
Stellwagen Bank National Marine Sanctuary	John Lipman
Ben Haskell	Steve Tucker (alternate)
US Army Corps of Engineers	Center for Coastal Studies
Thomas Fredette	Peter Borrelli
US Environmental Protection Agency	Conservation Law Foundation
Matthew Liebman	Priscilla Brooks
US Geological Survey	New England Aquarium
Michael Bothner	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)
	Wastewater Advisory Committee
	Edward Bretschneider

Monitoring Program

EPA and MADEP require monitoring to ensure compliance with the permit, to assess whether the outfall has effects beyond the area identified in the SEIS as acceptable, and to collect data useful for outfall management. In anticipation of these requirements, MWRA began some studies during 1989-1991 and implemented a broad baseline-monitoring program in 1992. Outfall ambient monitoring plans were originally developed and refined under the direction of an Outfall Monitoring Task Force (OMTF), made up of scientists, regulators, and environmental advocacy groups (MWRA 1991, 1997a). (The OMTF was disbanded upon creation of OMSAP.) Because the first years of monitoring following diversion of effluent to the bay found no unexpected changes to the system, changes to the plan that eliminated unnecessary work were proposed during 2003. A new plan (MWRA 2004) was implemented in the 2004 monitoring year.

The outfall ambient monitoring plan expands the general questions of public concern by translating them into possible "environmental responses," which are more specific questions directly related to the outfall (Table 1-2). To answer those questions, the monitoring program focuses on critical constituents of treatment plant effluent, such as nutrients, organic material, toxic contaminants, pathogens, and solids. Presence and potential effects of these constituents are evaluated within the context of four environmental measurement areas: effluent, water column, sea floor, and fish and shellfish (Table 1-3).

The basic program is augmented by special studies, which 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 construction allowed a relatively long period for baseline studies. Consequently, MWRA was able to document greater natural variability and develop a better understanding of the system than would have been possible in a briefer baseline period. MWRA was also able to evaluate the environmental response in Boston Harbor to other facilities improvements (*e.g.*, Leo *et al.* 1995, Pawlowski *et al.* 1996, Rex and Connor 1997, Rex 2000, Rex *et al.* 2002, Taylor 2002, 2003, 2004). The extended period also meant that the discharge to Massachusetts Bay, when it 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 continued measurements. MWRA's NPDES permit allows an annual list of proposed changes to the monitoring plan.

Table 1-2. Public concerns and environmental responses presented in the monitoring plan (MWRA 1991)

Public Concern: Is it safe to eat fish and shellfish? ▪ Will toxic chemicals accumulate in the edible tissues of fish and shellfish, and thereby contribute to human health problems? ▪ Will pathogens in the effluent be transported to shellfishing areas where they could accumulate in the edible tissues of shellfish and contribute to human health problems?
Public Concern: Are natural/living resources protected? ▪ Will nutrient enrichment in the water column contribute to an increase in primary production? ▪ Will enrichment of organic matter contribute to an increase in benthic respiration and nutrient flux to the water column? ▪ Will increased water-column and benthic respiration contribute to depressed oxygen levels in the water? ▪ Will increased water-column and benthic respiration contribute to depressed oxygen levels in the sediment? ▪ Will nutrient enrichment in the water column contribute to changes in plankton community structure? (Such changes could include stimulation of nuisance or noxious algal blooms and could affect fisheries.) ▪ Will benthic enrichment contribute to changes in community structure of soft-bottom and hard-bottom macrofauna, possibly also affecting fisheries? ▪ Will the water column near the diffuser mixing zone have elevated levels of some contaminants? ▪ Will contaminants affect some size classes or species of plankton and thereby contribute to changes in community structure and/or the marine food web? ▪ Will finfish and shellfish that live near or migrate by the diffuser be exposed to elevated levels of some contaminants, potentially contributing to adverse health in some populations? ▪ Will the benthos near the outfall mixing zone and in depositional areas farther away accumulate some contaminants? ▪ Will benthic macrofauna near the outfall mixing zone be exposed to some contaminants, potentially contributing to changes in community structure?
Public Concern: Is it safe to swim? ▪ Will pathogens in the effluent be transported to waters near swimming beaches, contributing to human health problems?
Public Concern: Are aesthetics being maintained? ▪ Will changes in water clarity and/or color result from the direct input of effluent particles or other colored constituents, or indirectly through nutrient stimulation of nuisance plankton species? ▪ Will the loading of floatable debris increase, contributing to visible degradation?

Table 1-3. Summary of the monitoring program

Task	Objective	Analyses
Effluent		
Effluent sampling	Characterize wastewater discharge from Deer Island Treatment Plant	Flow Organic material (cBOD) Solids pH Bacterial indicators Total residual chlorine Toxicity Nutrients Toxic contaminants Floatables
Water Column		
Nearfield surveys	Collect water quality data near outfall location	Temperature Salinity Dissolved oxygen Nutrients Solids Chlorophyll Water clarity Photosynthesis Respiration Phytoplankton Zooplankton
Farfield surveys	Collect water quality data throughout Massachusetts and Cape Cod bays	
Moorings (GoMOOS and USGS)	GoMOOS near Cape Ann and USGS near outfall provide continuous oceanographic data near outfall location	Currents Temperature Salinity Water clarity Chlorophyll
Remote sensing	Provides oceanographic data on a regional scale through satellite imagery	Surface temperature Chlorophyll
Sea Floor		
Soft-bottom studies	Evaluate sediment quality and benthos in Boston Harbor and Massachusetts Bay	Sediment chemistry Sediment profile imagery Community composition
Hard-bottom studies	Characterize marine benthic communities in rock and cobble areas	Topography Substrate Community composition
Fish and Shellfish		
Winter flounder	Determine contaminant body burden and population health	Tissue contaminant concentrations Physical abnormalities, including liver histopathology
American lobster	Determine contaminant body burden	Tissue contaminant concentrations Physical abnormalities
Blue mussel	Evaluate biological condition and potential contaminant bioaccumulation	Tissue contaminant concentrations

Contingency Plan

The MWRA Contingency Plan (MWRA 1997b, 2001) 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 parameters that represent environmentally significant components of the effluent or the ecosystem and that, if specific threshold levels are exceeded, indicate a potential for environmental risk (Table 1-4). The plan provides a process for evaluating parameters that exceed thresholds and formulating appropriate responses.

Table 1-4. Contingency Plan threshold parameters

Measurement Area	Parameter
Effluent	pH Fecal coliform bacteria Residual chlorine Total suspended solids Biochemical oxygen demand Toxicity PCBs Plant performance Flow Total nitrogen load Floatables Oil and grease
Water Column	Dissolved oxygen concentration and saturation Dissolved oxygen depletion rate Chlorophyll Nuisance and noxious algae Effluent dilution
Sea Floor	Redox potential discontinuity depth Benthic community structure
Fish and Shellfish	PCBs, mercury, chlordanes, dieldrin, and DDTs in mussels and flounder and lobster tissue Lead in mussels Liver disease in flounder

Threshold values, the measurements selected as indicators of the need for action, are based on permit limits, state water quality standards, and expert opinion. To alert MWRA to any changes, some parameters have more conservative "caution" as well as "warning" thresholds. Exceeding caution or warning thresholds could indicate a need for increased attention or study. If a caution 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 making adjustments in plant operations or undertaking an engineering feasibility study regarding specific potential corrective activities.

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. Revision 1 to the Contingency Plan was approved during 2001.

Data Management

The monitoring program has generated extensive data sets. 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 or threshold calculations, 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 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 regular reports on effluent quality and extensive reporting on the monitoring program. A variety of reports are submitted to OMSAP for review (Table 1-5). Changes to the monitoring program or the associated 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 1-5. 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, 2004)	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.
Special Studies Reports	Discuss, analyze, and cross-synthesize data related to specific 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, has been prepared for most baseline-monitoring years and for each year that the permit has been in place (Gayla *et al.* 1996, 1997a, 1997b, Werme and Hunt 2000a, 2000b, 2001, 2002, 2003, 2004). The report includes a scientific summary for the year of monitoring. Overviews for 1995-1999 included only baseline information. With the outfall operational, subsequent reports have included information relevant to the Contingency Plan, such as data that exceeded thresholds, responses, and corrective actions. When data suggest that monitoring activities, parameters, or thresholds should be changed, the report summarizes those recommendations.

This year's outfall monitoring overview presents monitoring program results for effluent and field data for 2004. It compares all results to Contingency Plan thresholds. The overview also includes a section on data relevant to the Stellwagen Bank National Marine Sanctuary.

2. Effluent

Background

Pollution Prevention and Wastewater Treatment

Ensuring that the final treated effluent is clean is the most important element in MWRA's strategy to improve the environmental quality of Boston Harbor without degrading Massachusetts and Cape Cod bays. MWRA ensures clean effluent through a vigorous pretreatment program and by maintaining and operating the treatment plant well.

The MWRA Toxic Reduction and Control Program (TRAC) sets and enforces limits on the types and amounts of pollutants that industries can discharge into the sewer system and works with industries to encourage voluntary reductions in their use of toxic chemicals. TRAC has also implemented programs to reduce mercury from dental facilities and to educate the public about proper disposal of hazardous wastes. A booklet, *A Healthy Environment Starts at Home* (available at www.mwra.com), identifies household products that could be hazardous and recommends alternatives.

Secondary treatment further reduces the concentrations of contaminants of concern, except for nutrients. The Deer Island Treatment Plant removes approximately 85-90% of the suspended solids and biochemical oxygen demand (BOD), 50-90% of the toxic chemicals, and about 20% of the nitrogen from the influent.

To prevent accidental discharge of pollutants and mitigate effects should an accident occur, MWRA has implemented best management practice plans at the treatment plant, its headworks facilities, the combined sewer overflow facilities, its pumping stations, and the sludge-to-fertilizer plant. The plans include daily visual inspections and immediate corrective actions. Effectiveness of best management practices is assessed by non-facility staff.

Environmental Concerns

Sewage effluent contains a variety of contaminants that can, at too high levels, affect the marine environment, public health, and aesthetics. The MWRA permit sets limits on these contaminants so as to ensure that these attributes will be protected. Several specific questions in the MWRA ambient monitoring plan respond to public concerns and possible environmental responses by addressing whether the effluent is meeting permit limits (Table 2-1). Other questions require the use of effluent data in conjunction with plume studies (Hunt *et al.* 2002a, 2002b) and water column monitoring (see Section 3, Water Column).

Table 2-1. Monitoring questions related to effluent monitoring

Is it safe to eat fish and shellfish? *Will pathogens in the effluent be transported to shellfishing areas where they could accumulate in the edible tissues of shellfish and contribute to human health problems?* ▪ Do effluent pathogens exceed the permit limit? ▪ Are pathogens transported to shellfish beds at levels that might affect shellfish consumer health?
Are natural/living resources protected? *Will the water column near the diffuser-mixing zone have elevated levels of some contaminants?* ▪ Do effluent contaminant concentrations exceed permit limits? ▪ What are the concentrations of contaminants and characteristic tracers of sewage in the influent and effluent and their associated variability? *Will finfish and shellfish that live near or migrate by the diffuser be exposed to elevated levels of some contaminants, potentially contributing to adverse health in some populations?* ▪ Does acute or chronic toxicity of effluent exceed permit limits? ▪ Do levels of contaminants in water outside the mixing zone exceed state water quality standards?
Is it safe to swim? *Will pathogens in the effluent be transported to waters near swimming beaches, contributing to human health problems?* ▪ Do effluent pathogens exceed the permit limit? ▪ Are pathogens transported to beaches at levels that might affect swimmer health?
Are aesthetics being maintained? *Will changes in water clarity and/or color result from the direct input of effluent particles or other colored constituents, or indirectly through nutrient stimulation of nuisance plankton species?* *Will the loading of floatable debris increase, contributing to visible degradation?* ▪ Do conventional pollutants in the effluent exceed permit limits? ▪ Has the clarity and/or color of the water around the outfall changed? ▪ Has the amount of floatable debris around the outfall changed?

The effluent constituents of greatest concern include pathogens, toxic contaminants, organic material, solid material, nutrients, oil and grease, and "floatables," including plastic and other debris. The MWRA permit also sets limits for chlorine and pH:

- **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.
- **Toxic contaminants** include heavy metals, such as copper and lead, polychlorinated biphenyls (PCBs), pesticides, polycyclic aromatic hydrocarbons (PAHs), and petroleum hydrocarbons. Toxic contaminants can lower survival and reproduction rates of marine organisms. Some toxic contaminants can accumulate in

marine life, potentially affecting human health through seafood consumption.

- **Organic material**, a major constituent of sewage, 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 animal communities on the sea floor.
- **Suspended solids**, small particles 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.
- 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.
- **Oil and grease** slicks and floating debris known as **floatables** pose aesthetic concerns. 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 marine mammals. Plastic and other debris can also entangle animals and cause them to drown.
- Sewage effluent is disinfected by addition of a form of **chlorine**, sodium hypochlorite, which is the active ingredient in bleach. While sodium hypochlorite is effective in destroying pathogens, at high enough concentrations, it is harmful to marine life. Consequently, MWRA dechlorinates the effluent with sodium bisulfite before discharge.
- 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 on a scale of 1 to 14. Consequently, the outfall permit sets both upper and lower values for pH of the effluent.

Monitoring Design

Effluent monitoring measures the concentrations and variability of constituents of the effluent to assess compliance with NPDES permit limits, which are based on state and federal water quality standards and criteria and on ambient conditions. Effluent monitoring also provides accurate mass loads of effluent constituents, so that fate, transport, and risk of contaminants can be assessed.

The permit includes numeric limits (Table 2-2) for suspended solids, fecal coliform bacteria, pH, chlorine, 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 any of those limits.

Table 2-2. Reporting requirements of the outfall permit

Parameter	Sample Type	Frequency	Limit
Permit-required monitoring			
Flow	Flow meter	Continuous	Report only
Flow dry day	Flow meter	Continuous	436 MGD annual average
cBOD	24-hr composite	1/day	40 mg/l weekly 25 mg/l monthly
TSS	24-hr composite	1/day	45 mg/l weekly 30 mg/l monthly
pH	Grab	1/day	Not <6 or >9
Fecal coliform bacteria	Grab	3/day	14,000 col/100ml
Total residual chlorine	Grab	3/day	631 µg/l daily 456 µg/l monthly
PCB, Aroclors	24-hr composite	1/month	0.045 ng/l
Toxicity LC50	24-hr composite	2/month	50%
Toxicity C-NOEC	24-hr composite	2/month	1.5%
Settleable solids	Grab	1/day	Report only
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	
Contingency Plan-required monitoring			
Oil and grease, as petroleum hydrocarbons	Grab	Weekly	Warning threshold/ 15 mg/l
Floatables	Continuous	Under development	
Plant performance	Ongoing		5 violations/year

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 limits based on the tests. Allowable concentrations of contaminants were based on the predicted dilution at the outfall, which was verified in the field during 2001.

Most parameters are measured in 24-hour composite samples, and some must meet daily, weekly, or monthly limits. Flow is measured continuously. Nutrient measurements include total nitrogen, ammonia, nitrate, and nitrite. 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 fish (*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.

The Contingency Plan also sets limits for overall plant performance, annual nitrogen load, floatables, and oil and grease. Methods for measuring floatables remain under development.

Beyond the requirements of ordinary discharge monitoring, the MWRA monitoring plan requires additional nutrient measurements and non-standard, low-detection methods to measure toxic contaminants (Table 2-3). These measurements are made to better interpret field-monitoring results.

The monitoring plan also calls for an evaluation of indicators of human pathogens. To date, MWRA has collected data on anthropogenic viruses, viral indicators, and *Enterococcus* bacteria in the influent and effluent. Section 6, Special Studies, reports on virus monitoring in Boston Harbor and the Charles River.

Table 2-3. Monitoring plan parameters for effluent

Parameter	Sample Type	Frequency
Total Kjeldahl nitrogen	Composite	Weekly
Ammonia	Composite	Weekly
Nitrate	Composite	Weekly
Nitrite	Composite	Weekly
Total phosphorus	Composite	Weekly
Total phosphate	Composite	Weekly
Acid base neutrals	Composite	Bimonthly
Volatile organic compounds	Grab	Bimonthly
Cadmium	24-hour composite	Weekly
Copper	24-hour composite	Weekly
Chromium	24-hour composite	Weekly
Mercury	24-hour composite	Weekly
Lead	24-hour composite	Weekly
Molybdenum	24-hour composite	Weekly
Nickel	24-hour composite	Weekly
Silver	24-hour composite	Weekly
Zinc	24-hour composite	Weekly
17 chlorinated pesticides	24-hour composite	Weekly
Extended list of PAHs	24-hour composite	Weekly
20 PCB congeners	24-hour composite	Weekly

Results

Average daily flow of effluent from the Deer Island Treatment Plant in 2004 was slightly lower than in 2003 (Figure 2-1). Approximately 90% of the flow received secondary treatment.

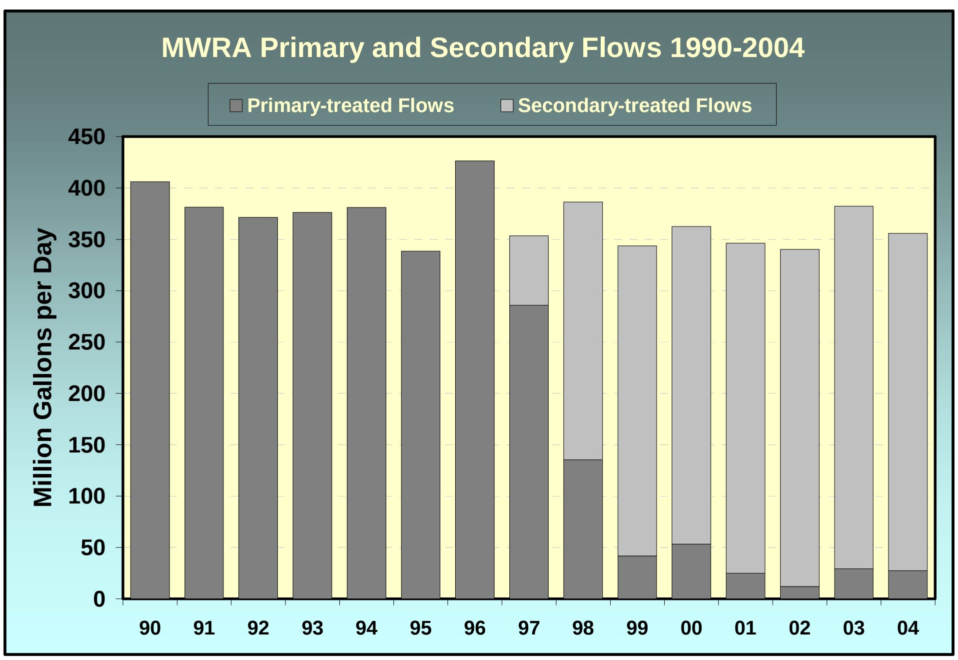
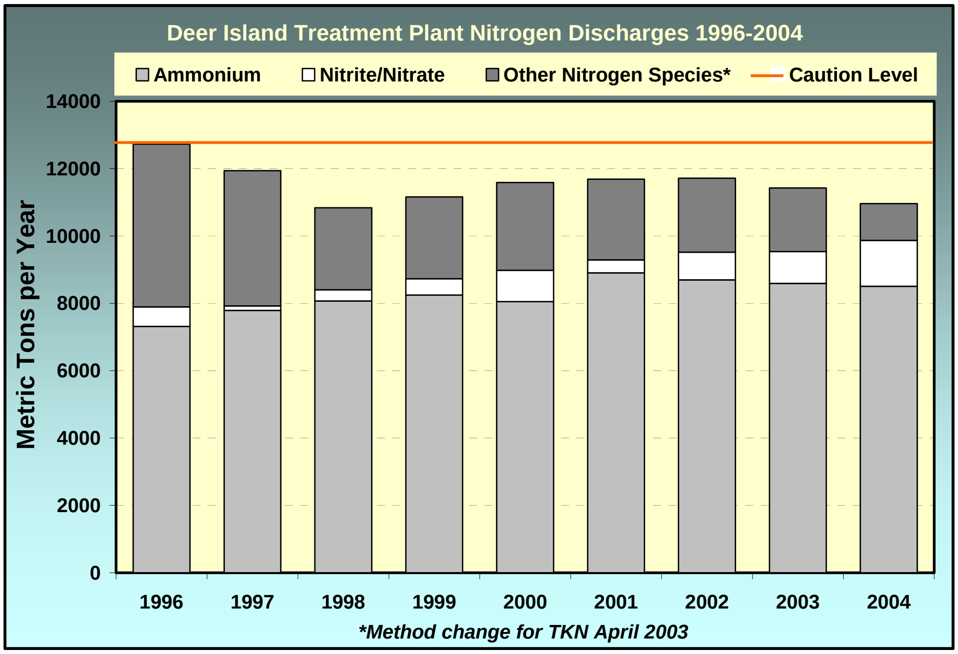


Figure 2-1. Annual effluent flows, 1990-2004

Nitrogen and solids discharges decreased slightly in 2004 (Figure 2-2), reflecting the lower flow. Similarly, metals loads were slightly lower in 2004 than in 2003 (Figure 2-3, top). Overall, toxic compound concentrations decrease with increased levels of secondary treatment (see for example, mercury in Figure 2-3, bottom).



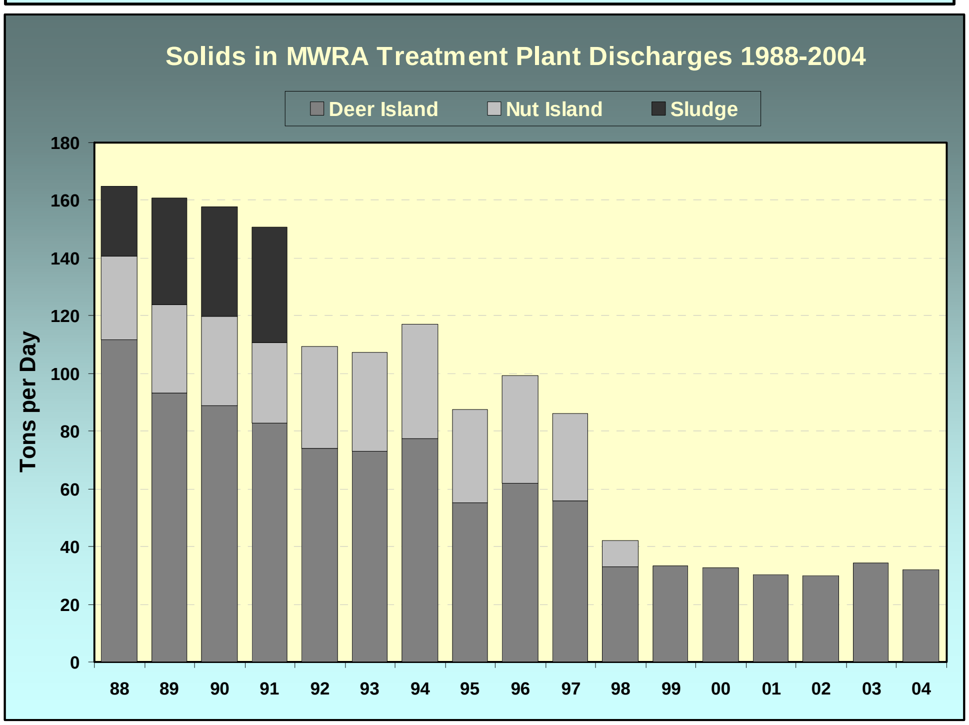


Figure 2-2. Annual nitrogen (top) and solids (bottom) discharges

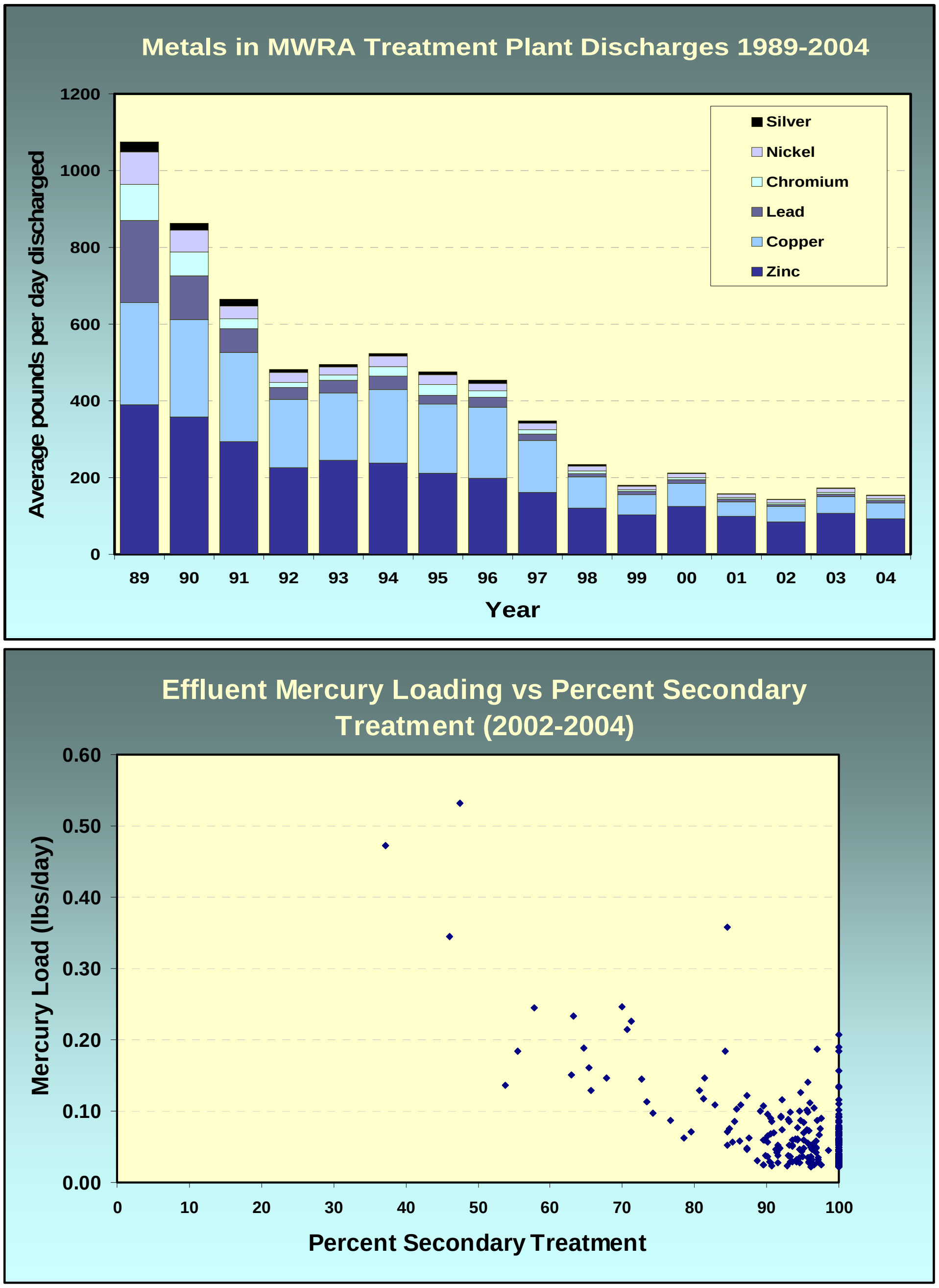


Figure 2-3. Top: Annual metals discharges; Bottom: mercury loads as a function of amount of secondary treatment

Contingency Plan Thresholds

The Deer Island Treatment Plant had one permit violation during 2004 (Table 2-4). The permit and Contingency Plan specify that for fecal coliform bacteria, the daily geometric mean of at least three samples taken prior to entrance of the effluent into the outfall tunnel may not exceed 14,000 colonies per 100 ml. During an early April storm, the geometric mean of three samples was 15,233 colonies per 100 ml. Rough weather at the outfall site precluded a corresponding measurement of ambient conditions but also promoted increased dilution, minimizing the chances of any environmental consequence of the threshold exceedance.

Table 2-4. Contingency Plan threshold values and 2004 results for effluent monitoring

Parameter	Caution Level	Warning Level	2004 Results
pH	None	<6 or >9	Not exceeded
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)	One exceedance of daily geometric mean level.
Chlorine, residual	None	631 ug/l daily, 456 ug/l monthly	Not exceeded
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 exceeded
Flow	None	Flow >436 for annual average of dry days	Not exceeded
Total nitrogen load	12,500 mtons/year	14,000 mtons/year	Not exceeded
Floatables			Threshold pending
Oil and grease	None	15 mg/l weekly	Not exceeded

3. Water Column

Background

Circulation and Water Properties

Circulation, water properties, and consequently, the biology of Massachusetts and Cape Cod bays are driven by the larger pattern of water flow in the Gulf of Maine (Figure 3-1) and by regional and local winds.

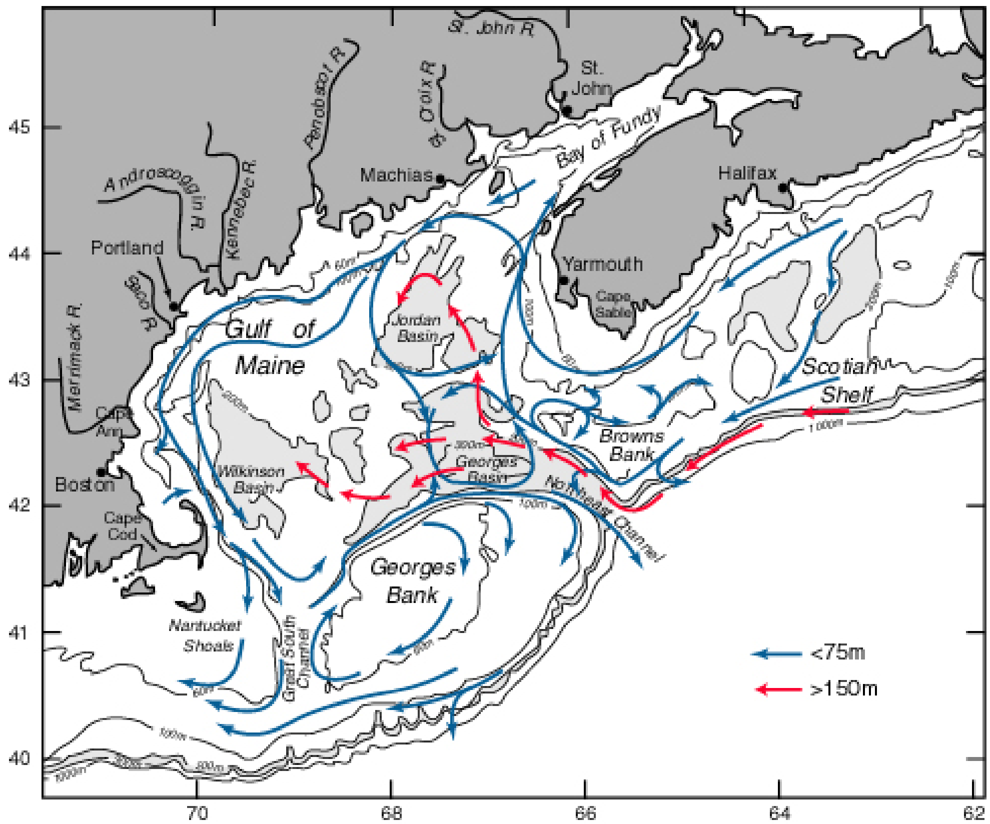


Figure 3-1. General circulation within Massachusetts Bay (from Beardsley et al. 1997)

A coastal current flows southwestward along the Maine and New Hampshire coasts; it may enter the bays by Cape Ann to the north of Boston. This current drives a mean counterclockwise circulation in Massachusetts Bay and Cape Cod Bay. Water flows back out of the bays to the north of Race Point at the tip of Cape Cod. Whether the coastal current enters the bays and whether it continues south into Cape Cod Bay depends on the strength of the current and the direction and speed of the wind. Because the coastal current is strongest during the spring period of high runoff from rivers and streams, the spring circulation pattern is more consistent than that of the summer and fall (Geyer *et al.* 1992).

During the summer and fall, freshwater inflow is less, and so the wind and water density interact in a different, more complex way, with alternating periods of upwelling and downwelling in various locations, depending primarily on the wind direction and strength (Lermusiaux 2001). Water flow is variable, as the weather patterns change from week to week. Flow at any particular time depends on the wind speed and direction relative to the topography of the sea floor. At times, flow can “reverse,” with flow northward along the coast. There are transient gyres in Massachusetts and Cape Cod bays, which can spin in either direction.

As in many coastal waters, during the winter, the water is well-mixed from top to bottom, and nutrient levels are high. As light levels increase in the early spring, phytoplankton populations often begin a period of rapid growth known as a spring bloom. Contrary to popular wisdom, however, spring blooms do not occur every year. During the years in which they occur, spring blooms begin in the shallowest waters of Cape Cod Bay. Blooms in the deeper Massachusetts Bay 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 lighter, less saline 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 through the pycnocline to the bottom. While oxygen levels remain high in the surface waters throughout the year, levels fall in the bottom waters, as bottom-dwelling animals respire, and bacteria use up oxygen as the phytoplankton decompose. Bottom-water oxygen levels are typically lowest during the late summer or early fall.

Cooling surface waters and strong winds during the autumn months 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. Similar to the spring, varying meteorological and oceanographic conditions greatly influence the timing, magnitude, and spatial extents of the blooms, and fall blooms do not always occur. When they do occur, the fall blooms typically end in the early winter, when declining light levels limit photosynthesis. Plankton die and decay, replenishing nutrients in the water column.

Environmental Concerns

Water-column monitoring questions focus on the possible effects of nutrients, organic matter, pathogens, and floatable debris from wastewater on the water quality of Massachusetts Bay (MWRA 1991, Table 3-1). Due to source reduction and treatment, toxic contaminants discharged in the MWRA effluent are so low in concentrations that it is impractical to measure them in the water column. Because organic material, pathogens, and floatables are effectively removed by treatment, but nutrients are not, nutrient issues cause the greatest concern.

The monitoring program looks extensively at possible effects of discharging nutrient-rich effluent into Massachusetts Bay. One concern is that excess nutrients, particularly nitrogen, could over-stimulate algal blooms, which would be followed by low levels of dissolved oxygen when the phytoplankton organisms die, sink, and decompose. Another concern 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 fundyense* (the *A. fundyense/ tamarense* species group), the diatom *Pseudo-nitzschia multiseries*, and the colonial flagellate *Phaeocystis pouchetii*. *Alexandrium fundyense* blooms are known in New England as red tides. The associated toxin, when sufficiently concentrated, can cause paralytic shellfish poisoning (PSP), which can be fatal to marine mammals, fish, and humans. At high concentrations (more than 1 million cells per liter), some diatoms in the genus *Pseudo-nitzschia* may produce sufficient quantities of toxic domoic acid to cause a condition known as amnesic shellfish poisoning, which is marked by gastrointestinal and neurological symptoms, including dementia. Toxin-forming species occur with and appear identical to non-toxin forming species when identified under a microscope. *Phaeocystis pouchetii* is not toxic, but individual cells can aggregate in gelatinous colonies that may be aesthetically displeasing, clog nets, or be poor food for zooplankton.

Dissolved oxygen concentrations in bottom waters naturally decrease during the stratified period as part of the natural seasonal pattern. Discharged nutrients that stimulated large phytoplankton blooms could lead to even lower levels of dissolved oxygen when the cells sink to the bottom and decay.

Table 3-1. Monitoring questions related to the water column

Is it safe to eat fish and shellfish?

Will pathogens in the effluent be transported to shellfishing areas where they could accumulate in the edible tissues of shellfish and contribute to human health problems?

- Are pathogens transported to shellfish beds at levels that might affect shellfish consumer health?

Are natural/living resources protected?

Will nutrient enrichment in the water column contribute to an increase in primary production?

Will nutrient enrichment in the water column contribute to changes in plankton community structure?

- Have nutrient concentrations changed in the water near the outfall; have they changed at farfield stations in Massachusetts Bay or Cape Cod Bay, and, if so, are they correlated with changes in the nearfield?
- Has the phytoplankton biomass changed in the vicinity of the outfall or at selected farfield stations in Massachusetts Bay or Cape Cod Bay, and, if so, can changes be correlated with effluent or ambient water nutrient concentrations, or can farfield changes be correlated with nearfield changes?
- Have the phytoplankton production rates changed in the vicinity of the outfall or at selected farfield stations, and, if so, can these changes be correlated with effluent or ambient water nutrient concentrations, or can farfield changes be correlated with nearfield changes?
- Has the abundance of nuisance or noxious phytoplankton species changed in the vicinity of the outfall?
- Has the species composition of phytoplankton or zooplankton changed in the vicinity of the outfall or at selected farfield stations in Massachusetts Bay or Cape Cod Bay? If so, can these changes be correlated with effluent or ambient water nutrient concentrations, or can farfield changes be correlated with nearfield changes?

Will increased water-column and benthic respiration contribute to depressed oxygen levels in the water?

- Do the concentrations (or percent saturation) of dissolved oxygen in the vicinity of the outfall and at selected farfield stations meet the state water quality standard?
- Have the concentrations (or percent saturation) of dissolved oxygen in the vicinity of the outfall or at selected farfield stations in Massachusetts Bay or Cape Cod Bay changed relative to pre-discharge baseline or a reference area? If so, can changes correlated with effluent or ambient water nutrient concentrations, or can farfield changes be correlated with nearfield changes?

Is it safe to swim?

Will pathogens in the effluent be transported to waters near swimming beaches, contributing to human health problems?

- Are pathogens transported to beaches at levels that might affect swimmer health?

Are aesthetics being maintained?

Will changes in water clarity and/or color result from the direct input of effluent particles or other colored constituents, or indirectly through nutrient stimulation of nuisance plankton species?

Will the loading of floatable debris increase, contributing to visible degradation?

- Has the clarity and/or color of the water around the outfall changed?
- Has the amount of floatable debris around the outfall changed?

Information on transport and fate necessary to answer all the questions

- Are model estimates of short-term (less than 1 day) effluent dilution and transport accurate?
- What are the nearfield and farfield water circulation patterns?
- What is the farfield fate of dissolved, conservative, or long-lived effluent constituents?

Because of the concern that lowered levels of dissolved oxygen could affect animals in the vicinity of the outfall, it was important during the baseline-monitoring period to develop an understanding of the natural fluctuations of oxygen levels within the system. Modeling and measurements showed that the typical periods of low oxygen in bottom waters correlate with warmer and saltier bottom waters. Ongoing monitoring assesses potential diversions from the natural conditions.

Monitoring Design

Water-column monitoring includes assessments of water quality, phytoplankton, and zooplankton in Massachusetts and Cape Cod bays. Regular monitoring includes four components: nearfield surveys, farfield surveys, continuous recording, and remote sensing (Table 3-2). Plume-tracking studies, conducted in 2001, verified the assumed dilution at the outfall and confirmed assumptions that bacteria and toxic contaminant concentrations in the discharged effluent are very low.

Nearfield surveys provide vertical and horizontal profiles of physical, chemical, and biological characteristics of the water column in the area around the outfall where some effects of the effluent are expected and have been observed. Farfield surveys assess differences across the bays and seasonal changes over a large area. Several farfield stations mark the boundary of the monitoring area and are in or near the Stellwagen Bank National Marine Sanctuary. Two of those stations denote the "northern boundary," representing water entering Massachusetts Bay from the Gulf of Maine. Other stations are in Boston Harbor, coastal and offshore regions, and in Cape Cod Bay (Figure 3-2). Monitoring in 2004 constituted the first year of implementation of revisions to the program, refocusing monitoring away from localized, short-term effects and towards determining the potential for long-term effects (MWRA 2004). Twelve surveys of seven nearfield stations and six surveys of 25 farfield stations were conducted. Parameters measured are listed in Tables 3-3 and 3-4.

Table 3-2. Components of water-column monitoring

Task	Objective
Nearfield surveys	Collect water quality data near the outfall
Farfield surveys	Collect water quality data throughout Massachusetts and Cape Cod bays
Moorings (GoMOOS and USGS)	GoMOOS near Cape Ann and USGS near outfall provide continuous oceanographic data near outfall location
Remote sensing	Provides oceanographic data on a regional scale through satellite imagery

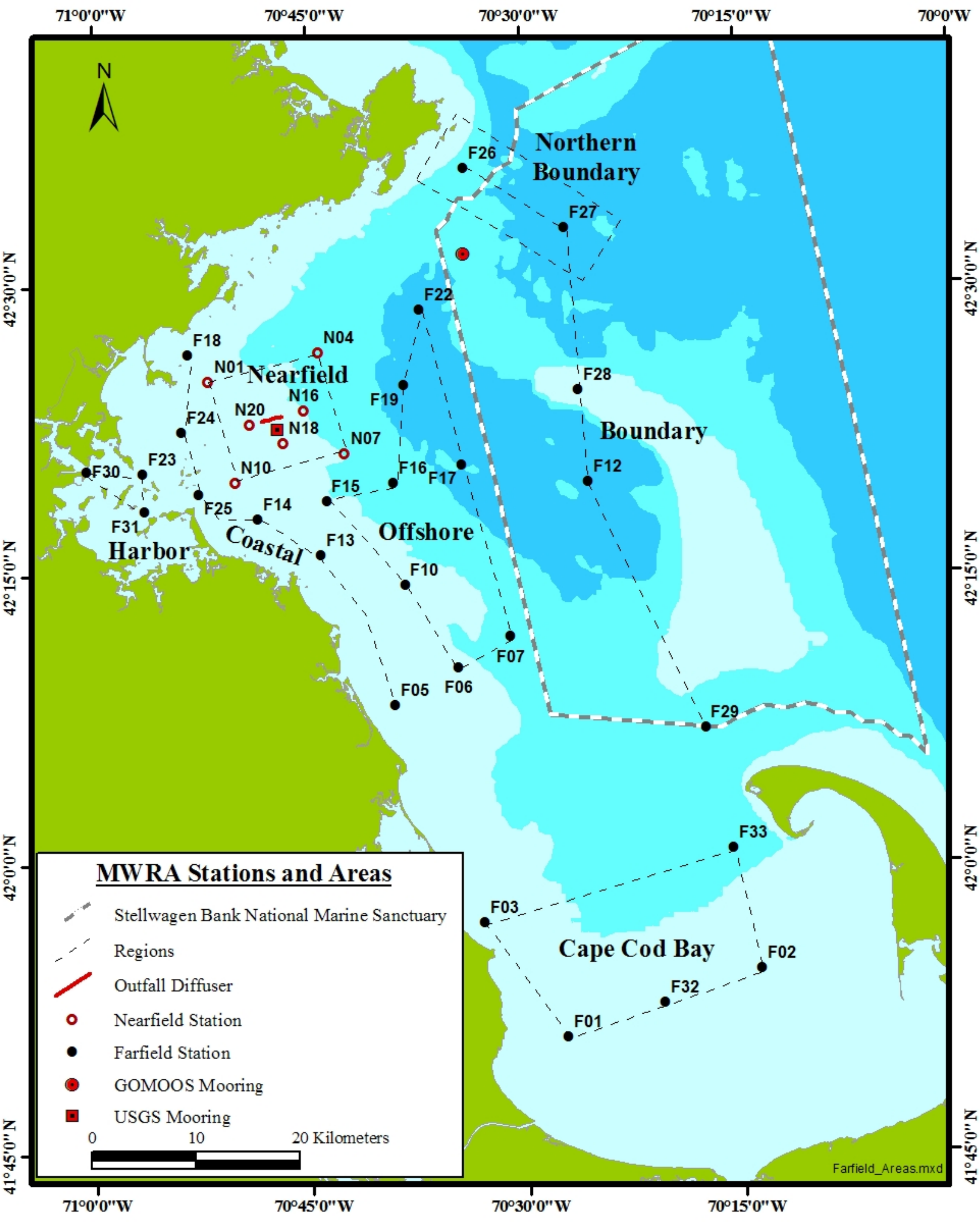


Figure 3-2. Water column sampling stations and regions

Table 3-3. Nearfield water column monitoring parameters

Parameter	Measurement details
Temperature Salinity Dissolved oxygen Chlorophyll fluorescence Transmissometry Irradiance Depth of sensors	In-situ sensor measurements Boat surveys of seven stations Every half meter depth
Ammonium Nitrate Nitrite Phosphate Silicate	Inorganic nutrients sampling Seven stations Five depths
Dissolved inorganic carbon Dissolved nitrogen Dissolved phosphorus Particulate carbon Particulate nitrogen Particulate phosphorus Particulate biogenic silica Total suspended solids	Additional nutrients sampling Seven stations Three depths
Primary productivity Respiration Phytoplankton Zooplankton	Rates and plankton sampling Two stations Variable depths
Floatables	Net tows

Table 3-4. Farfield water column monitoring parameters

Parameter	Measurement details
Temperature Salinity Dissolved oxygen Chlorophyll fluorescence Transmissometry Irradiance Depth of sensors	In-situ sensor measurements Boat surveys of 25 stations Every half meter depth
Ammonium Nitrate Nitrite Phosphate Silicate	Inorganic nutrients sampling 23 stations at five depths Two stations at three depths
Dissolved inorganic carbon Dissolved nitrogen Dissolved phosphorus Particulate carbon Particulate nitrogen Particulate phosphorus Particulate biogenic silica Total suspended solids Phytoplankton Zooplankton	Additional nutrients and plankton sampling Ten stations Variable depths
Primary productivity	Rates sampling One station Five depths
Respiration	Rates sampling Two stations Three depths

Parameters measured in the water column 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. Nutrients measured include the major forms of nitrogen, phosphorus, and silica. The measurements focus on the dissolved inorganic forms, which are the forms most readily used by phytoplankton. Since 1999, the surveys have also included observations and net tows in the outfall area to assess the presence of floatable debris.

The continuous recording components of the program, the U.S. Geological Survey (USGS) and Gulf of Maine Ocean Observing System (GoMOOS) moorings, capture temporal variations in water quality between nearfield surveys. Remote sensing by satellite captures spatial variations in water quality on a larger, regional scale.

Results

Physical Conditions

Over the course of the entire year, runoff to Massachusetts Bay in 2004 was typical of all the years of monitoring, very similar to 2003 and greater than in the drought years of 1992, 1995, and 2002 (Libby *et al.* 2005a; Figure 3-3). The months January through March were dry, followed by a typically rainy April and higher than average flow in September and October.

On average, temperature, salinity, and stratification in the nearfield since the outfall went on-line are similar to the baseline. Baseline and post-discharge monitoring has shown that the north-south component of the wind stress in the region is important in determining water conditions, as those winds determine the degree of upwelling and downwelling. For most of 2004, the winds followed a typical pattern of wind stresses, beginning with downwelling, transitioning to upwelling in the summer, and returning to downwelling in the late fall. The summer upwelling was somewhat weaker than usual, and there was an unusually strong period of downwelling in the fall, causing warm bottom temperatures throughout the fall (Figure 3-4 top). Salinity and stratification patterns were typical (Figure 3-4, middle and bottom). Strong northeast winds that occurred during storms in September and October appeared to cause partial mixing of the near-bottom waters.

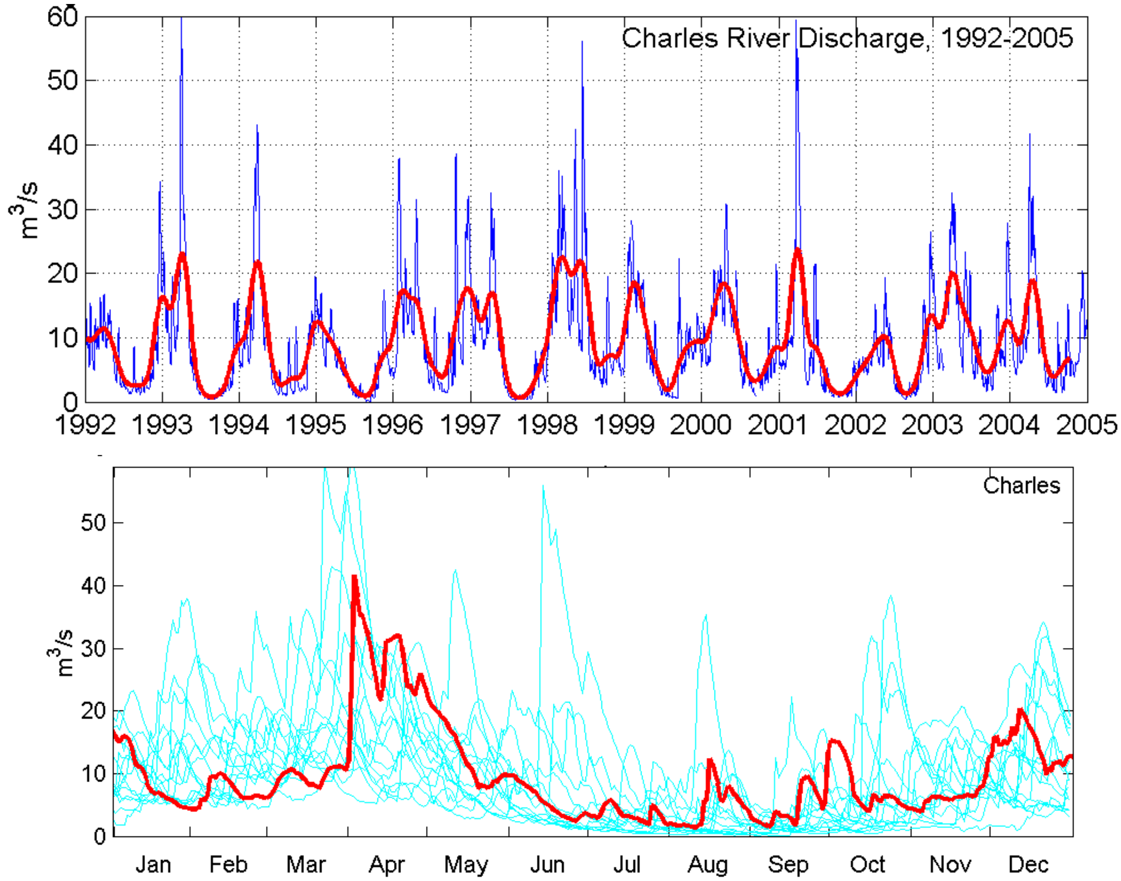
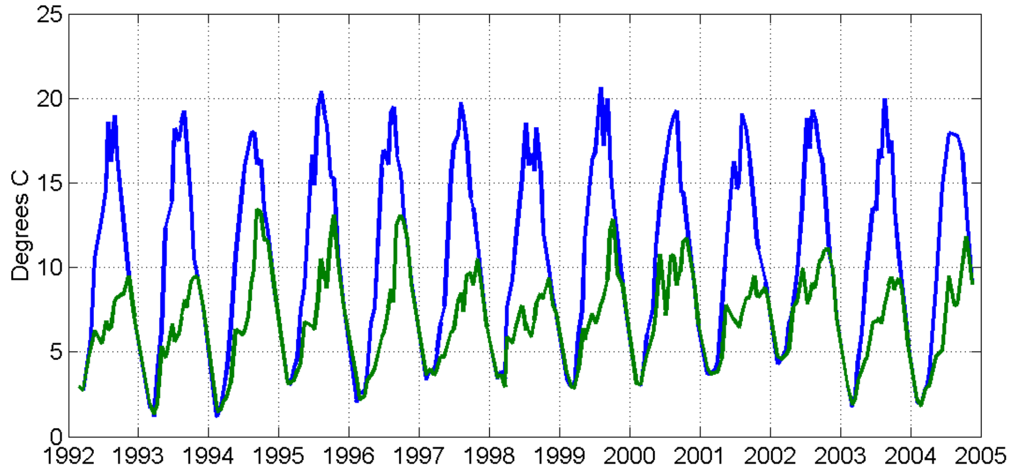


Figure 3-3. Top: Charles River discharge, 1992-early 2005 (data from a gauge at Waltham and 3-month moving average); Bottom: 2004 Charles River discharge compared to observations since 1992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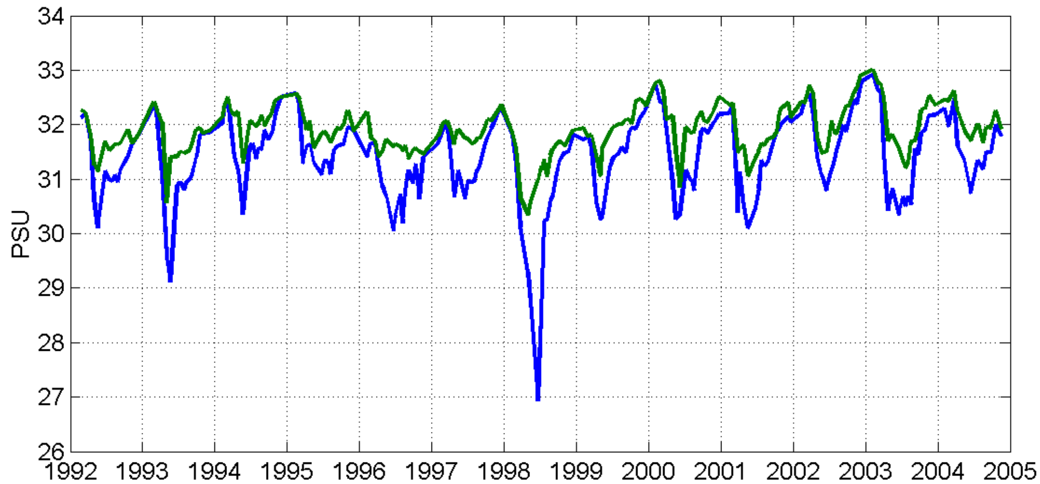
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1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005

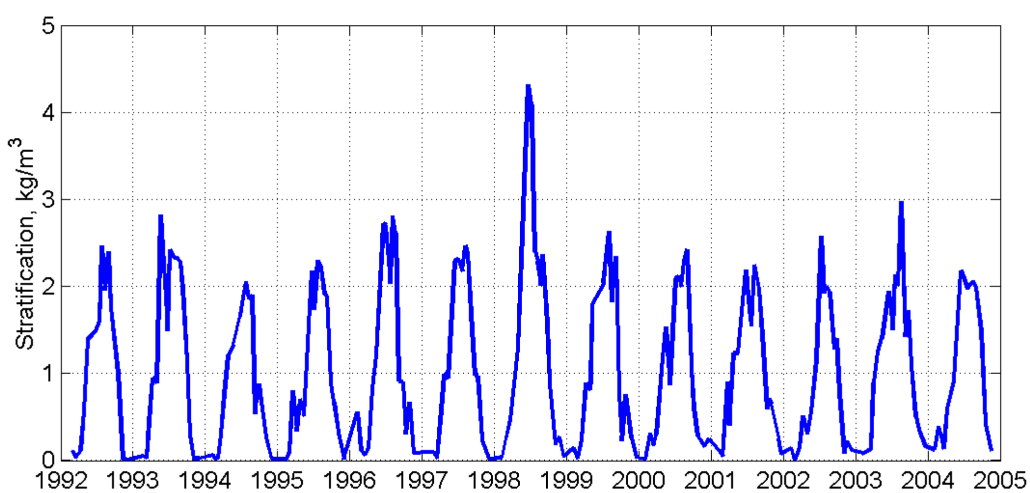
Stratification, kg/m3
0
1
2
3
4
5
1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005

Figure 3-4. Nearfield surface and bottom water temperature, salinity, and stratification (Surface measurements are the upper line for temperature and the lower line for salinity.)

Water Quality

As in every year since the Massachusetts Bay outfall began operation, water quality measurements in 2004 continued to confirm predictions that it would be possible to detect localized effects of the discharge for some parameters, but that there would be no adverse effects on the farfield (Libby *et al.* 2005a). For example, while increased concentrations of ammonia have been observed in the nearfield, decreased concentrations have been observed in Boston Harbor and along the coast (Figure 3-5, top). Concentrations of nitrate show almost no change from baseline conditions (Figure 3-5, bottom).

Ammonia is the form of nitrogen most readily taken up by phytoplankton, and localized, elevated concentrations have been observed in the nearfield during most surveys since the outfall began operation (Figure 3-6). These elevated levels had been anticipated, because a large portion of the dissolved inorganic nitrogen in treated effluent is ammonia; in fact, ammonia has proven to be a good short-term tracer of the effluent plume.

Conversely, concentrations of ammonia in Boston Harbor dropped dramatically following effluent diversion to Massachusetts Bay and have remained low (Figure 3-7). Averaged over the entire year, the increase in ammonia concentrations in the vicinity of the outfall has been small in comparison to the large decrease in ammonia concentrations in the harbor. Ammonia concentrations have also declined at the coastal stations compared to the years immediately preceding the outfall diversion. Because of the volume of water available for dilution in the offshore, the increase in ammonia in the nearfield is smaller than the corresponding decrease in the harbor.

Unlike 2001, 2002, and 2003, there were some surveys in 2004 during which nearfield ammonia concentrations were not elevated over baseline levels. Reasons for this outcome varied by season. During April 2004, all available nutrients were being taken up by a large *Phaeocystis pouchetii* bloom. In July, a deep and strong pycnocline constrained nutrients to deeper waters, causing nutrient depletion in the surface waters and decreased mean water column values. A third event, in October, was not as easily explained but may have resulted from current flow and horizontal advection away from the nearfield.

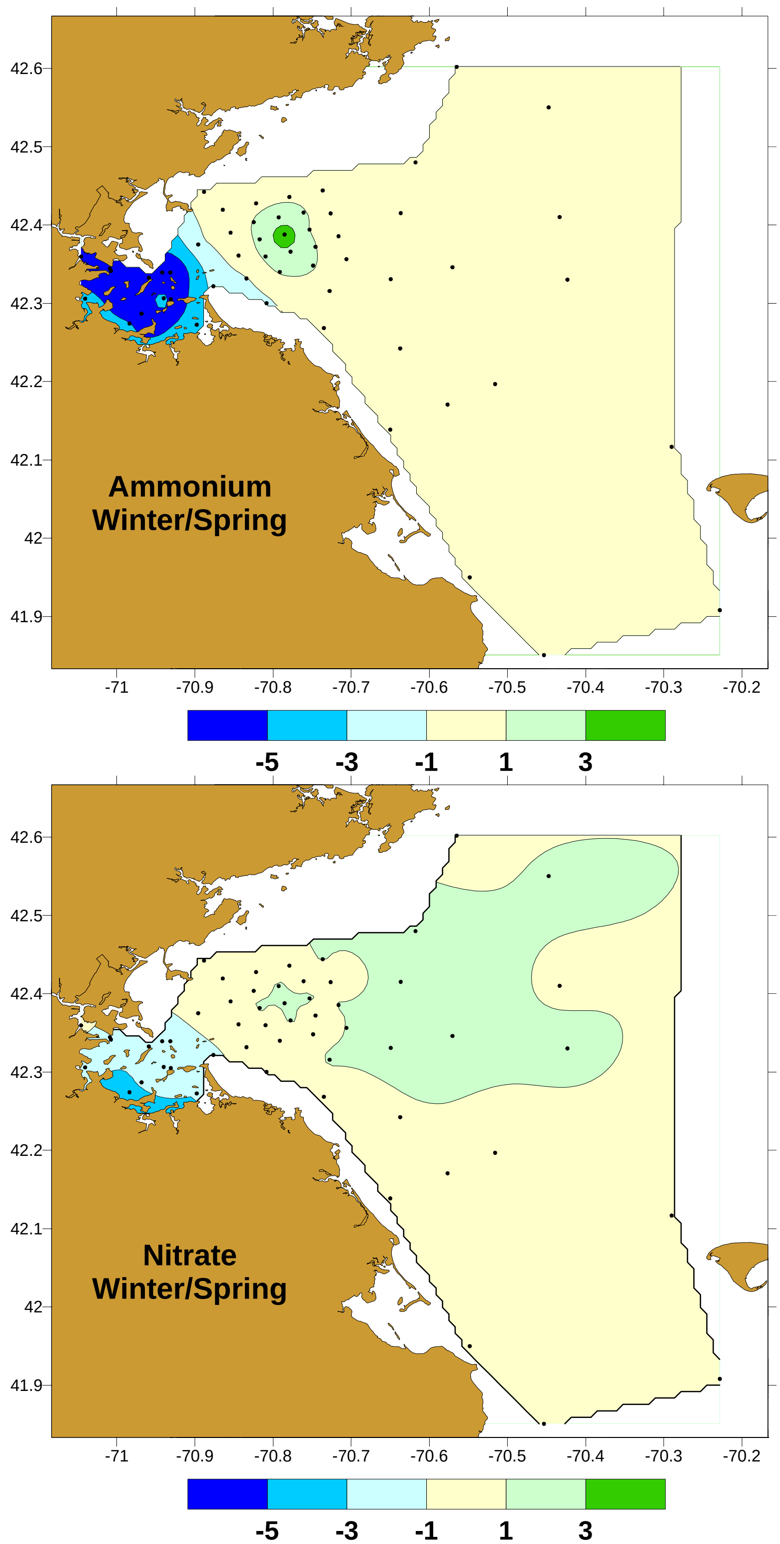

Figure 3-5. Post-diversion winter concentrations of ammonia (top) and nitrate (bottom) expressed as change from the baseline in micromoles (µM). Both plots are winter/spring data and reflect the changes from 1992-2000 to 2001-2004.

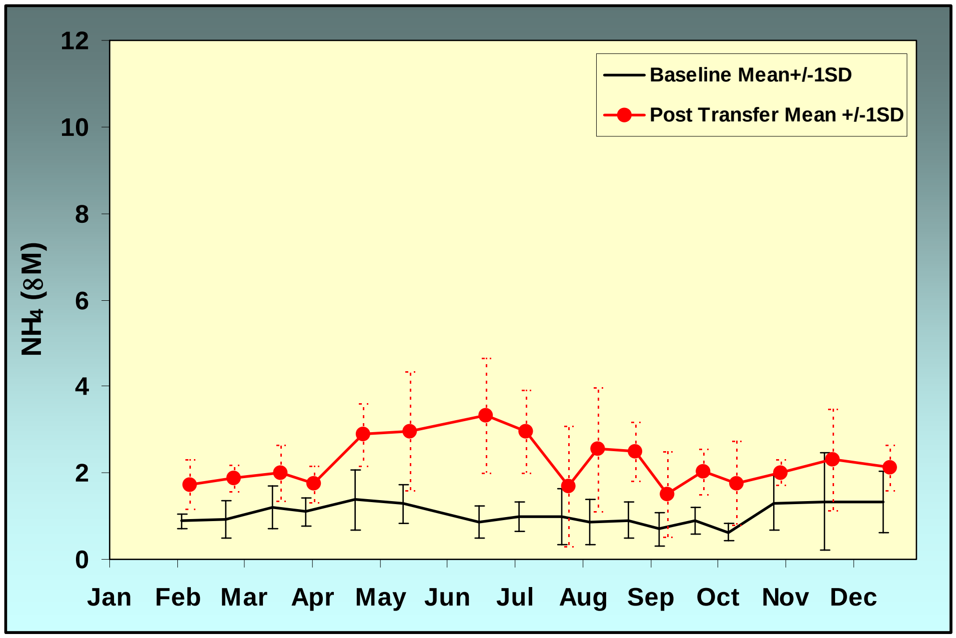

Figure 3-6. Post-transfer nearfield ammonia concentrations compared to baseline

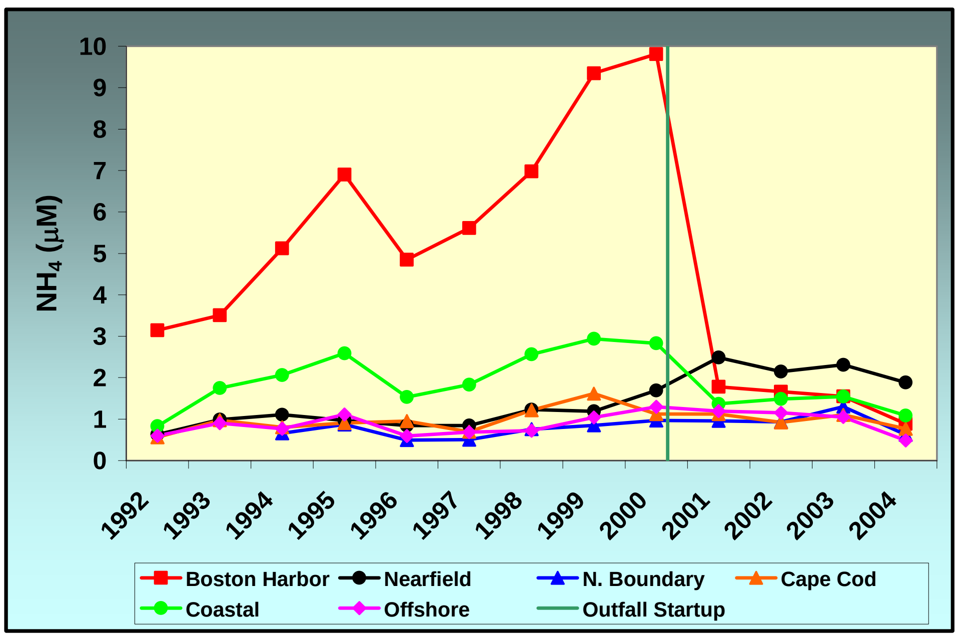

Figure 3-7. Annual mean ammonia concentrations in Massachusetts Bay regions

Unlike ammonia, for most surveys, concentrations of nitrate, another form of nitrogen readily used by phytoplankton and present in the effluent, have fallen within the baseline range and showed the same seasonal pattern as seen in baseline monitoring (Figure 3-8), and there have been no regional changes (Figure 3-9). Higher nitrate concentrations have been observed during the early part and at the end of the year. Seasonal stratification has continued to lead to typical, nutrient depletion in the surface waters, with no evidence of inputs from the outfall.

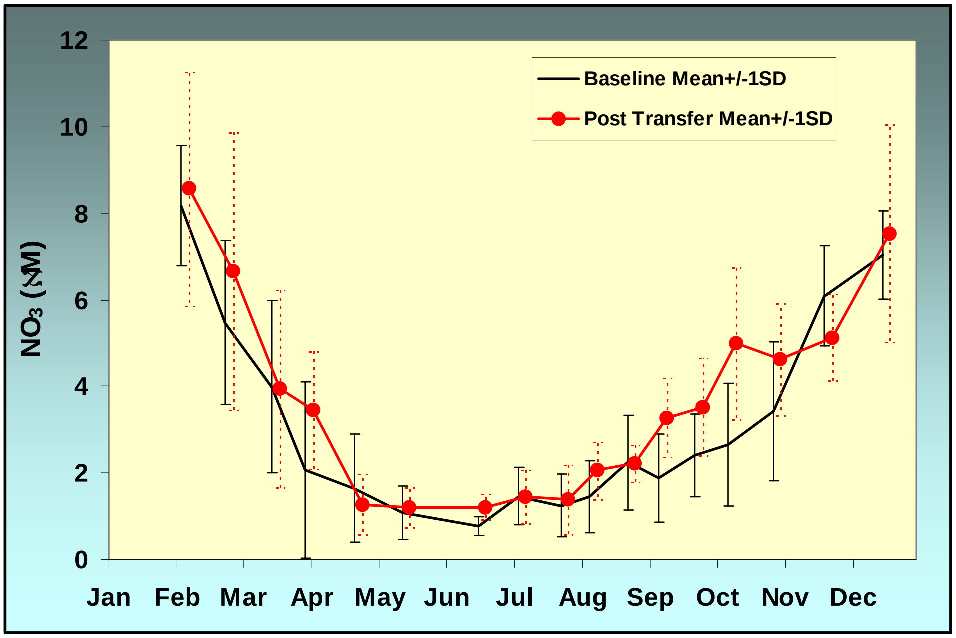

Figure 3-8. Post-transfer nearfield nitrate concentrations compared to baseline

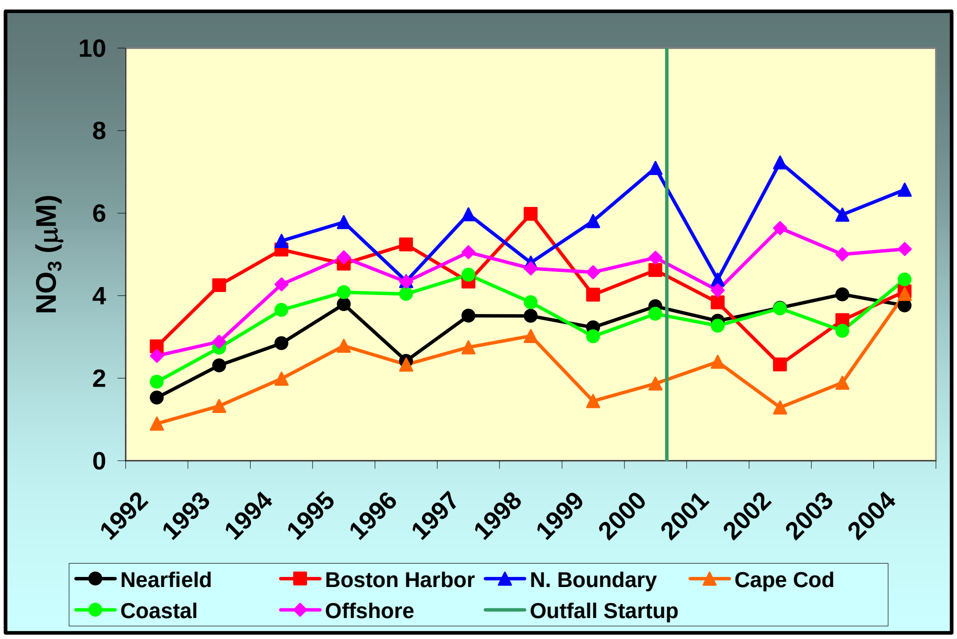

Figure 3-9. Annual mean nitrate concentrations in Massachusetts Bay regions

Chlorophyll (mg per square meter), a measure of phytoplankton biomass, has also shown no response to nutrient enrichment of the outfall, even in the nearfield (Figure 3-10), although the data are marked by large variability in timing and magnitude of spring and fall peaks. Annual chlorophyll measurements have shown no response to the outfall in the nearfield or any region of the farfield. The year 2004 was somewhat unusual in that no fall phytoplankton bloom was detected by the sampling program, and SeaWIFS satellite imagery confirmed that no major bloom occurred during or after sampling had been completed for the year. Consequently, chlorophyll values remained low in all regions from June through November (data not shown). The strong downwelling conditions that were present at the time may have contributed to the lack of a bloom.

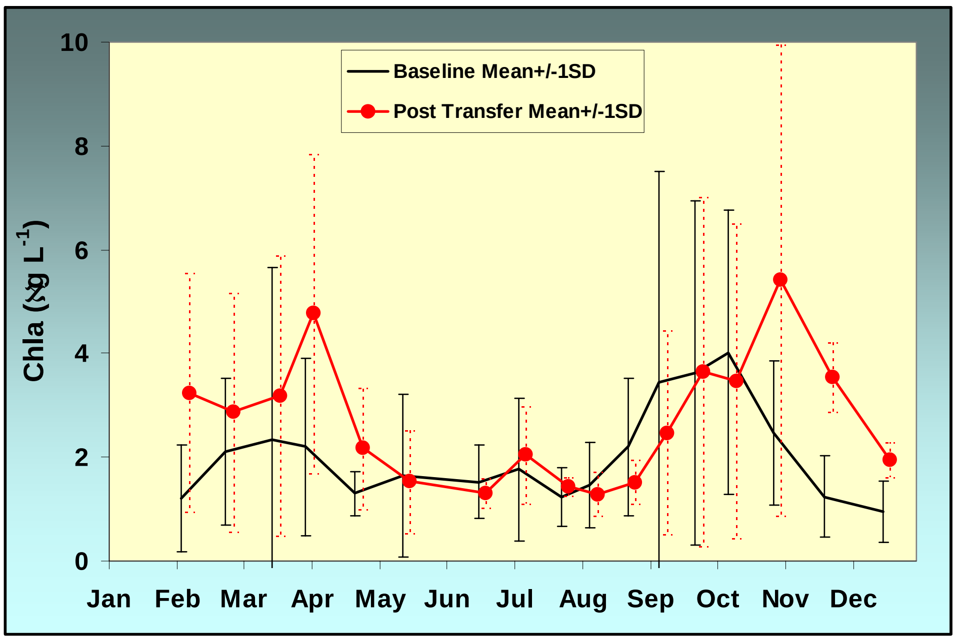

Figure 3-10. Post-transfer nearfield chlorophyll compared to baseline

Measurements of concentrations (Figure 3-11) and percent saturation (not shown) of dissolved oxygen in the bottom waters have also shown no response to nutrient enrichment or addition of organic matter from the outfall. As in other post-baseline years, the seasonal cycle of higher concentrations during the winter and spring and lower concentrations in the summer and fall, returning to higher concentrations following a fall overturn continued. In fact, the fall 2004 near-bottom oxygen concentrations were higher than predicted from temperature and salinity data, probably due to the partial mixing of the bottom waters during the September and October storms.

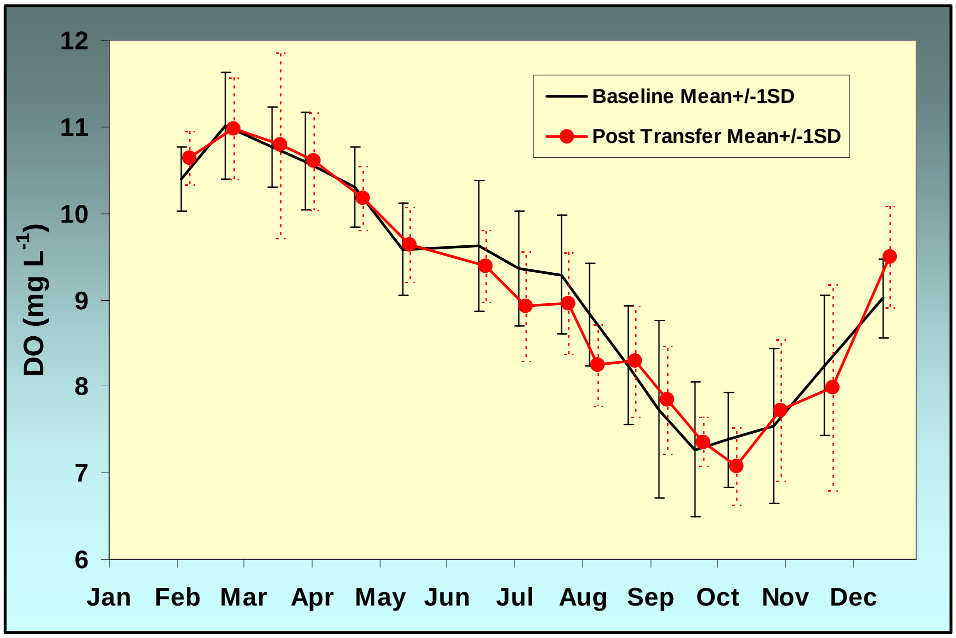

Figure 3-11. Post-transfer nearfield dissolved oxygen concentrations compared to baseline

Phytoplankton Communities

Seasonal abundance of phytoplankton in the post-outfall diversion years has remained similar to the baseline mean for most survey dates (Libby *et al.* 2005a; Figure 3-12), and the taxonomic composition of the phytoplankton community has been relatively consistent. Small microflagellates and cryptomonads are numerically dominant throughout the year, peaking in abundance during the warm summer months. Diatoms are usually abundant during the winter, spring, and fall. In some years, there are major blooms of a single species, such as *Asterionellopsis glacialis* in the fall or *Phaeocystis pouchetii* in the spring. The blooms tend to occur on broad regional scales, and the reasons they occur are not well understood.

The most pronounced change in the phytoplankton community over the course of the monitoring program has been an increase in the frequency of *Phaeocystis pouchetii* blooms (Figure 3-13, top). During the baseline period, there were spring *Phaeocystis* blooms approximately every three years, in 1992, 1994 (only recorded in the farfield), 1997, and 2000. Since the outfall began operation, the blooms have occurred annually, in 2001, 2002, 2003, and 2004.

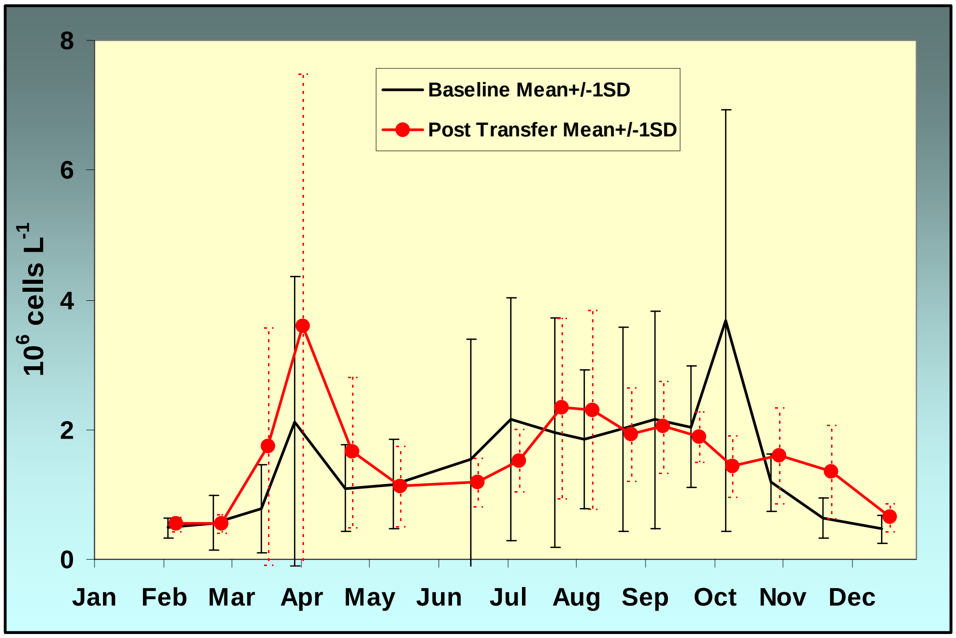

Figure 3-12. Post-transfer nearfield phytoplankton abundance compared to baseline

There has also been an earlier onset and longer duration of *Phaeocystis* blooms (Figure 3-13, middle). Prior to 2002, the blooms tended to occur primarily during late March and April. Since 2002, blooms have started earlier in March and lasted until early May. The 2004 bloom was the largest recorded, with a nearfield survey maximum of 8 million cells per liter. Cells were first detected in mid-March, peaked in April, and declined in May.

The broad geographic extent of *Phaeocystis* blooms argues against an effect of the outfall. The blooms have occurred well beyond the boundaries of Massachusetts and Cape Cod bays, and there have been no obvious spatial associations with the outfall. Conceivably, increased ammonia in the nearfield could enhance the magnitude and duration of the bloom in the nearfield, but the local nutrient regime cannot explain the overall increase in frequency of the regional blooms.

The regional temperature regime may be one factor contributing to the increased duration of the blooms that has been observed since 2002. Regression analysis using temperature data from the Boston Buoy indicates that the 2002, 2003, and 2004 blooms corresponded to years when temperatures cooler than 14°C persisted into June (Figure 3-13, bottom). (Data from years prior to 2000 were not included in the analysis because of insufficient phytoplankton or temperature data.) Temperature has been suggested as a major factor controlling *Phaeocystis* blooms around the world (Schoemann *et al.* 2005).

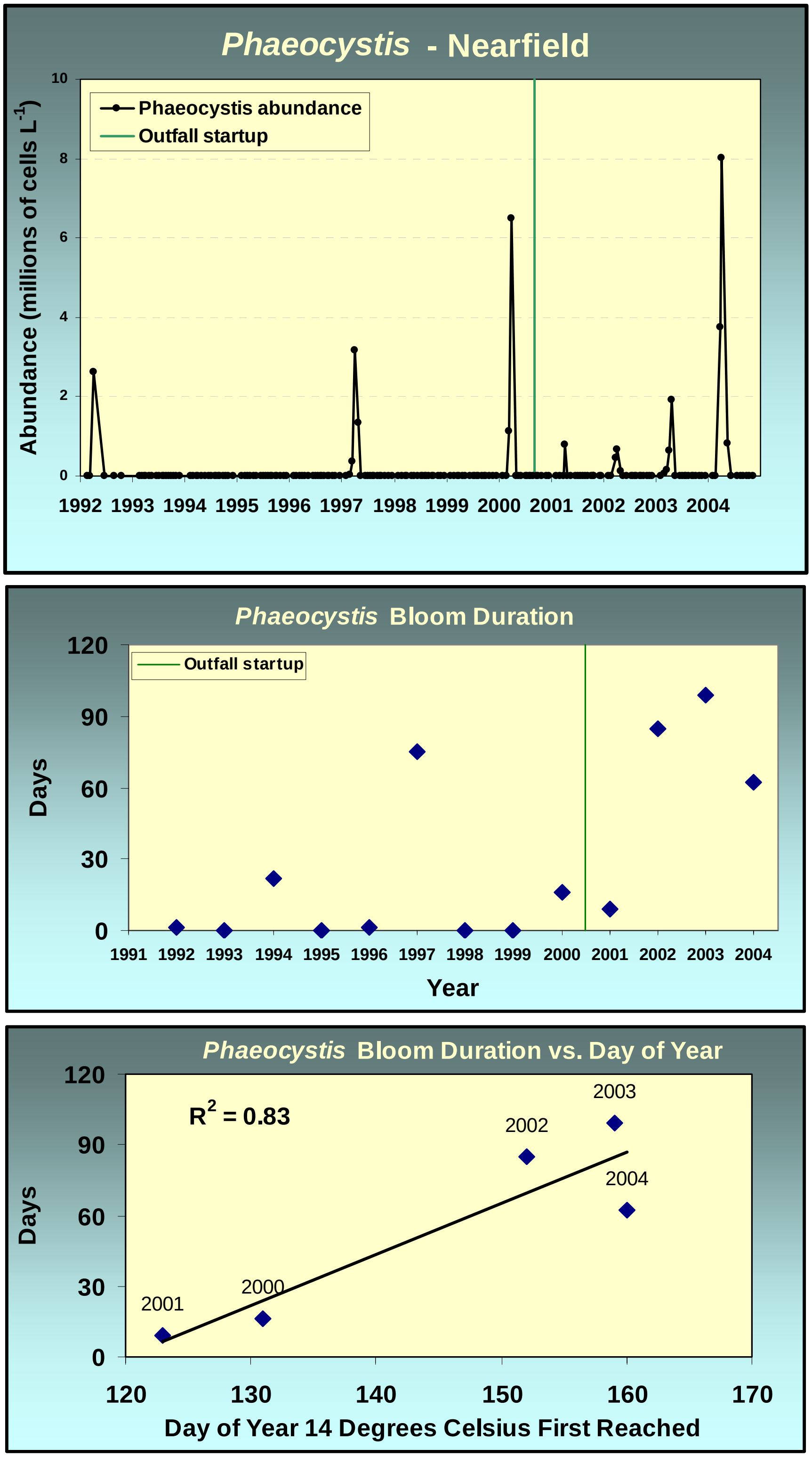

Figure 3-13. Top: Abundance of Phaeocystis pouchetii in the nearfield, 1992-2004; Middle: Duration of blooms by year; Bottom: duration of blooms vs. day of the year that water temperatures reached 14°C

In 2004, as in other post-diversion years, there were no detectable increases in other nuisance species compared to the baseline. The dinoflagellates *Alexandrium* spp. and diatoms in the genus *Pseudo-nitzschia* were present but in low numbers. (A large *Alexandrium* bloom occurred in 2005; that event is described briefly in Section 6, Special Studies, and will be described in full in the 2005 outfall monitoring overview.)

Zooplankton Communities

The structure of the zooplankton community in 2004 was similar to many earlier years and continued to show no effects of the outfall (Libby *et al.* 2005a). As in prior years, abundance was dominated by copepod nauplii and copepodites and adults of the small copepod *Oithona similis*. Other, less dominant, copepods typically include *Calanus finmarchicus*, *Paracalanus parvus*, *Centropages typicus*, and *C. hamatus*. The planktonic early life stages of bivalves, gastropods, barnacles, and polychaetes occur in sporadic pulses.

There has, however, been a measurable decrease in total zooplankton abundance during 2001-2004 in comparison to the baseline period (Figure 3-14). Total abundance has been lower during the late spring and early summer and during the fall.

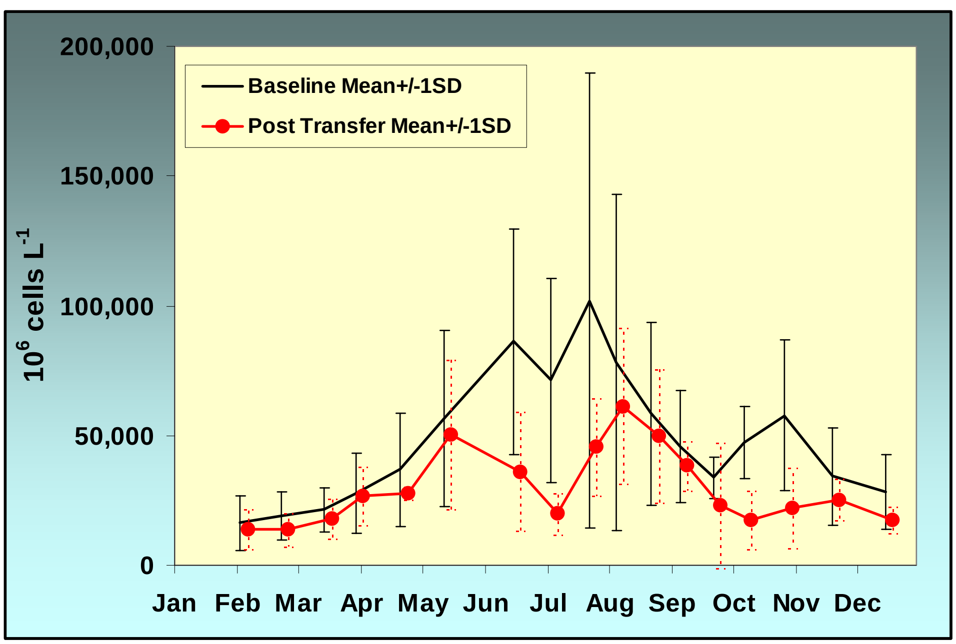

Figure 3-14. Post-transfer nearfield zooplankton abundance compared to baseline

The low mean nearfield abundance during the late spring and summer reflects low abundance of the small, dominant, *Oithona similis*; abundance of other species, such as the larger *Calanus finmarchicus*, a forage species for right whales, has remained at or above the baseline mean. The decline may be due to normal, large variability, but may also be a response to the consecutive *Phaeocystis pouchetii* blooms that have occurred during those years. Some investigators have suggested that *Phaeocystis* is unpalatable to certain animals, such as right whales, but the effects on various zooplankton species are poorly understood. Regression analysis of the monitoring data indicates that there decreased abundance of *Oithona* but increased abundance of *Calanus finmarchicus* with increases in *Phaeocystis* abundance.

The mean decrease in total nearfield zooplankton abundance during the fall months appears to be a response to late summer and fall blooms of the ctenophore *Mnemiopsis leidyi*, a zooplankton predator, which first appeared in the region in October 2000. Subsequent *Mnemiopsis* blooms, when they have occurred, have spanned a geographic larger area, beginning in August and persisting to November. *Mnemiopsis* was relatively low in abundance in 2004, but the lack of a fall phytoplankton bloom may have provided less food and contributed to continuing low fall abundance of zooplankton.

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.

Thresholds and baseline values presented in Table 3-5 were recalculated in 2004 to account for the changes in the monitoring program. There were two exceedances of thresholds in 2004—the spring and summer *Phaeocystis* thresholds. The summer threshold has been exceeded each year since 2001, due to the extended duration of the blooms that have occurred in recent years and to the extremely low summer threshold. All other monitoring results were within ranges that met the thresholds.

Table 3-5. Contingency Plan threshold values for water-column monitoring

Location/ Parameter	Specific Parameter	Baseline	Caution Level	Warning Level	2004 Results
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	Lowest survey mean = 7.55 mg/l
	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	Lowest survey mean = 80.4%
Bottom water Stellwagen Basin	Dissolved oxygen concentration	Background 5th percentile 6.2 mg/l	6.5 mg/l for any survey (June-October) unless background conditions lower	Lower than 6.0 mg/l for any survey (June-October) unless background conditions are lower	Lowest survey mean = 7.72 mg/l
	Dissolved oxygen percent saturation	Background 5th percentile 66.3%	Lower than 80% for any survey (June-October) unless background conditions	Lower than 75% for any survey (June-October) unless background conditions are lower	Lowest survey mean = 80.4%
Bottom water nearfield	DO depletion rate (June-October)	0.024 mg/l/d	0.037 mg/l/d	0.049 mg/l/d	0.020 mg/l/d
Chlorophyll nearfield	Annual	79 mg/m^2	118 mg/m^2	158 mg/m^2	69 mg/m^2
	Winter/spring	62 mgml^2	238 mg/m^2	None	101 mg/m^2
	Summer	51 mg/m^2	93 mg/m^2	None	61 mg/m^2
	Autumn	97 mg/m^2	212 mg/m^2	None	44 mg/m^2
Nuisance algae nearfield *Phaeocystis pouchetii*	Winter/spring	468,000 cells/l	2,020,000 cells/l	None	2,870,000 cells/l, caution exceedance
	Summer	72 cells/l	357 cells/l	None	164,000 cells/l, caution exceedance
	Autumn	317 cells/l	2,540 cells/l	None	0 cells/l
Nuisance algae nearfield *Pseudo-nitzschia*	Winter/spring	6,200 cells/l	21,000 cells/l	None	11 cells/l
	Summer	14,600 cells/l	43,100 cells/l	None	3,375 cells/l
	Autumn	9,940 cells/l	24,700 cells/l	None	660 cells/l
Nuisance algae nearfield *Alexandrium fundyense*	Any nearfield sample	Baseline maximum = 163 cells/l	100 cells/l	None	5 cells/l maximum
Farfield	PSP toxin extent	Not applicable	New incidence	None	No toxicity or shellfish closures

4. Sea Floor

Background

Bottom Characteristics and Sediment Transport

The sea floor of Massachusetts and Cape Cod bays was originally shaped by the glaciers, which sculpted the bottom and deposited debris, forming 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 outfall is marked by underwater 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 1997, 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. 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. An updated review of sediment transport is being completed by USGS and will be presented in the 2005 outfall monitoring overview.

Environmental Concerns

Within Boston Harbor, studies of the sediments have documented recovery following the cessation of sludge and effluent discharges and other improvements. Conversely, relocating the outfall raised concerns about potential effects on the offshore sea floor. Concern has focused on three mechanisms of potential disruption to the animal communities living on the seafloor: eutrophication and related low levels of dissolved oxygen, accumulation of toxic contaminants in depositional areas, and smothering (Table 4-1).

Table 4-1. Monitoring questions related to the sea floor

Are natural/living resources protected?
Will benthic enrichment contribute to changes in community structure of soft-bottom and hard-bottom macrofauna, possibly affecting fisheries?
Will benthic macrofauna near the outfall mixing zone be exposed to some contaminants, potentially contributing to changes in the community?
Will the benthos near the outfall mixing zone and in depositional areas farther away accumulate some contaminants?
▪ What is the level of sewage contamination and its spatial distribution in Massachusetts and Cape Cod bays sediments before discharge through the new outfall?
▪ Has the level of sewage contamination or its spatial distribution in Massachusetts or Cape Cod bays sediments changed after discharge through the new outfall?
▪ Have the concentrations of contaminants in sediments changed?
▪ Has the soft-bottom community changed?
▪ Are any benthic community changes correlated with changes in levels of toxic contaminants (or sewage tracers) in sediments?
▪ Has the hard-bottomed community changed?
Will increased water-column and benthic respiration contribute to depressed oxygen levels in the sediment?
▪ Have the sediments become more anoxic; that is, has the thickness of the sediment oxic layer decreased?

If transfer of the nutrient loads to offshore were to cause eutrophication, the depressed levels of dissolved oxygen that were also a concern in water-column monitoring could adversely affect bottom-dwelling animals. An increase in the amounts 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 caused concern about accumulation of toxic contaminants in Cape Cod Bay and Stellwagen Basin. Similarly, concentrations of particulate matter were expected to be low, but there remained some concern that bottom communities near the outfall could be affected by deposition.

Monitoring Design

Sea-floor monitoring includes several components: measurements of sediment characteristics, sewage effluent tracers, and contaminant concentrations in sediments; sediment-profile imaging to provide a rapid assessment of benthic communities and sediment quality; studies of nearfield and farfield soft-bottom communities (sampling sites in Figures 4-1 and 4-2); and study of hard-bottom communities (sampling sites in Figure 4-3).

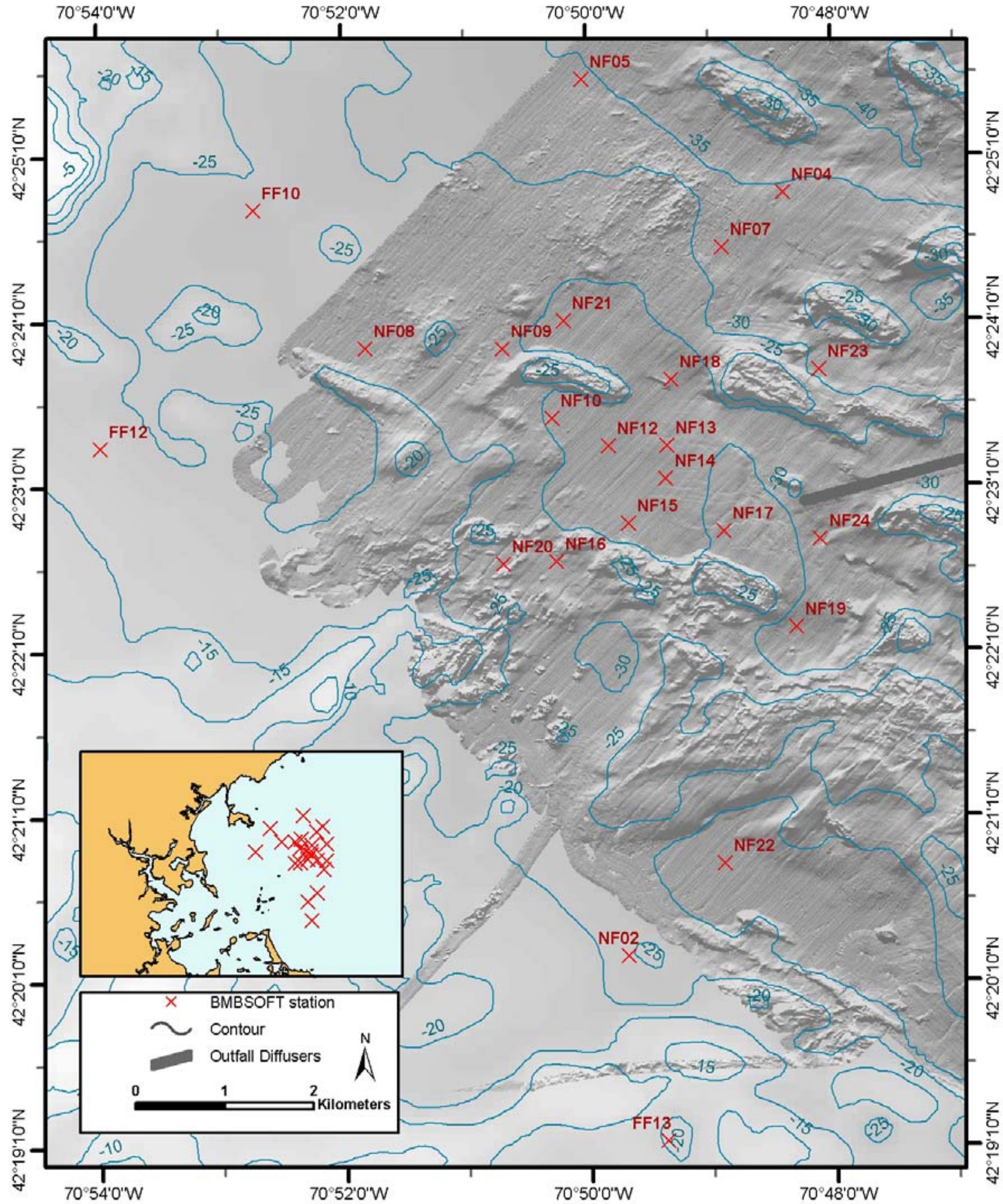

Figure 4-1. Locations of nearfield soft-bottom stations sampled in August 2004 (BMBSOFT=soft-bottom)

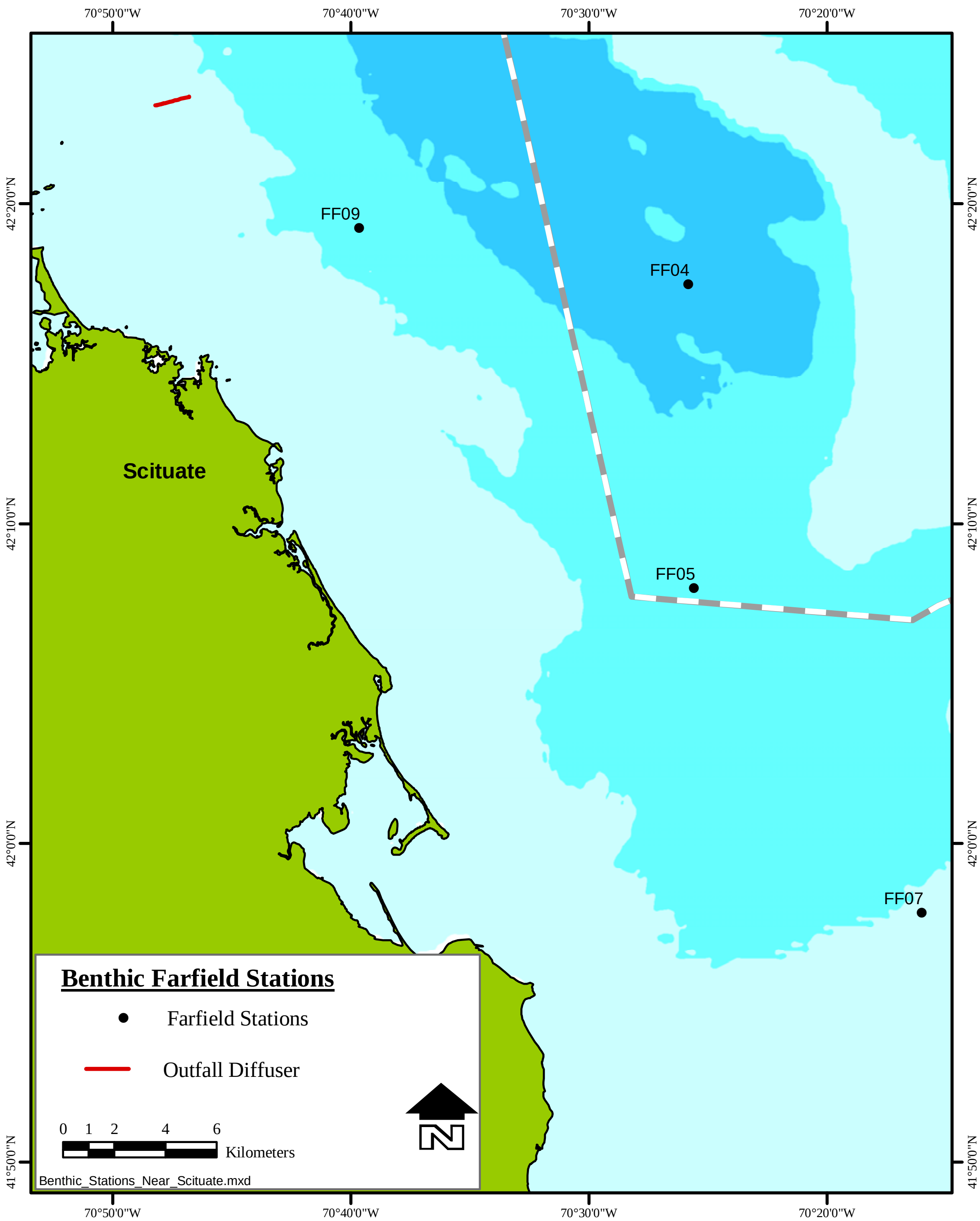

Figure 4-2. Locations of farfield soft-bottom stations sampled in August 2004

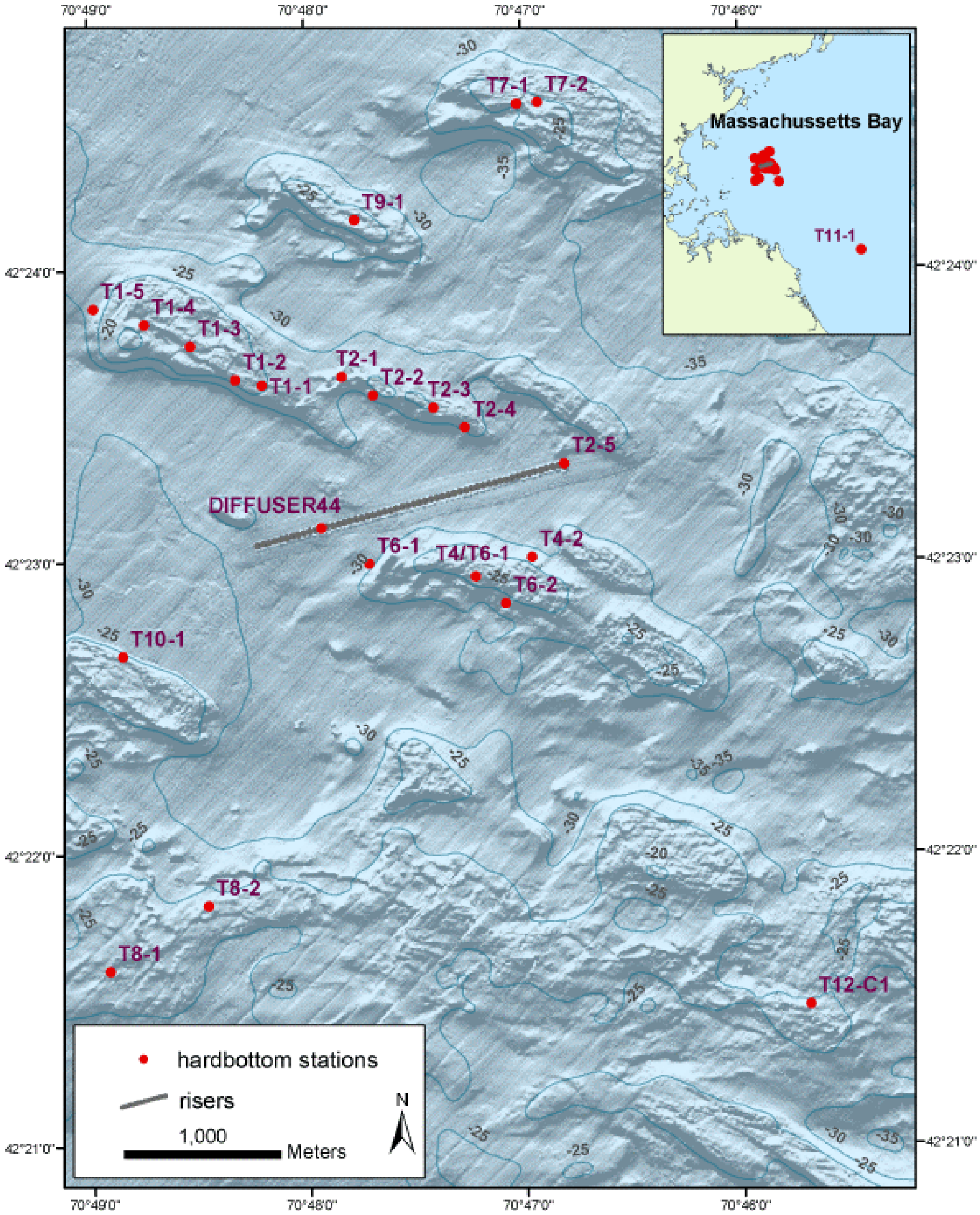

Figure 4-3. Locations of hard-bottom stations monitored in June 2004

Measurements of sediment characteristics, tracers, and contaminants include analyses of grain size, total organic carbon (TOC), *Clostridium perfringens* spores, PAHs, PCBs, chlorinated pesticides, and metals. Sediment-contaminant monitoring has been complemented by special studies. One study, a collaborative effort between MWRA and USGS, has investigated sediment transport and contaminant levels in Boston Harbor, Massachusetts Bay, and Cape Cod Bay. USGS has periodically sampled four stations within Boston Harbor since 1977 and has taken sediment cores three times a year from two stations, one sandy and one muddy, near the Massachusetts Bay outfall since 1989. USGS also uses a mooring in the nearfield to collect hydrographic data and samples of suspended matter in sediment traps. Suspended matter samples are analyzed for metals, grain size, TOC, and effluent tracers.

Sediment-profile image monitoring is conducted each August to give area-wide assessments of sediment quality and benthic community status. The sediment-profile images provide more rapid assessments 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 to which oxygen penetrates, known as the oxidation-reduction (redox) 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.

Monitoring the soft-bottom benthic infauna also includes annual surveys conducted in August. Samples are collected with a 0.04-m^2 Young-Van Veen benthic grab, sieved on 300-µm mesh, and fixed in formalin in the field, then transferred to alcohol and stained with Rose Bengal in the laboratory. Animals are sorted, identified, and counted.

Most pollutant-effect monitoring studies of benthic communities, including the MWRA monitoring program, focus on the soft-bottom areas with finer-grained sediments, but 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. Video and still photographs are taken at a series of stations or waypoints, including diffuser head #44 of the outfall (which was not opened) and diffuser head #2. These annual surveys are conducted in June. Photographs are examined for substrate type (top or flank of the drumlin, with relief defined by presence of boulders and cobbles), amount of sediment drape (the degree to which a layer of fine material covers the hard surface), and biota (taxa identified to species or species groups and counted).

Several changes to the monitoring design were implemented in 2003 and 2004, as the monitoring program shifted its emphasis from the potential for short-term, nearfield effects to investigation of long-term effects (MWRA 2004). To effect these changes, the existing 23 nearfield and 8 farfield soft-bottom stations were split into two subgroups. This division was made randomly after accounting for regional representation and level of replication, with two stations (NF12 and NF17, which are also sampled by USGS) being included in both groups. The adjusted program includes the following:

- Sediment characteristics and tracers, such as TOC, sediment grain size, and *Clostridium perfringens* spore counts, are sampled in one subset in alternate years, such that each station is sampled at least once every two years.
- Chemical constituents, including PAHs, PCBs, pesticides, and metals, are measured annually at the two stations included in both groups and once every three years at stations being sampled for other parameters, with the next sampling scheduled for 2005.
- Sediment-profile images for the measurement of RPD depth continue to be taken at all 23 nearfield stations each year.
- Benthic infauna is studied at the same stations as are sampled for sediment characteristics. Species composition and abundance are assessed for all stations sampled.
- Hard-bottom monitoring continues as previously, except that two stations were discontinued and two stations were added in 2003.

Results

Sediment Characteristics, Tracers, and Contaminants

Baseline sampling at nearfield stations found that the area around the outfall was composed of heterogeneous sediments that had received historic inputs of contaminants from Boston Harbor, the atmosphere, and other sources. In the nearfield, contaminant concentrations have been correlated with grain size, with the muddier stations having more organic carbon and higher concentrations of contaminants.

Since the outfall began operation, sediment grain size and total organic carbon content at most stations have remained within the range of variability measured during the baseline period (Maciolek *et al.* 2005). Small increases in percentage of clay and total organic carbon have been detected at some stations, but there has been no indication of any regional effect. Abundance of the sewage tracer *Clostridium perfringens* spores has been within the baseline range, although increases in abundance in comparison to the two years immediately prior to the outfall startup could be measured. These increases were detected at stations located within approximately two kilometers of the outfall. Abundances of *Clostridium perfringens* spores, normalized to sediment grain size, decreased in 2003 and 2004 compared to 2001 and 2002.

Data from the two stations sampled for toxic contaminants in 2004 remained within the baseline range for most samples. Small increases in some metals and organic contaminants have been measured in some samples during 2001 through 2004, but there have been no systematic or widespread changes compared to the baseline.

Sediment-Profile Imaging

Sediment-profile imaging measurements in 2004 showed no changes from the baseline to the post-baseline period (Figure 4-4). No relationship between RPD depth and outfall operation has been detected, and no regional trends have appeared during the years that the outfall has been operating.

Both physical and biological processes appeared to be responsible for structuring the surface sediments in 2004 (Figure 4-5). The prominence of biogenic features was similar to what was seen in 2003, but less than what had been observed during the last years of the baseline period. All but one station had high densities of small polychaete tubes.

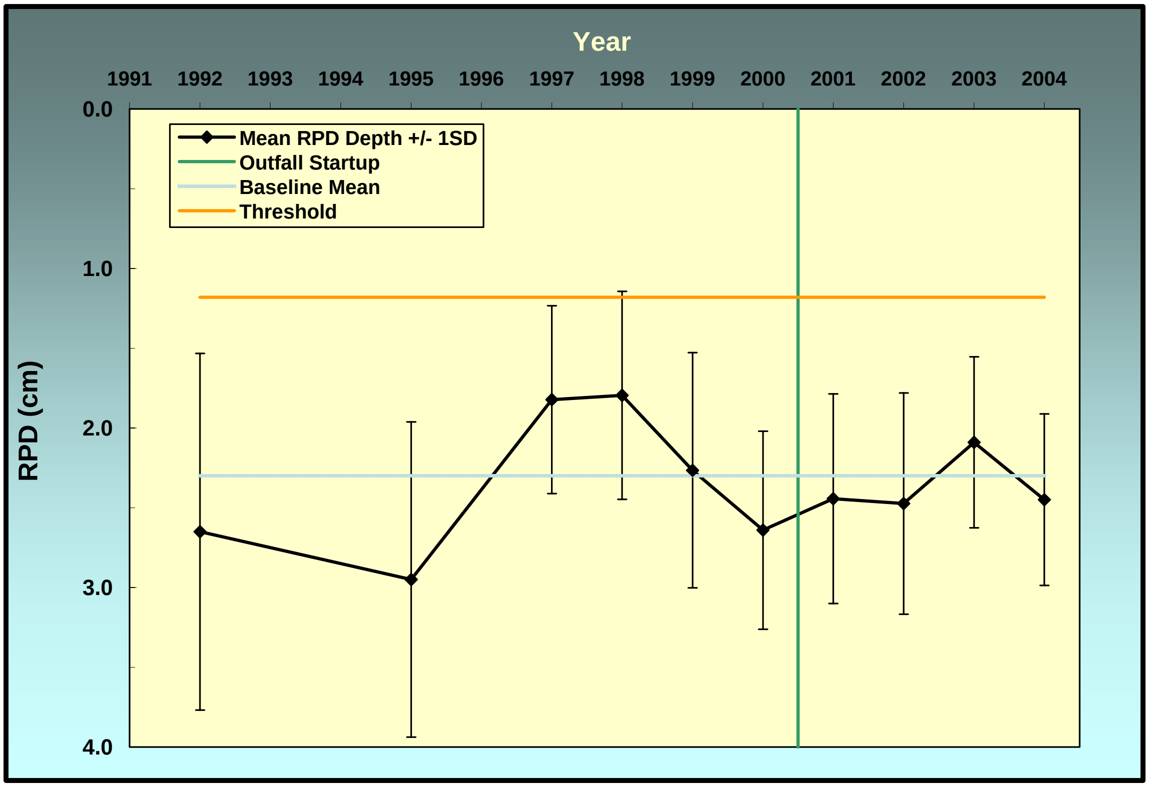

Figure 4-4. Apparent color RPD for all data from nearfield stations

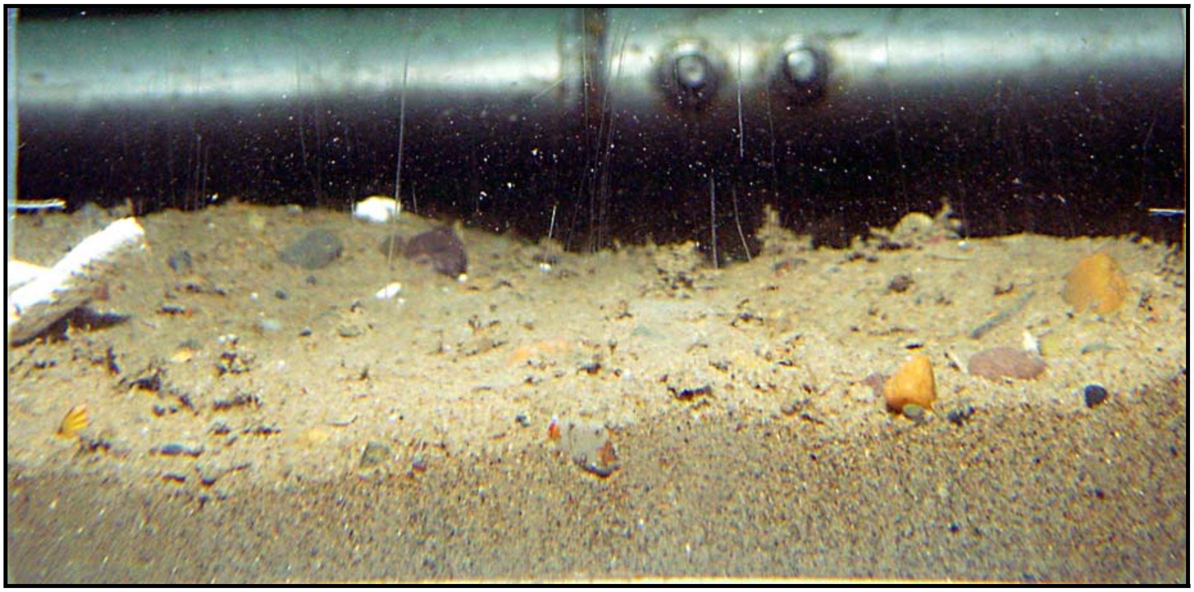

Figure 4-5. Top: Sediment profile image from Station NF23, showing physically structured sediment surface ("pipe" is part of profiling gear): Bottom: Image from Station NF08, showing biologically structured surface

Soft-bottom Communities

The soft-bottom communities have also shown no response to the outfall (Maciolek *et al.* 2005). During the baseline period, multivariate analyses indicated that sediment grain size was the dominant factor in structuring the benthic communities. In the nearfield, stations with fine sediments have been dominated by polychaete worms, such as *Prionospio steenstrupi*, *Spio limicola*, *Mediomastus californiensis*, and *Aricidea catherinae*. Sandier stations have been inhabited by the sand dollar *Echinarachnius parma*, polychaetes *Exogenes hebes, E. verugera, Spiophanes bombyx*, and *Owenia fusiformis*, and the amphipod *Crassicorophium crassicorne*.

The benthic communities of the farfield have differed from those in the nearfield, as the farfield stations span a greater depth range, are geographically widespread, and generally have finer sediments than those in the nearfield. Polychaete worms, including *Eucone incolor*, *Aricidea quadrilobata*, and *Levinsenia gracilus*, have predominated at most stations. *Prionospio steenstrupi* has also been common at some of the farfield stations. Another polychaete, *Cossura longicirrata*, has dominated at a station in Cape Cod Bay.

The nine years of baseline monitoring provided a broad base for understanding the potential responses of the benthic communities to the discharge. During the baseline period, some stations were severely affected by winter storms, while other, deeper stations exhibited more stability over time. The years of post-discharge-transfer monitoring have detected some statistical differences in community parameters, such as increased numbers and dominance of some species at some stations. These changes are considered to be natural fluctuations rather than patterns that can be related to the discharge.

In 2004, mean total abundance fell in both the nearfield (Figure 4-6, top) and the farfield (not shown), primarily because of a major decline in the abundance of one species, *Prionospio steenstrupi* (Maciolek *et al.* 2005). Changes in species richness and diversity measured as log-series alpha (Figure 4-6, middle and bottom), appeared to be part of the natural cycles rather than indicative of any effects of the outfall. Both Shannon diversity and Pielou’s evenness indices (not shown) were higher in 2004 than in previous years, and above the baseline means. The changes in these indices reflect the decrease in abundance of the formerly dominant *Prionospio steenstrupi* while numbers of total species remained fairly constant.

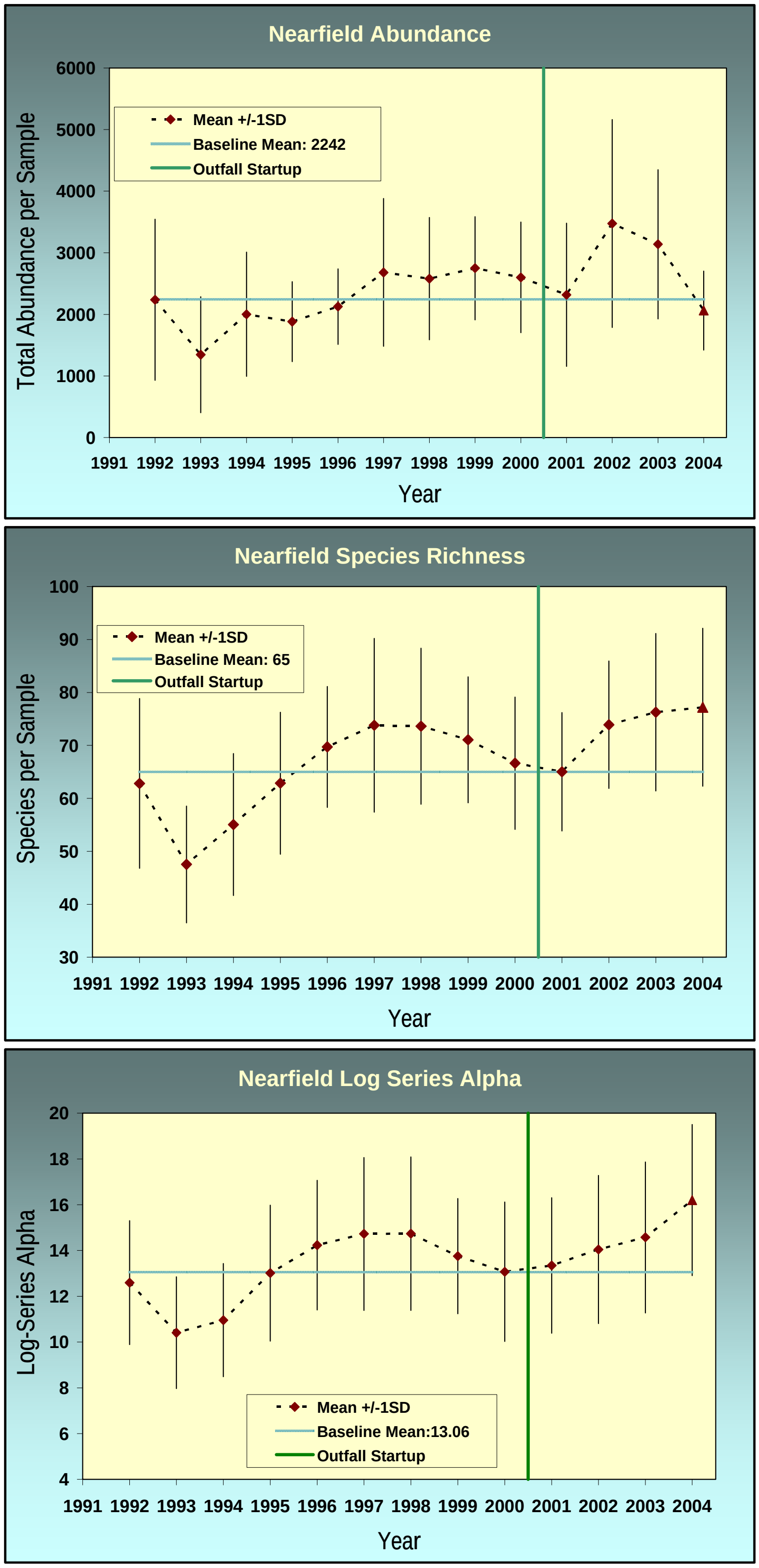

Figure 4-6. Community parameters in the nearfield, 1992-2004: abundance per sample, species richness (number species per sample, log-series alpha)

Hard-bottom Communities

Rocky environments in the vicinity of MWRA's outfall support communities of algae and invertebrates similar to those found throughout northern New England. Near the outfall, these environments and the communities they support are stable from year to year but vary over relatively short distances, on the scale of tens of meters. The habitat ranges from large boulders to cobbles to gravel pavements.

Some changes in the hard-bottom communities have been detected since the outfall began operation, but they have been modest, and it is difficult to attribute them to outfall operation. Lush epifaunal growth continues to thrive, even on the diffuser heads (Figure 4-7). Sediment drape has increased at some stations north and south of the outfall, with concurrent declines in coralline algae cover at the same stations. Declines in upright algae had been detected some stations in 2003, but that trend did not continue in 2004.

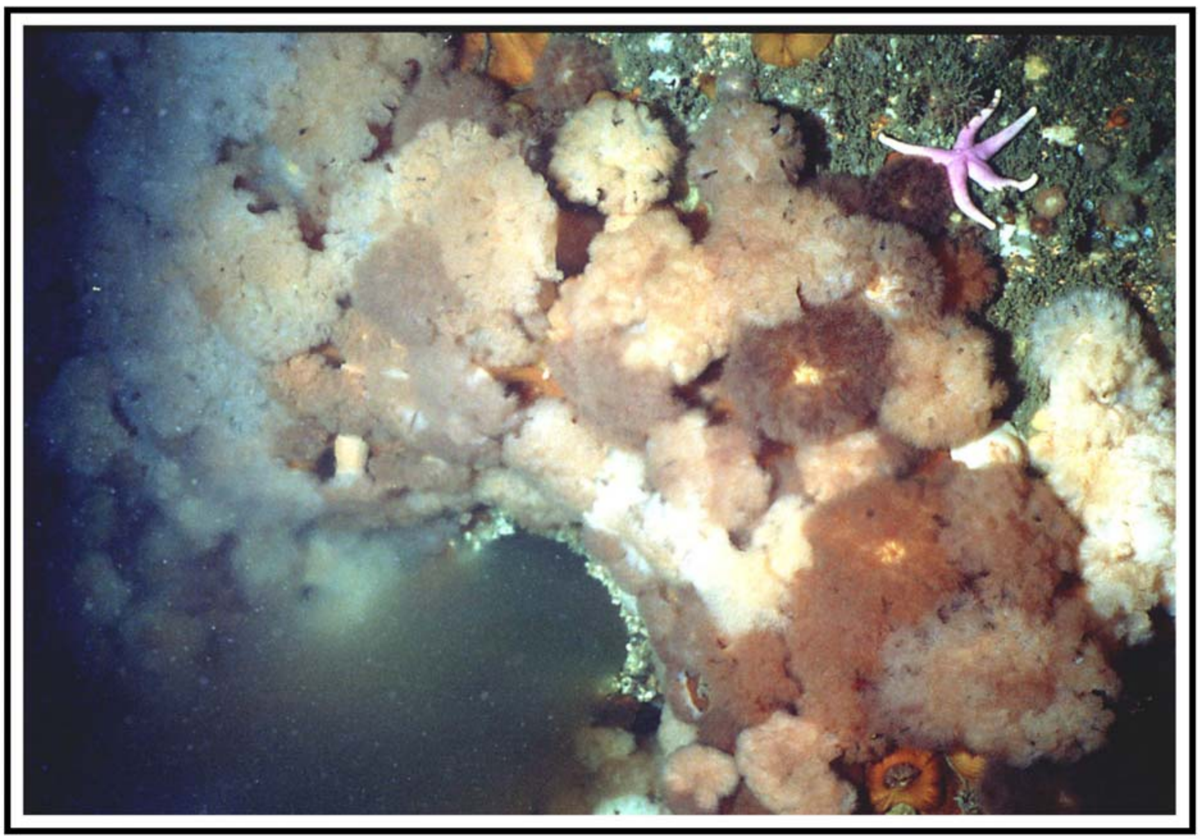

Figure 4-7. Head of active diffuser #2, with frilly anemones surrounding the discharge port.

Contingency Plan Thresholds

The revisions to the monitoring program that were enacted in 2004 required recalculating some Contingency Plan thresholds to account for splitting the soft-bottom sampling into two subgroups (Table 4-2). None of those Contingency Plan thresholds for sea-floor monitoring were exceeded in 2004. No comparisons to thresholds for contaminants concentrations in sediments were made.

Table 4-2. No Contingency Plan baseline and threshold values for sea-floor monitoring were exceeded in 2004

Location	Parameter	Caution Level	Warning Level	2004 Results
Sediments, nearfield	RPD depth	1.18 cm	None	2.4 cm
Even years, Benthic diversity, nearfield	Species per sample	<48.41 or >82.00	None	77
	Fisher's log-series alpha	<9.99 or >16.47	None	14.87
	Shannon diversity	<3.37 or >4.14	None	4.07
	Pielou's evenness	<0.58 or >0.68	None	0.66
Odd years, Benthic diversity, nearfield	Species per sample	<46.52 or >79.95	None	Not applicable
	Fisher's log-series alpha	<9.95 or >15.17	None	Not applicable
	Shannon diversity	<3.30 or >3.91	None	Not applicable
	Pielou's evenness	<0.56 or >0.66	None	Not applicable
Benthic opportunists	% opportunists	>10%	>25%	0.23%

5. Fish and Shellfish

Background

MWRA monitors fish and shellfish because of concerns for public health and because some fish and shellfish species are good indicators of effects of pollutants on overall marine health (Table 5-1). The fish and shellfish industry is an important part of the regional identity and economy of Massachusetts. Concerns have been expressed that the relocation of sewage effluent into the relatively clean waters of Massachusetts Bay could result in chemical contamination of the fisheries and that contaminants could cause direct damage to the fishery stocks.

Table 5-1. Monitoring questions related to fish and shellfish

Is it safe to eat fish and shellfish? *Will toxic chemicals accumulate in the edible tissues of fish and shellfish, and thereby contribute to human health problems?* ▪ Has the level of contaminants in the tissues of fish and shellfish around the outfall changed since discharge began? ▪ Do the levels of contaminants in the edible tissue of fish and shellfish around the outfall represent a risk to human health? ▪ Are the contaminant levels in fish and shellfish different between outfall, Boston Harbor, and a reference site?
Are natural/living resources protected? *Will fish and shellfish that live near or migrate by the diffuser be exposed to elevated levels of some contaminants, potentially contributing to adverse health in some populations?* ▪ Has the level of contaminants in the tissues of fish and shellfish around the outfall changed since discharge began? ▪ Are the contaminant levels in fish and shellfish different between the outfall, Boston Harbor, and a reference site? ▪ Are the contaminant levels in fish and shellfish different between outfall, Boston Harbor, and a reference site? ▪ Has the incidence of disease and/or abnormalities in fish or shellfish changed?

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. Consumption of filter-feeding animals by predators could result in transferring contaminants up the food chain and ultimately to humans.

Monitoring Design

The monitoring program focuses on three indicator species: winter flounder, lobster, and blue mussel. Winter flounder and lobster are important resource species in the region. The blue mussel is also a fishery species and a common biomonitoring organism.

Like all flatfish, winter flounder live and feed on the bottom, often lying partially buried in the sediments. Consequently, flounder can be exposed to contaminants directly, through contact with the sediments, or indirectly, by ingesting contaminated prey. Flounder livers are examined to quantify disease, including three types of vacuolation (centrotubular, tubular, and focal, representing increasing severity), microphage aggregation, biliary duct proliferation, and neoplasia or tumors. Neoplasia and vacuolation have been associated with chronic exposure to contaminants. Chemical analyses of winter flounder tissues are also made to determine tissue burden and to evaluate whether contaminant burdens approach human health consumption limits. Chemical analyses (Table 5-2) of composite samples of fillets and livers include PCBs, pesticides, mercury, and lipids. Liver samples are also analyzed for PAHs, lead, silver, cadmium, chromium, copper, nickel, and zinc.

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. 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. Mussels are collected from clean reference sites (which have included Rockport, Gloucester, and Sandwich, Massachusetts, and Stover's Point, Maine). They are placed in cages and deployed in replicate arrays. 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, lipids, mercury, and lead.

Table 5-2. Chemical analyses of fish and shellfish

Parameter	Measurement details
Flounder fillet	
Mercury PCBs Chlorinated pesticides Lipids	Three composites of fillets from five flounder
Flounder liver	
Trace metals PAHs PCBs Chlorinated pesticides Lipids	Three composites of livers from five flounder
Lobster meat	
Mercury PCBs Chlorinated pesticides Lipids	Three composites of meat from five lobsters
Lobster hepatopancreas	
Trace metals PAHs PCBs Chlorinated pesticides Lipids	Three composites of hepatopancreas from five lobsters
Mussel	
Mercury Lead PAHs PCBs Chlorinated pesticides Lipids	Six composites of soft tissue from ten mussels

Revisions to the monitoring program (MWRA 2004) reduced the frequency of fish and shellfish monitoring, because the aim is to detect long-term rather than acute effects. Flounder and lobster are sampled from Deer Island Flats, the outfall site, and eastern Cape Cod Bay. Flounder are also taken near Nantasket Beach and Broad Sound. Flounder and lobster are examined for external lesions. Histology analyses for flounder will be made every year; chemical analyses for lobsters and flounder will be completed every third year. Mussels will be deployed every three years at three locations: outside the mixing zone at the outfall, in Inner Boston Harbor, and at Deer Island Light.

Results

In 2004, only winter flounder were studied. Fifty sexually mature (at least three years old) winter flounder were taken from each of the five sampling sites during April. Each of the fish was examined for physical characteristics. All fish were used for histological and age analyses. Flounder tissue was also analyzed for mercury content.

As in previous years, the mild centrotubular hydropic vacuolation (CHV) was the most common form of vacuolation noted in histological analyses. Incidence of CHV was low at all sites (Figure 5-1) and below the baseline mean at the outfall site.

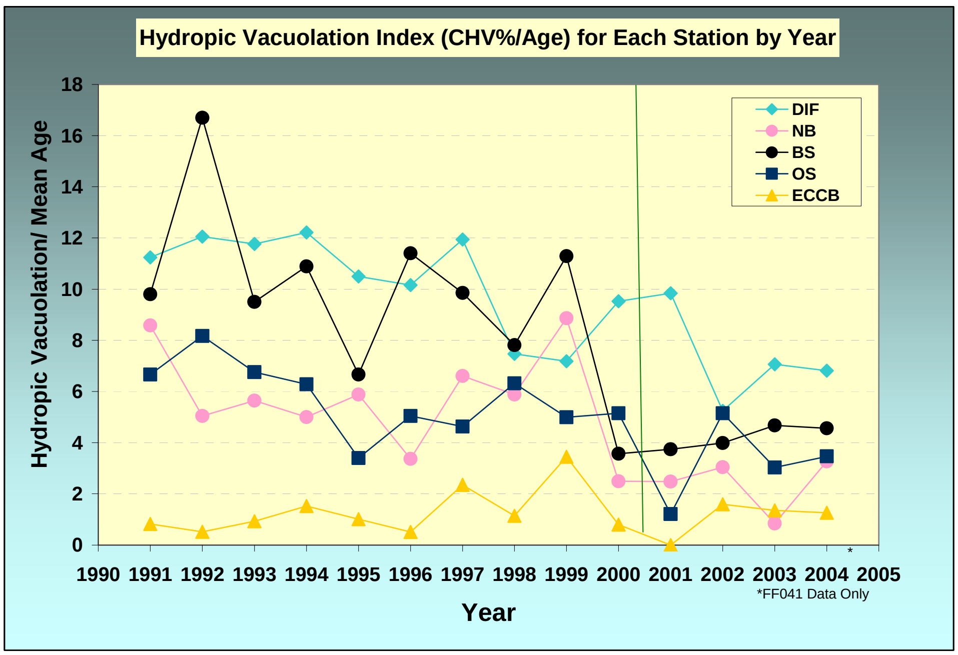

Figure 5-1. Prevalence of centrotubular hydropic vacuolation (CHV) normalized for age (DIF = Deer Island Flats, OS = Outfall Site, ECCB = Eastern Cape Cod Bay, NB = Nantasket Beach, and BS = Broad Sound)

As in 2003, external ulcers were noted on the blind side of many fish (Figure 5-2). Ulcers had not been specifically included as part of the physical assessment provided for in the monitoring plan, prompting additional studies, which were carried out in 2004 and early 2005 (Moore 2005). Studies included a review of additional information from other investigators, sampling at additional stations, attempts to culture bacteria that might be responsible for the ulcers, and additional histology. Surveys were made in late June, October, and December 2004 and early March 2005.

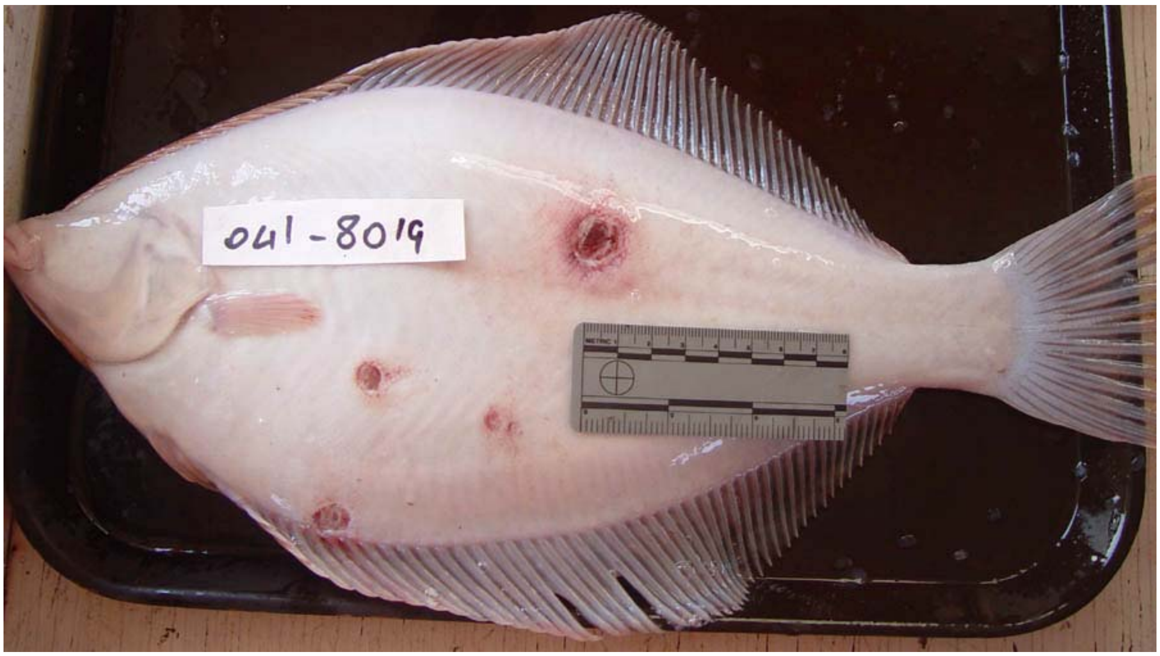

Figure 5-2. Blind-side flounder ulcers

Those additional studies found ulcers on flounder throughout Massachusetts Bay (Figure 5-3). Ulceration appeared to be limited to the spring, with evidence of healing in June. No specific pathogenic bacteria were found, and histological examination did not find evidence of a viral or fungal cause of the ulcers (Moore *et al.* 2004).

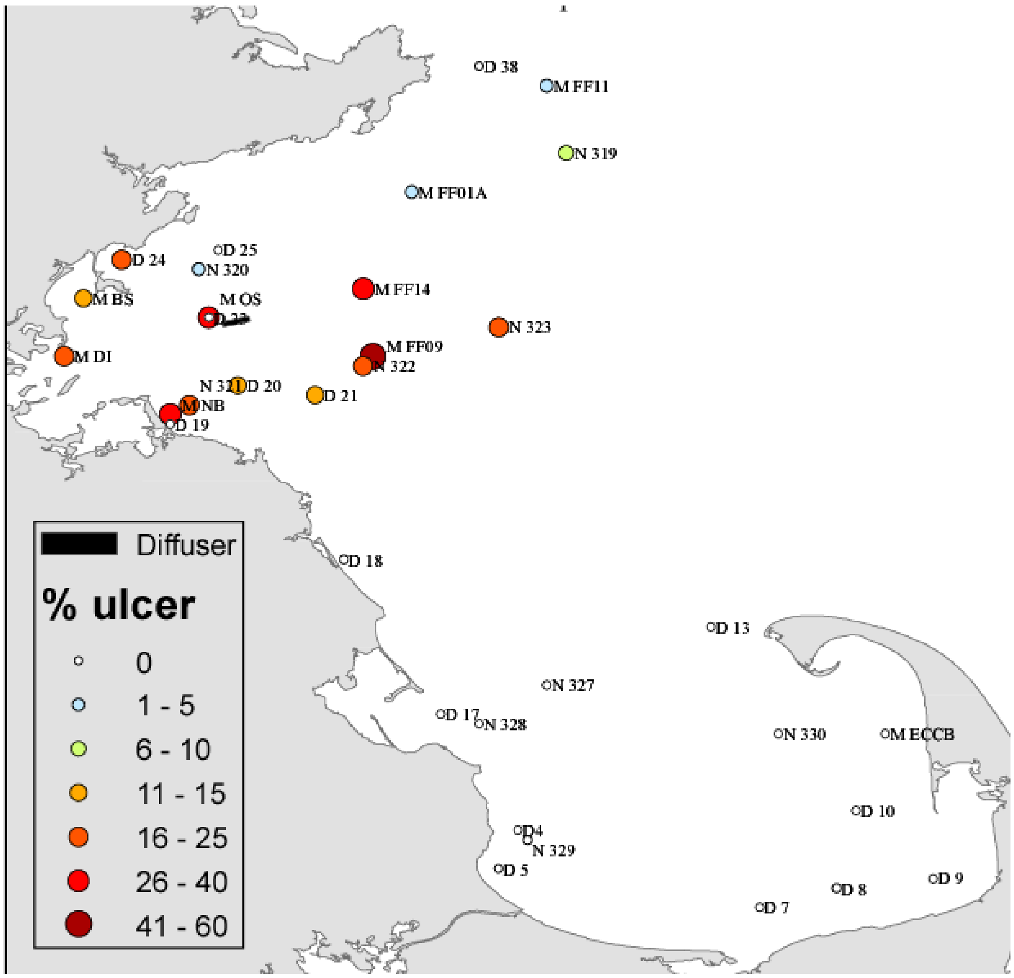

Figure 5-3. Percent of flounder with ulcers (M=March '05, J=June '04, N=October '04, D=December '04)

An OMSAP focus group met in March 2005 to review data and develop recommendations for additional studies. The focus group concluded that the appearance of ulcers was cause for concern and made suggestions for studies that might help identify a cause. OMSAP recommended that MWRA continue tracking and reporting on the prevalence of the ulcers.

Mercury levels in 2004 were within the baseline ranges in flounder fillets and liver samples (Figure 5-4, top and bottom). Elevated levels of mercury in fillets from fish taken near the outfall, which had been noted in 2003, were also found in 2004, but at a slightly lower degree of elevation.

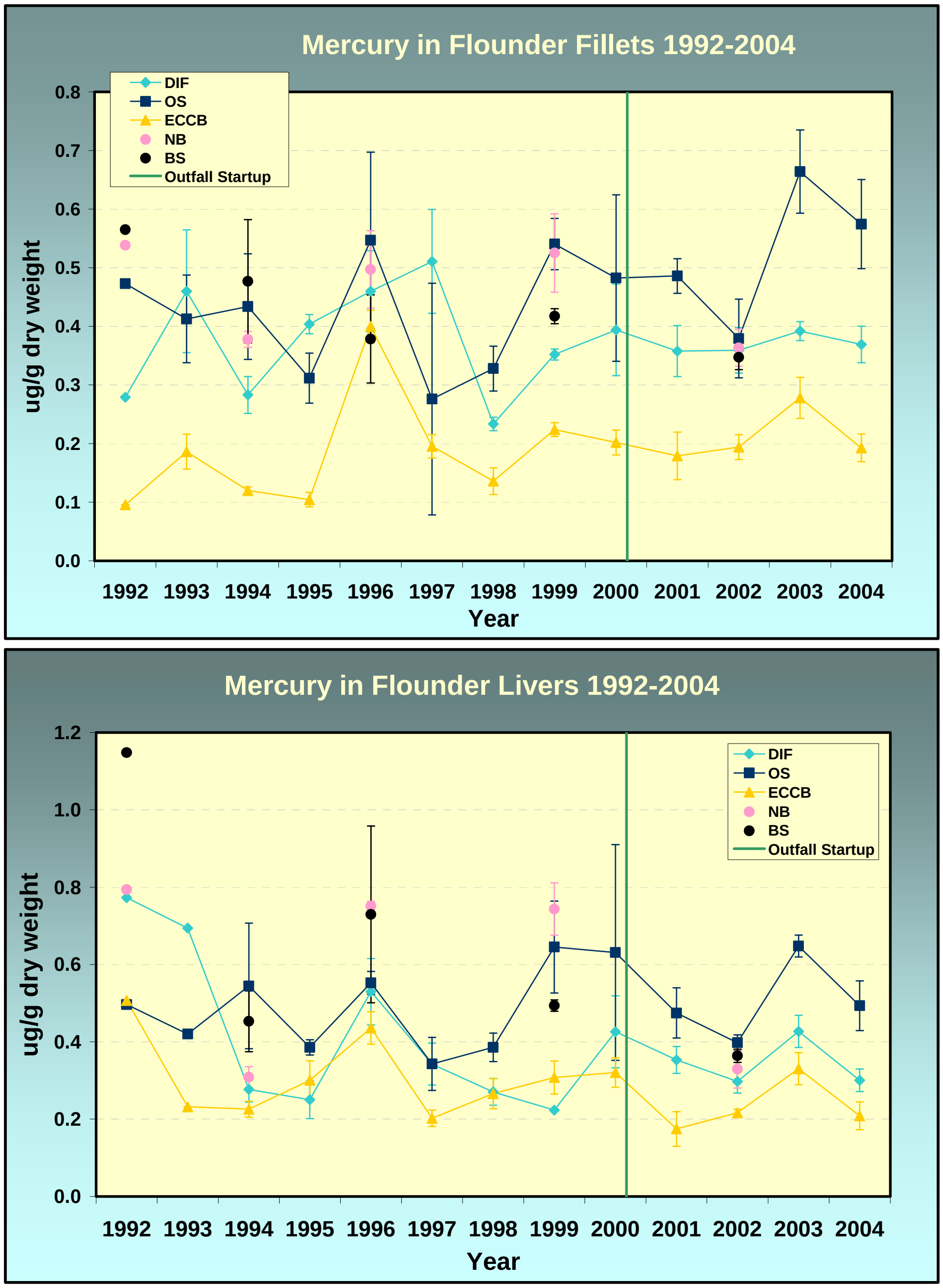

Figure 5-4. Mercury in flounder fillets and livers, 1992-2004

Contingency Plan Thresholds

Threshold parameters for fish and shellfish include levels of toxic contaminants in flounder, lobster, and mussels and liver disease in flounder (Table 5-3). Some thresholds are based on U.S. Food and Drug Administration (FDA) limits for maximum concentrations of specific contaminants in edible portions of food. Others are based on the baseline monitoring. During 2004, only two thresholds were tested: mercury in flounder tissue and liver disease in flounder. Both values remained well below caution and warning thresholds.

Table 5-3. Contingency Plan baseline, threshold, and 2004 values for fish and shellfish monitoring

Parameter Type/ Location	Parameter	Baseline	Caution Level	Warning Level	2004 Results
Flounder tissue nearfield	PCB	0.033 ppm	1 ppm wet weight	1.6 ppm wet weight	Not applicable
	Mercury	0.074 ppm	0.5 ppm wet weight	0.8 ppm wet weight	0.107 ppm
Flounder tissue, lipid normalized, nearfield	Chlordane	242 ppb	484 ppb	None	Not applicable
	Dieldrin	63.7 ppb	127 ppb	None	Not applicable
	DDT	775.9 ppb	1552 ppb	None	Not applicable
Flounder Nearfield	Liver disease (CHV)	24.4%	44.9%	None	18%
Lobster tissue nearfield	PCB	0.015 ppm	1 ppm wet weight	1.6 ppm wet weight	Not applicable
	Mercury	0.148 ppm	0.5 ppm wet weight	0.8 ppm wet weight	Not applicable
Lobster tissue, lipid normalized, nearfield	Chlordane	75 ppb	150 ppb	None	Not applicable
	Dieldrin	161 ppb	322 ppb	None	Not applicable
	DDT	341.3 ppb	683 ppb	None	Not applicable
Mussel tissue Nearfield	PCB	0.011 ppm	1 ppm wet weight	1.6 ppm wet weight	Not applicable
	Lead	0.415 ppm	2 ppm wet weight	3 ppm wet weight	Not applicable
	Mercury	0.019 ppm	0.5 ppm wet weight	0.8 ppm wet weight	Not applicable
Mussel tissue, lipid normalized, nearfield	Chlordane	102.3 ppb	205 ppb	None	Not applicable
	Dieldrin	25 ppb	50 ppb	None	Not applicable
	DDT	241.7 ppb	483 ppb	None	Not applicable
	PAH	1080 ppb	2160 ppb	None	Not applicable

6. 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. During 2004, special studies included nutrient flux at the sediment-water interface, marine mammal observations, water quality modeling, viruses, and contaminant loading to Boston Harbor. This section also includes a preliminary description of activities initiated in response to an *Alexandrium* bloom or red tide, which occurred in 2005.

Nutrient Flux

One concern about the outfall was that increased loads of organic matter might enhance benthic respiration and nutrient fluxes between the sediments and the water column in the nearfield. The resulting higher rates of benthic respiration or sediment oxygen demand might lead to lower levels of oxygen in both the sediments and the water column. The monitoring plan required a special study to measure the organic matter loads, sediment oxygen demand, denitrification, and the flux of nutrients in the vicinity of the outfall to assess the importance of these processes (Table 6-1). Comparable studies take place in Boston Harbor.

Table 6-1. Monitoring questions related to nutrient flux

Are natural/living resources protected? *How do the sediment oxygen demand, the flux of nutrients from the sediment to the water column, and denitrification influence the levels of oxygen and nitrogen in the water near the outfall?* *Have the rates of these processes changed?* ▪ Will increased water-column and benthic respiration contribute to depressed oxygen levels in the water? ▪ Will increased water-column and benthic respiration contribute to depressed oxygen levels in the sediment? ▪ Will enrichment of organic matter contribute to an increase in benthic respiration and nutrient flux to the water column?

In 2004, monitoring of three sites in the nearfield and one site in Stellwagen Basin continued to show little or no indication of any effect of the outfall discharge (Tucker *et al.* 2005). Total organic carbon levels were elevated above the baseline at one nearfield station, but the carbon-to-nitrogen ratio and chlorophyll measurements suggested a relation to the large spring *Phaeocystis* bloom rather than to the outfall.

Sediment oxygen demand continued to be typical of the years since the outfall came on line and at the low end of the baseline range. Nutrient fluxes also continued to be well within and at the low end of the baseline ranges.

Studies also continued at the four Boston Harbor stations, where positive effects of cessation of sludge disposal, improved sewage treatment, and diversion of the outfall continued. Sediment oxygen demand was lower than in any year except for 2002, and dissolved organic nitrogen and phosphate fluxes were lower than at any previous time during the monitoring period. For most measurements, there has been a 40-60% decrease in fluxes from the pre- to the post-diversion period.

Prior to the outfall diversion, Boston Harbor had high rates of sediment oxygen demand compared to those in other coastal systems (Figure 6-1). During the post-diversion years, the rates in the harbor have declined to levels lower than many estuaries, while the rates in Massachusetts Bay have remained unchanged. The change is even more dramatic if only the early part of the pre-diversion period (1993-1995) is considered. During those years (data not shown), the sediment oxygen demand in Boston Harbor was approximately the same as that of the Pawtuxent River. The remarkable improvements in Boston Harbor with corresponding little change in Massachusetts Bay is one measure of the success of the Boston Harbor clean-up.

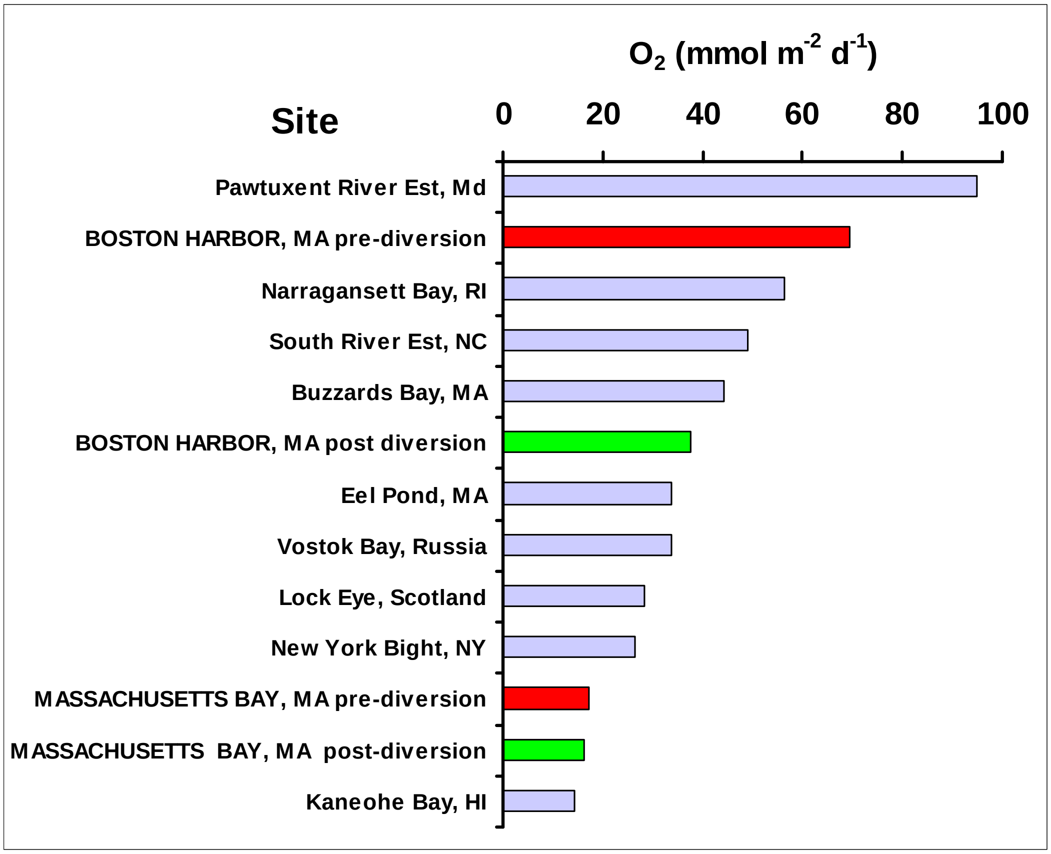

Figure 6-1. Sediment oxygen demand in Boston Harbor and the nearfield of Massachusetts Bay during pre- and post-diversion periods compared to other coastal ecosystems. Data for Boston Harbor and Massachusetts Bay are May-October averages; data for the other systems are summer rates from Nixon 1981

Marine Mammal Observations

Several endangered or threatened species of whales and turtles visit Massachusetts and Cape Cod bays, including the right, humpback, finback, sei, and blue whales. The minke whale, harbor porpoise, gray seal, harbor seal, and several species of dolphins, which are not endangered but are protected, also occur.

Since 1995, MWRA has included endangered species observers on monitoring surveys. In 2004, observers were included on all nearfield water quality surveys, three farfield surveys, and two fecal coliform surveys of the nearfield and near-shore area (Short and Shaub 2005). Besides providing observational data, the presence of trained marine mammal observers addresses a request by the National Marine Fisheries Service (NMFS) that MWRA take active steps to minimize the chances of a collision of one of its survey vessels with a right whale.

The surveys are not designed to determine possible effects of the outfall on marine mammals, but do provide some general information. During the 2004 surveys, 11 individual whales, 14 harbor porpoise, one unidentified porpoise, and more than 27 Atlantic white-sided dolphins were directly observed by the trained observers and other members of the monitoring team. The low number of whale sightings reflected a paucity of whales in Massachusetts Bay that has been confirmed by the Whale Center of New England, an organization founded in 1980 to study whales along the Massachusetts coast.

During the spring and summer of 2004, there were frequent reports of a beluga whale along the coast of Maine and Massachusetts, including the Boston Harbor area. Beluga whales are more typically seen in arctic waters, where their white coloring provides camouflage with ice flows. They are also more typically found in large social groups or pods. The whale was very sociable, frequently interacting with humans, including a diver on an MWRA survey who was in the water to free a tangled propeller (Figure 6-2). Sadly, in November 2004, the whale was found dead in southern Maine; a necropsy found no indication that its death was related to interactions with humans.

Figure 6-2. Beluga whale interacts with diver during MWRA survey in April 2004 (Photograph courtesy of Michael Moore, Woods Hole Oceanographic Institution)

Model Results

MWRA has used numerical models to simulate and predict the physical and biological conditions in Massachusetts Bay. A hydrodynamic model was developed by USGS (Signell *et al*. 1996) and a water quality model, known as the Bays Eutrophication Model (BEM), was developed by Hydroqual, Inc. (2000) for MWRA. Working now with the University of Massachusetts Boston, MWRA continues to maintain, enhance, and apply the models and in 2004 completed updates on each of the models (Jiang and Zhou 2004a, 2004b, additional reports in preparation). Figure 6-3 presents a comparison of modeled and observed data at one station in 2002.

The modeled results compare well with observed conditions for many factors, including seasonal changes in response to heat fluxes, daylight, freshwater inputs, and boundary forcing. The model was able to reproduce the strong response of the summer temperature, salinity, and circulation to upwelling and downwelling winds, which has been reported by Geyer *et al.* (1992, 2002) and by Libby *et al.* (2002, 2004). It also reproduces the seasonal cycles and spatial patterns of phytoplankton abundance, nutrients, and dissolved oxygen. It was not as successful at predicting variations in chlorophyll. For other parameters, modeled results did not match the actual conditions; for example, the model underestimates salinity in the nearfield during the summer and fall, and predicted summer current variations are out of phase with observed variations. At some stations, the model does not show the same seasonal variation in primary production as the data. As is usual for this type of model, the simulations tend to show less variability in space and time than the observations. The model can not reproduce very short-term events, especially when these events are not observed in the boundary data.

In September 2005, MWRA and the modeling team met with OMSAP's Bays Eutrophication Model Evaluation Group (BEMEG), to present recent results and discuss future directions for the modeling effort. Among other findings and recommendations, the BEMEG agreed that, even considering the model-data comparison issues mentioned above, the model reflects the current state of the science.

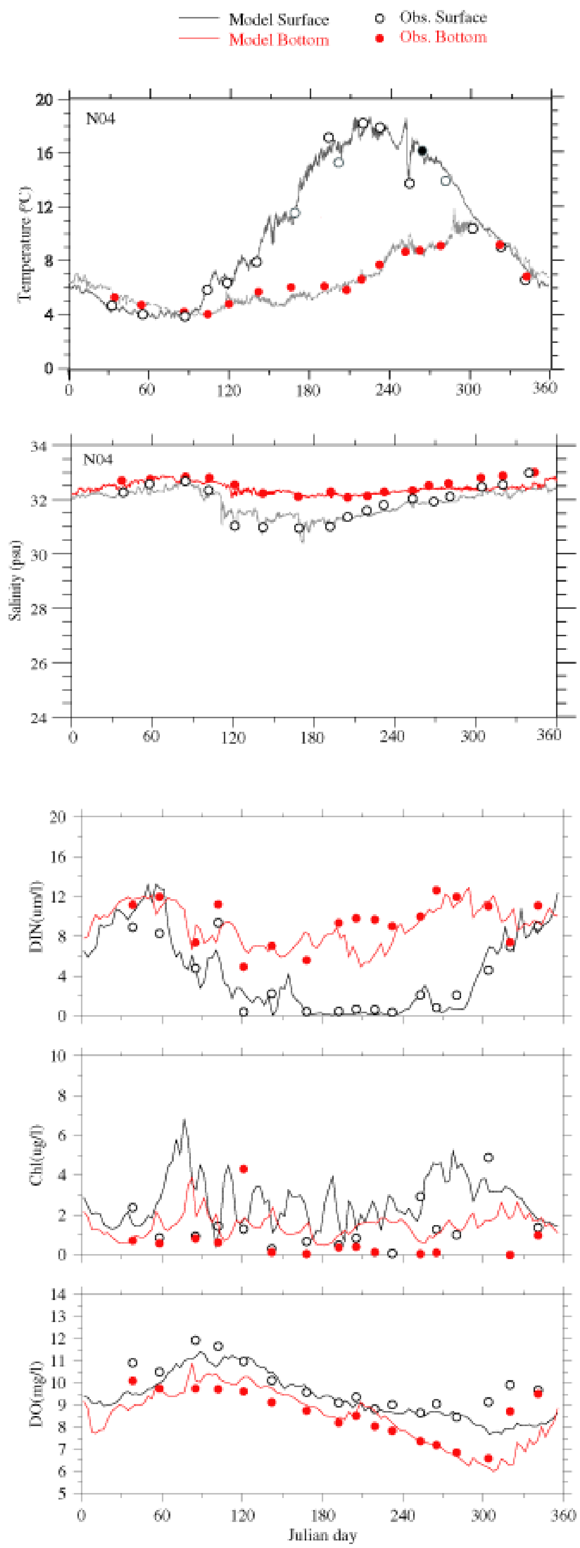

Figure 6-3. Time series of modeled and observed temperature, salinity, dissolved inorganic nitrogen, chlorophyll, oxygen, and productivity at station N04 near the outfall in 2002.

Virus Monitoring in Boston Harbor and the Charles River

MWRA's routine monitoring of water quality in Boston Harbor and the Charles River includes assessment of indicator bacteria (*E. coli* and *Enterococcus*) to gauge the potential risk to public health from pathogens. Use of these indicators over the past century has been crucial in the dramatic reduction of bacterial waterborne illnesses like typhoid fever and dysentery. Today, however, the most common waterborne diseases are caused by viruses, not bacteria, and there are scientific questions about whether bacteria-indicator monitoring adequately predicts the risk from viruses.

In 1995, MWRA began the first studies ever conducted of viral pathogens and viral indicators (also called coliphages) in Boston Harbor and the Charles River (Ballester *et al.* 2004). At that time, there was no information available about levels or prevalence of pathogens in the Charles River or Boston Harbor. Testing was also done at the Deer Island Treatment Plant and the Cottage Farm Combined Sewer Overflow (CSO) Treatment Facility, which discharges to the Charles River. Goals of this exploratory study were to learn whether human enteric viruses and viral indicators (coliphages) could be detected in the study area and at what levels; and to develop correlative data among bacterial sewage indicators, human disease-causing viruses, coliphages, and environmental parameters such as antecedent rainfall or CSO discharge.

During 1995-2003, 138 samples were taken from five locations in Boston Harbor, and 91 samples were taken from six locations in the lower Charles River. The study confirmed that pathogenic viruses could be detected in Boston Harbor and the Charles River—overall about 30% of samples had detectable virus, which is comparable to what investigators have found in other parts of the U.S. and the world. The lowest prevalence was at the beaches. The abundance of pathogens in the harbor and the river was very low; the highest count was about one virus per 10 liters of water and the overall average for all samples was less than two virus per 100 liters of water. Enteroviruses, which are common causes of gastroenteritis, were the most frequently detected type of virus. Treatment at the CSO treatment facility and at the Deer Island Treatment Plant both reduced the number of viruses in wastewater by about 90%.

Because pathogen presence is highly variable and sporadic in human populations, it is inherently difficult to predict. Neither coliphages nor bacterial indicators correlated well with the day-to-day presence of pathogenic viruses in wastewater or natural waters, but the overall picture of water quality at each location was reasonably consistent for both viruses and bacteria.

Recent Trends in Solids and Nutrient Loadings to Boston Harbor

In 2004, MWRA conducted a special study to update information on freshwater flows and nutrient loading to Boston Harbor (Taylor 2005). The study focused on the years 1994-2003; earlier studies (Menzie *et al.* 1999, Alber and Chan 1994) had synthesized data from the beginning years of the Boston Harbor Project. The 2004 study specifically focused on measurements that could influence eutrophication, such as total suspended solids, particulate organic carbon, total nitrogen, and total phosphorus.

The study confirmed reductions in freshwater flow and loadings of the eutrophication-related contaminants over the 10-year period (Figure 6-4).

Changes in flow and loadings can be divided into three periods:

- Period A: the period prior to 1998, when the harbor received discharges from both Deer Island Treatment Plant in the north and Nut Island Treatment Plant in the south. Freshwater flows and loadings of total nitrogen, total phosphorus, total suspended solids, and particulate organic carbon loadings were elevated, primarily due to inputs from the wastewater treatment plants.
- Period B: the two and a half years in which all effluent was discharged from Deer Island Treatment Plant to the harbor. Freshwater flows and loadings of nitrogen and phosphorus continued to be high, but there were decreased loadings of total suspended solids and particulate organic carbon. These reductions were brought about almost entirely by inter-island transfer and the upgrades to secondary treatment.
- Period C: the years after effluent discharge to the harbor ended. These years were characterized by lowered freshwater flows to the harbor, additional decreases in loadings of total suspended solids and particulate organic carbon, and relatively larger decreases in loadings of total nitrogen and total phosphorus. The transfer of effluent discharges from the harbor was largely responsible for the decreases.

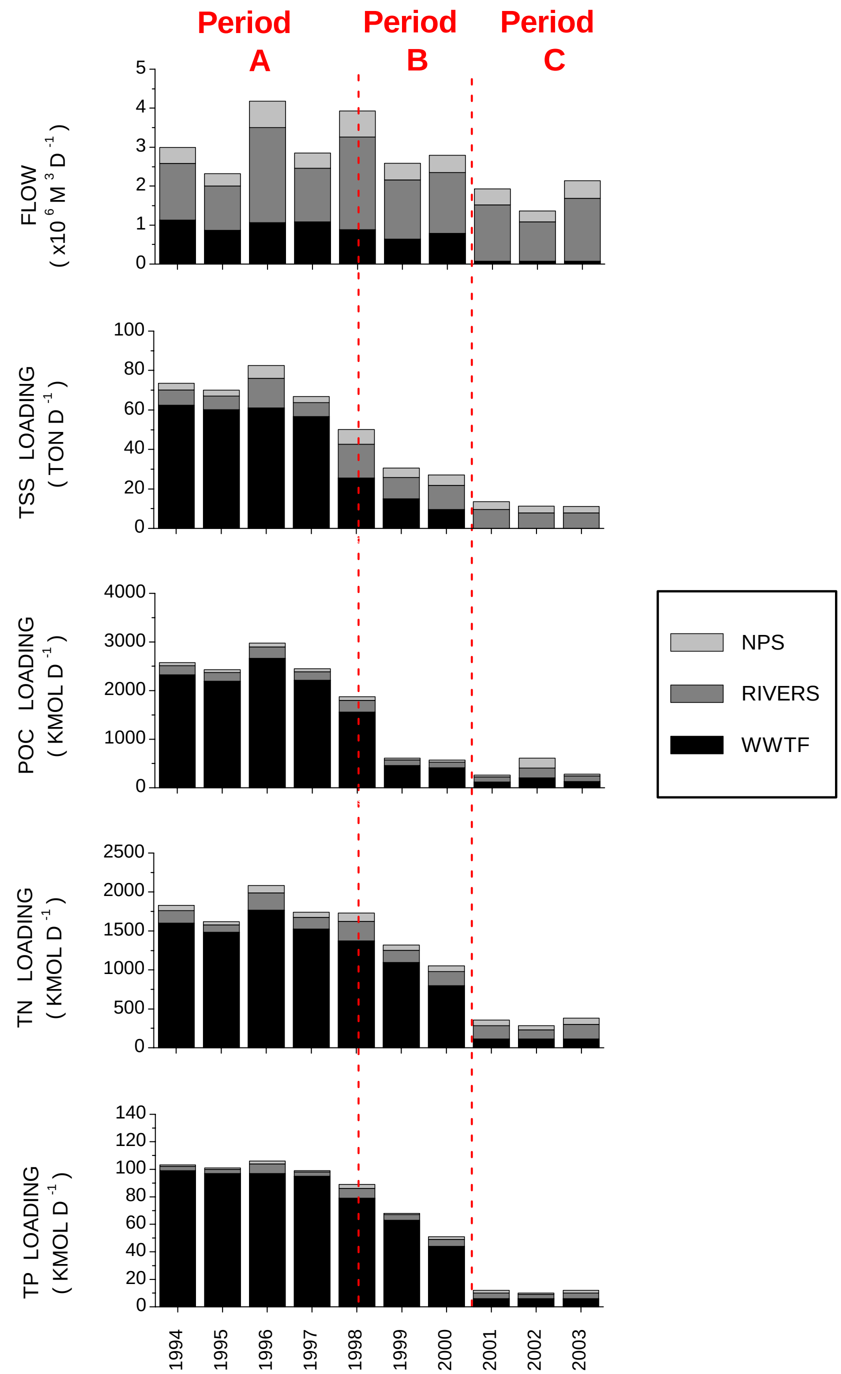

Figure 6-4. Changes in annual freshwater flow and loading to Boston Harbor, 1994-2003. TSS=total suspended solids, POC=particulate organic carbon, TN=total nitrogen, TP=total phosphorus, NPS=nonpoint sources, WWTF=wastewater treatment facility. Nonpoint source data are from Alber and Chan 1994. Data for September 2000 through 2003 include estimates of wastewater re-entering the harbor from the bay.

2005 *Alexandrium* Bloom

During May-July 2005, an extensive bloom of *Alexandrium fundyense* occurred along the coast of southern New England (Figure 6-5). MWRA monitoring detected levels well in excess of the Contingency Plan threshold of 100 cells per liter in the outfall nearfield and region-wide. *Alexandrium* is one of the nuisance algae of concern in water column monitoring, because it produces a toxin that can build up in shellfish to levels that can cause paralytic shellfish poisoning (PSP) in people. In Massachusetts, the Division of Marine Fisheries tests for PSP toxin in shellfish and closes beds if the level of toxin is too high. *Alexandrium* blooms, known as red tides, have sporadically caused shellfish bed closures in Massachusetts Bay since 1972, when a strong bloom was first observed. PSP toxicity was not observed in the Bay from 1994 to 2004.

Alexandrium cell counts during the 2005 bloom were higher than previously observed. The outbreak eventually closed shellfish beds from central Maine to Massachusetts, including Nantucket Island and portions of Martha's Vineyard, and resulted in the closure of 40,000 km^2 of offshore federal waters (Figure 6-6). The bloom was exceptional in several ways: high toxin levels were measured farther south than ever before in New England; levels of toxicity in many locations were higher than previously observed at those stations; for some locations, toxicity was above quarantine levels (levels high enough to close the shellfish beds) for the first time; and cell concentrations far exceeded those observed in the coastal waters of southern New England in the past.

MWRA participated in a region-wide collaborative monitoring effort intended to help understand the scale and duration and to evaluate the causes of this unprecedented red tide. Preliminary indications were that a large spring bloom occurred in the coastal waters of Maine, and this bloom moved south with stronger-than-usual coastal currents, a result of high spring runoff from large rivers in Maine. The bloom was transported into Massachusetts and Cape Cod bays and to waters south of the Cape by two strong northeast storms in May.

The causes and effects of the bloom continue to be evaluated, and a more complete analysis will be presented in the 2005 outfall monitoring overview. The MWRA outfall is not suspected to be a significant factor in the size or extent of this bloom. More complete analysis will help determine whether the outfall may have had a local effect.

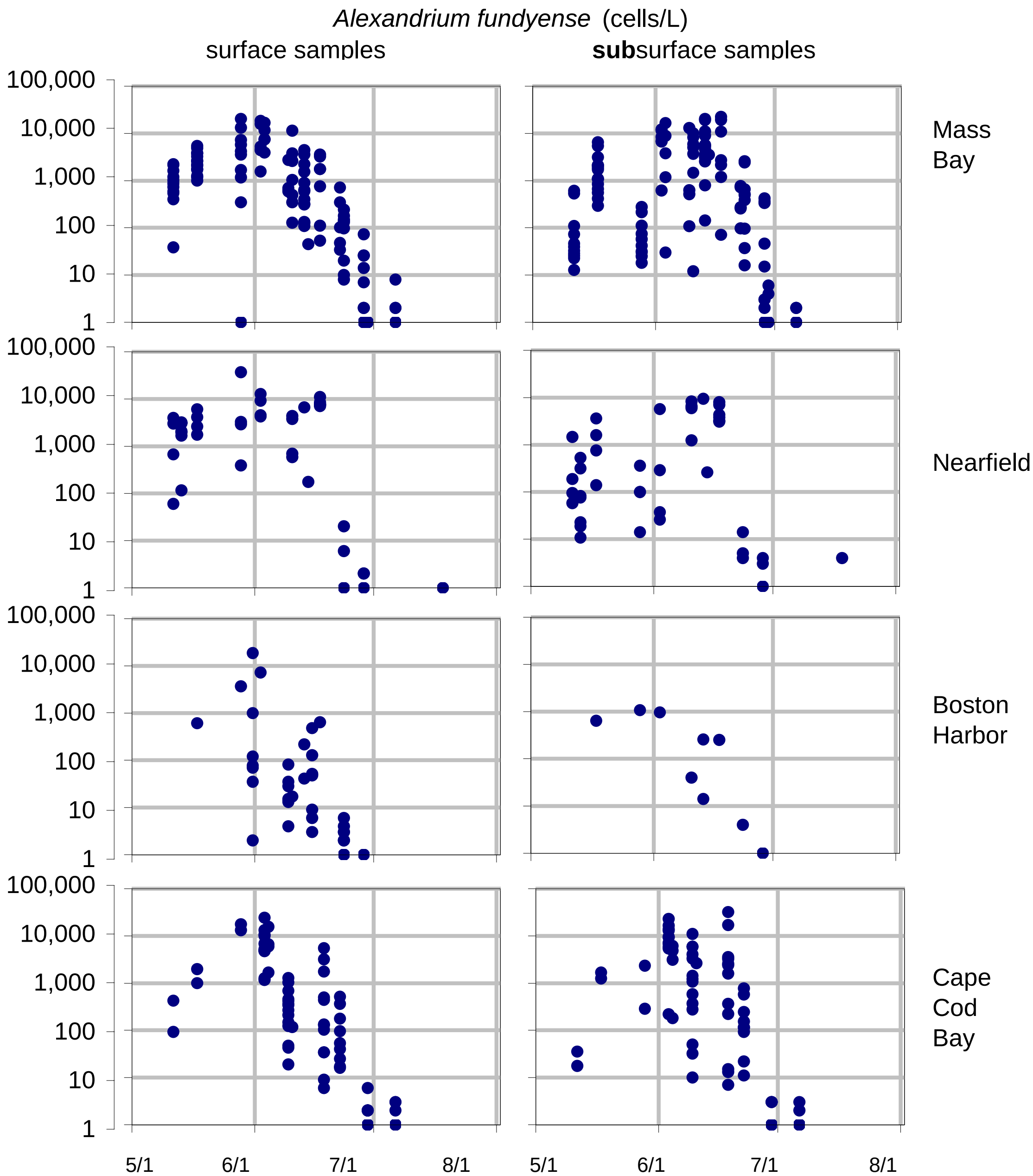

Figure 6-5. Alexandrium cell counts measured during MWRA monitoring surveys in response to the red tide

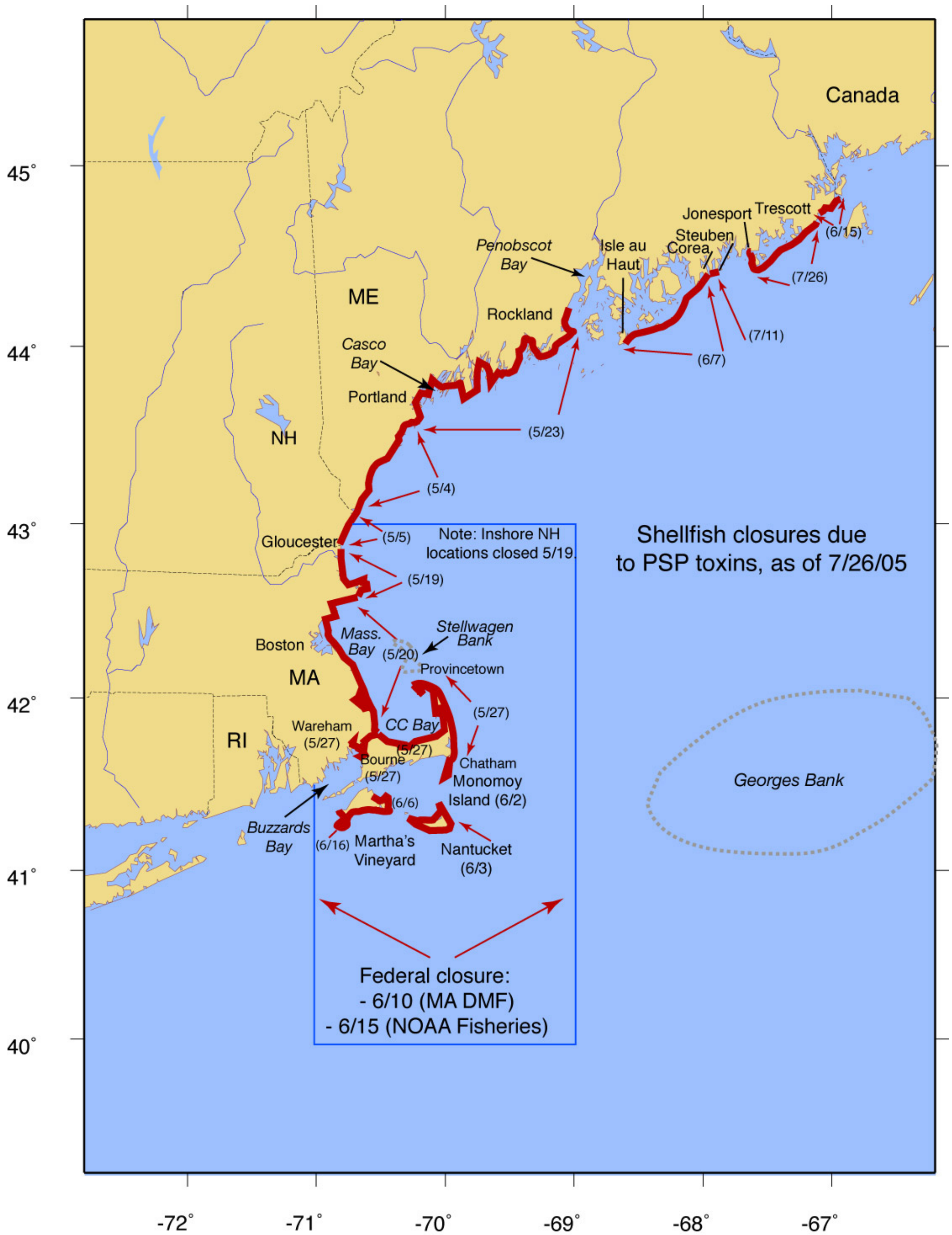

Figure 6-6. Geographic extent of shellfish bed closures in July 2005 (figure courtesy of Don Anderson, Woods Hole Oceanographic Institution)

7. Stellwagen Bank National Marine Sanctuary

Background

The Gerry E. Studds Stellwagen Bank National Marine Sanctuary comprises 842 square miles located at the boundary between Massachusetts Bay and the rest of the Gulf of Maine. The Sanctuary's landward boundaries lie approximately 25 miles east of Boston, three miles north of Provincetown, and three miles south of Gloucester. Stellwagen Basin, which is partially within the sanctuary, is the deepest part of Massachusetts Bay and a long-term sink for fine-grained sediments. Stellwagen Bank, a sand-and-gravel plateau, lies to the east of Stellwagen Basin and has water depths of about 65 feet. Tidal mixing of nutrients throughout the relatively shallow water column creates a rich habitat for marine life on Stellwagen Bank.

The MWRA permit recognizes concerns about possible effects of the outfall on the sanctuary and requires an annual assessment of those possible effects.

Monitoring Design

MWRA's regular water-column and sea-floor monitoring efforts include stations within and near the sanctuary. Five water-column stations, including four within the sanctuary and one just outside its northern border, are considered "boundary" stations, because they mark the boundary between Massachusetts Bay and the rest of 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 regional processes in the Gulf of Maine. Eight water-column stations located between the sanctuary and the coast are considered "offshore" stations by the MWRA program. The revisions to the water-column portion of the monitoring program implemented in 2004 did not change the stations sampled within and in the vicinity of the sanctuary.

Since 2001, the sanctuary managers, in conjunction with MWRA's contractor Battelle, have conducted a supplemental monitoring program, which added four stations to the August and October MWRA surveys (Figure 7-1). These sites were selected to provide a more comprehensive evaluation of water quality across the sanctuary and to increase the understanding of the potential effects of the relocated outfall. The program and results for 2004 are presented described in Libby *et al.* (2005b).

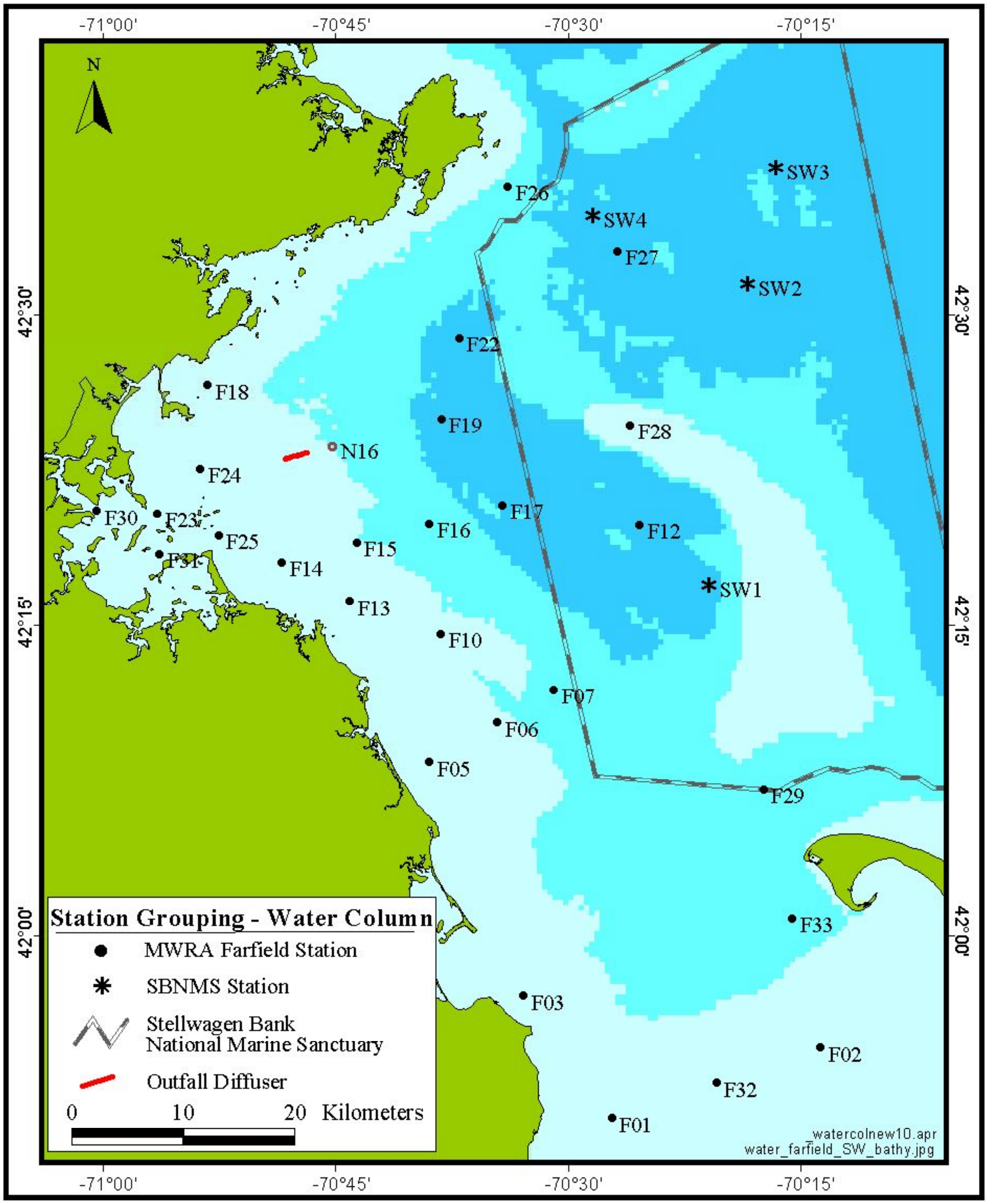

Figure 7-1. Water column stations, including the additional Stellwagen Bank National Marine Sanctuary stations sampled in August and October 2001-2004

Two MWRA sea-floor stations are within the sanctuary, one at the southern boundary and one within Stellwagen Basin (FF04 and FF05, see Figure 4-2). A third sea-floor station (FF11) is just north of the sanctuary boundary and a fourth station (FF14) is located outside the sanctuary, but within Stellwagen Basin. These four stations are the deepest of those included in the MWRA monitoring program and have similar properties, with muddy sediments and moderate concentrations of total organic carbon. The station north of the sanctuary and the one within Stellwagen Basin are east or northeast of the outfall, outside the general circulation pattern that transports diluted effluent south and southeastward in Massachusetts Bay. From 1992 through 2003, these stations were sampled annually in August. Changes to the benthic monitoring program implemented in 2004 call for sampling approximately half the stations each year. In 2004, only Stations FF04 and FF05 were sampled, with Stations FF11 and FF14 to be sampled in 2005.

Results

Water Column

Overall, water quality within the sanctuary was excellent during 2004. There was no indication of any effect of the MWRA outfall (Libby *et al.* 2005a, 2005b). Annual mean nutrient concentrations in the sanctuary have not changed substantially since the outfall began operation. While ammonia concentrations have risen in the nearfield, there has been no comparable annual increase in Stellwagen Bank or Cape Cod Bay (Figure 7-2, top). Nitrate concentrations have shown a long upward trend in all regions; this trend predates the outfall diversion. Concentrations of nitrate in the sanctuary have remained the consistently higher than levels at other monitoring stations (Figure 7-2, bottom).

The mean annual chlorophyll levels have not changed in response to the outfall discharge (Figure 7-3). Annual chlorophyll levels were similar in the nearfield, Cape Cod Bay, and Stellwagen Bank.

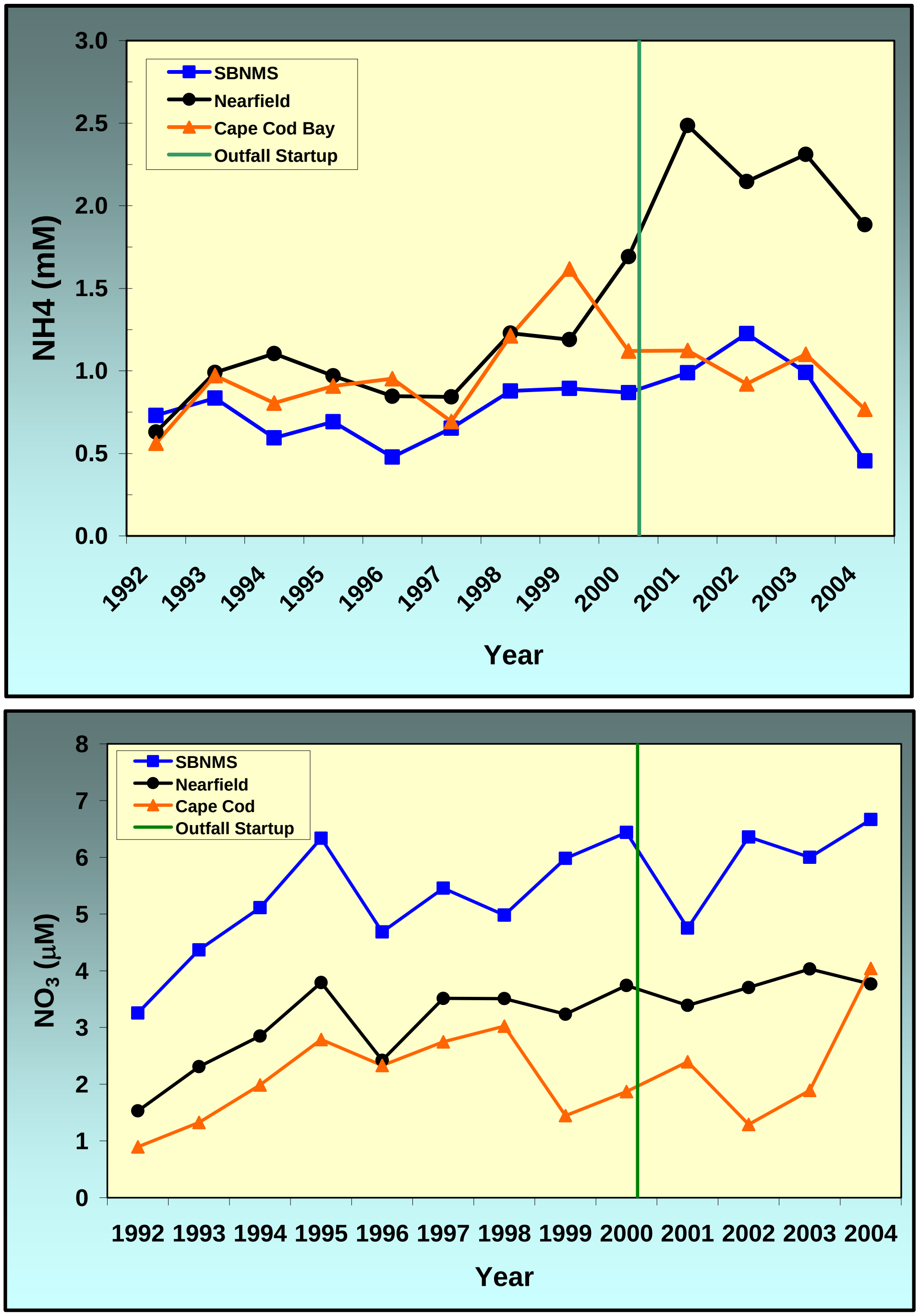

Figure 7-2. Annual mean ammonia (top) and nitrate (bottom) in the Stellwagen Bank National Marine Sanctuary and other regions of Massachusetts and Cape Cod bays

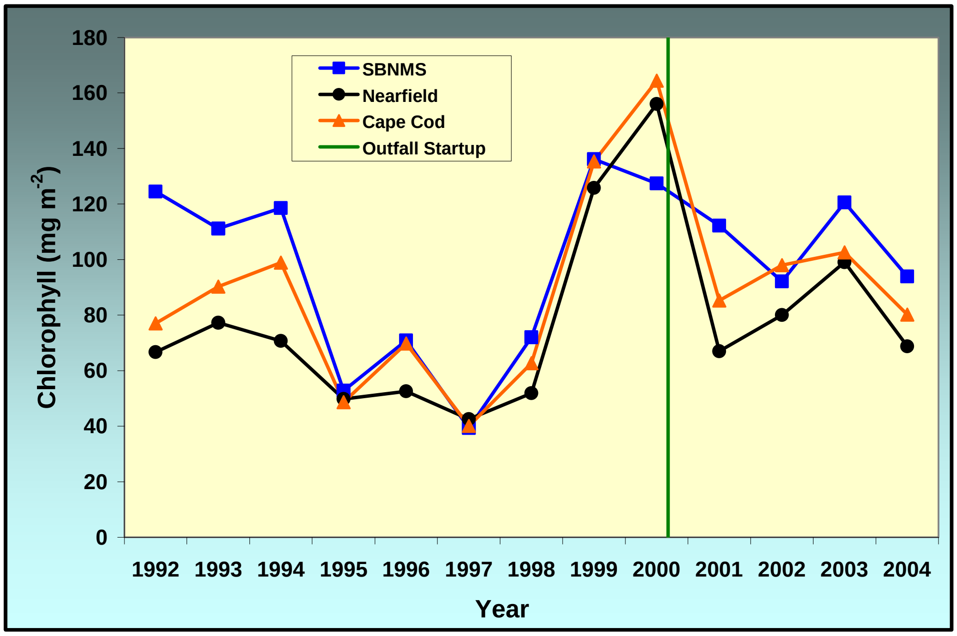

Figure 7-3. Annual mean chlorophyll in Stellwagen Bank National Marine Sanctuary and other regions

There were no confirmed blooms of harmful or nuisance phytoplankton species during August-October 2004 (Libby *et al.* 2005a). The MWRA monitoring program documented a spring *Phaeocystis pouchetii* bloom throughout Massachusetts and Cape Cod bays. This large bloom is discussed in Section 3, Water Column.

Concentrations of dissolved oxygen and percent saturation have remained unchanged in the Stellwagen Basin, as well as in the nearfield (data not shown). Levels in 2004 were relatively high compared to other years of baseline and post-discharge-transfer monitoring.

Sea Floor

No changes in concentrations of sewage tracers or sewage-related contaminants were observed in the sediments from stations within the sanctuary, and there were no changes in community parameters in 2004 (Maciolek *et al.* 2005).

The deep-water stations continued to support a distinct infaunal community with recognizable differences from communities in the nearfield and Cape Cod Bay. Benthic community parameters at individual stations showed no pattern of change following start-up of the outfall in 2000 (Figure 7-4). Overall, the numbers of individual organisms and species per sample have increased, paralleling results from throughout Massachusetts Bay. No consistent pattern has been found that relates to outfall operation.

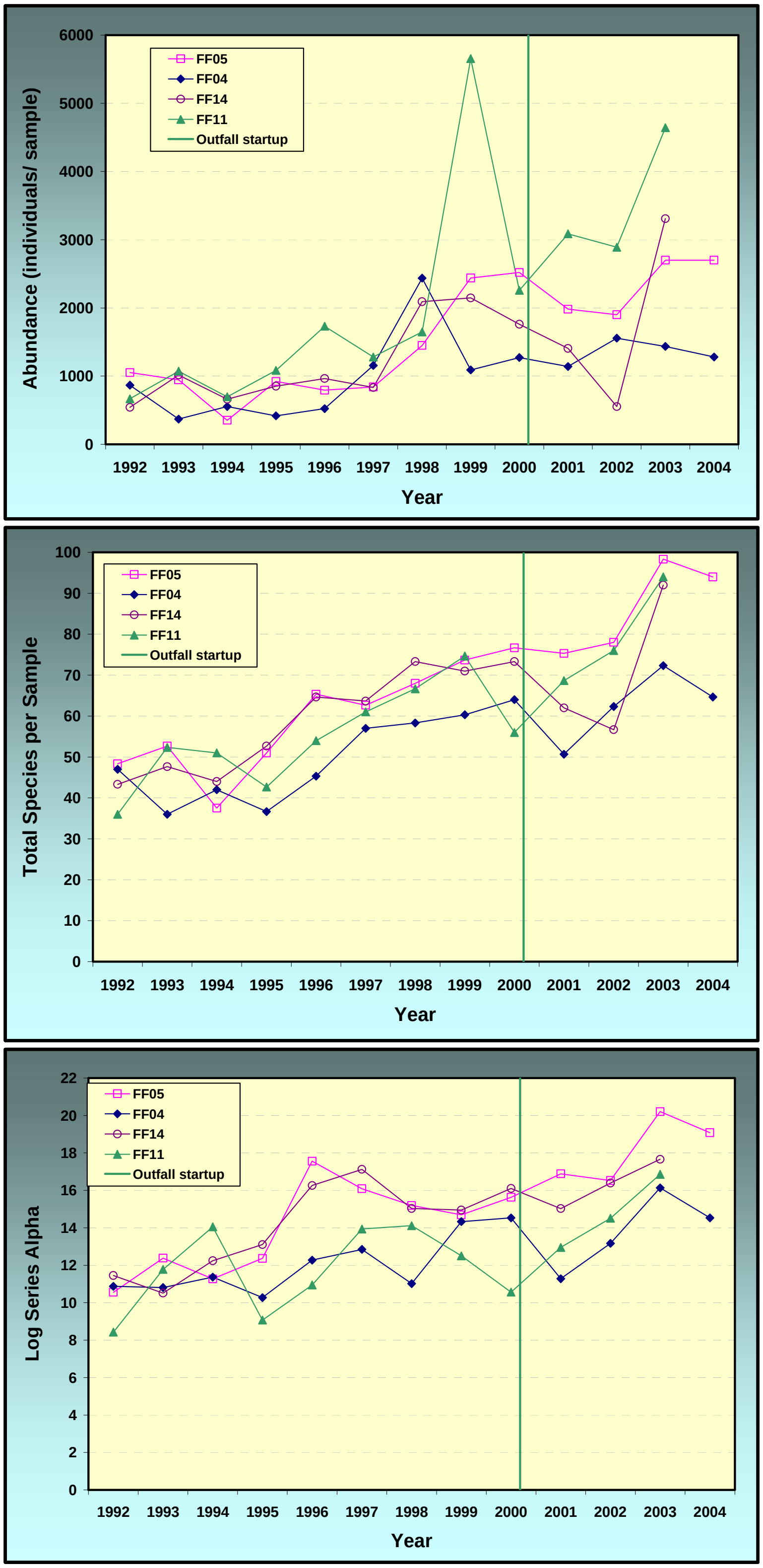

Figure 7-4. Benthic community parameters at stations within the boundary region, 1992-2004

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List of Acronyms

BEM	Bays Eutrophication Model
BEMEG	Bays Eutrophication Model Evaluation Group
BOD	Biochemical oxygen demand
BS	Broad Sound
cBOD	Carbonaceous biochemical oxygen demand
CCB	Cape Cod Bay
CHV	Centrotubular hydropic vacuolation
C-NOEC	Chronic test, no observable effect concentration
CSO	Combined sewer overflow
DDT	Dichlorodiphenyltrichloroethane
DO	Dissolved oxygen
ECCB	Eastern Cape Cod Bay
EPA	U.S. Environmental Protection Agency
FDA	U.S. Food and Drug Administration
FF	Farfield
GoMOOS	Gulf of Maine Ocean Observation System
IAAC	Inter-agency Advisory Committee
LC50	50% mortality concentration
MADEP	Massachusetts Department of Environmental Protection
MGD	Million gallons per day
MWRA	Massachusetts Water Resources Authority
NA	Not analyzed
NB	Nantasket Beach
ND	Not detected
NMFS	National Marine Fisheries Service
NPS	Nonpoint source
NOEC	No observable effect concentration
NPDES	National Pollutant Discharge Elimination System
OMSAP	Outfall Monitoring Science Advisory Panel
OMTF	Outfall Monitoring Task Force
OS	Outfall site
PAH	Polycyclic aromatic hydrocarbon
PC	Particulate carbon
PCB	Polychlorinated biphenyl
ppb	Parts per billion
ppm	Parts per million
PIAC	Public Interest Advisory Committee
RPD	Redox potential discontinuity
PSP	Paralytic shellfish poisoning
SeaWIFS	Sea-viewing Wide Field-of-view Sensor
SBNMS	Stellwagen Bank National Marine Sanctuary
SEIS	Supplemental Environmental Impact Statement
SPI	Sediment-profile imaging
TCR	Total chlorine residual
TOC	Total organic carbon

TRAC	Toxic Reduction and Control Program
TSS	Total suspended solids
USGS	U.S. Geological Survey
WWTF	Wastewater treatment facility

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