2006 outfall monitoring overview

Massachusetts Water Resources Authority

Environmental Quality Department
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2006
Outfall Monitoring Overview

submitted to

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Summary

Each year, the Massachusetts Water Resources Authority (MWRA) prepares this report, an overview of monitoring activities related to the Massachusetts Bay sewage effluent outfall. Overviews have been prepared for most baseline-monitoring years and for each year that the permit to discharge from the outfall has been in place. Overviews for 1994 through 1999 included only baseline information. With the outfall operational, subsequent reports have included information relevant to the MWRA Contingency Plan, such as threshold exceedances, 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 from 2006, marking six full years of post-discharge monitoring. It compares all results to Contingency Plan thresholds. The overview also includes sections on special studies and the Stellwagen Bank National Marine Sanctuary.

During 2006, the Deer Island Treatment Plant continued to operate as designed, and there were no unexpected effects on the ecosystems of Massachusetts and Cape Cod bays. Total loads of many parameters measured within the effluent, including solids and metals, remain low. Deer Island effluent continuously met secondary treatment numerical limits and water quality standards, and effluent quality continues to be as good or better than predicted in EPA's Secondary Environmental Impact Statement prior to the construction of the plant.

After nine years of baseline monitoring and six years of discharge monitoring, the MWRA has been able to answer 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 as a result of the offshore outfall. Therefore, based upon the existing extensive monitoring results that clearly answer the questions asked when the monitoring began, it may be appropriate that the upcoming NPDES permit incorporate significant reductions in MWRA's outfall monitoring program.

There were four Contingency Plan exceedances during the year (Table 2). One of four monthly toxicity tests, the fish chronic growth-and-survival test, did not meet the Contingency Plan warning threshold for a series of samples collected in July. Analysis of the test data suggests that the exceedance may have been related to elevated levels of ammonium in a subsample of effluent. The levels of ammonium reached in the laboratory do not suggest similar conditions or possible effects on animals in the ambient receiving waters.

The reported mean nearfield chlorophyll value for May through August exceeded the caution level threshold. The high level resulted from a summer bloom of a diatom species that is not considered to be harmful or a nuisance.

As in every year since 2002, summer concentrations of the nuisance algal species *Phaeocystis pouchetii* exceeded the caution level. The wide geographical extent of the blooms suggests that regional processes, particularly the speed with which waters warm in the spring, rather than the outfall, have been responsible for the increasing frequency and duration of *Phaeocystis* blooms.

For a second year, the threshold for the toxic alga species *Alexandrium fundyense* was exceeded during the May red tide. Shellfish beds in Massachusetts were closed from the New Hampshire border to Duxbury. The threshold for paralytic shellfish poisoning (PSP) toxin extent was not exceeded, because the spatio-temporal pattern of the red tide was consistent with past blooms, beginning in the north and progressing to the south. The MWRA outfall is not suspected to be a significant factor in the size or extent of this bloom.

As in other years, no effects of the outfall on the Stellwagen Bank National Marine Sanctuary were detected. Plume tracking, water column, and sea floor studies suggested that no effects of the outfall on the sanctuary were likely, and none have been measured.

Table 1. Summary of monitoring questions and status as of the end of 2006

Monitoring Question	Status
Do effluent pathogens exceed the permit limits?	No. Compliance with permit limits, secondary treatment and disinfection effectively remove pathogens.
Does acute or chronic toxicity of effluent exceed the permit limit?	General compliance with permit limits, one exceedance of chronic toxicity test in 2006.
Do effluent contaminant concentrations exceed permit limits?	No. 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?	No. Compliance with permit limits, 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?	No. 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?	No. Dilution is sufficient for pathogens to reach background concentrations before reaching shellfish beds, confirmed by plume studies conducted in 2001.
Are pathogens transported to beaches at levels that might affect swimmer health?	No. Dilution is sufficient for pathogens to reach background concentrations before reaching beaches, confirmed by plume studies conducted in 2001.
Has the clarity and/or color of the water around the outfall changed?	No. 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?	Yes. 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, and influenced by tides and local wind. Bottom currents around the outfall can flow in any direction with no mean flow direction.
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 of the outfall but is diluted over a few days and 10s of kilometers. In 2006, ammonium levels were similar to baseline.
Do the concentrations (or percent saturation) of dissolved oxygen in the water column meet the state water quality standards?	Yes. Conditions unchanged from baseline.

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?	No. Conditions not changed from baseline.
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. No substantial change detected. Summer 2006 chlorophyll levels were high but similar to conditions in 2000 before the outfall came on line.
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?	Productivity patterns in Boston Harbor may be changing, as the area transitions from eutrophic conditions to a more typical coastal regime. No concurrent increase in productivity in Massachusetts Bay.
Has the abundance of nuisance or noxious phytoplankton changed in the vicinity of the outfall?	Frequency of *Phaeocystis* blooms has increased, but the phenomenon is regional in nature. *Alexandrium* blooms in 2005 and 2006 were regional and have not been attributed to 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 of ambient water nutrient concentrations, or can farfield changes be correlated with nearfield changes?	Increase in frequency of *Phaeocystis* blooms is the most marked change in the phytoplankton community, but that change is not attributed to the outfall. No marked changes in the zooplankton community.
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. Concentrations fell dramatically in 2006 compared to other years since the outfall came on line.
Has the concentration of contaminants in sediments changed?	No general increase in contaminants. Effluent signal can be detected as some tracers within 2 km of the diffuser.
Has the soft-bottom community changed?	Changes have occurred but are not significant and cannot be attributed to the outfall.
Have the sediments become more anoxic; that is, has the thickness of the sediment oxic layer decreased?	No. The sediment RPD has been deeper during post-discharge years rather than shallower; that is, the sediments are more rather than less oxic.
Are any benthic community changes correlated with changes in levels of toxic contaminants (or sewage tracers) in sediments?	No changes detected, even within 2 km of the outfall.
Has the hard-bottom community changed?	No substantial changes detected. Decreases in coralline algae detected at some stations, but the geographic pattern does not suggest an outfall effect.

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 the outfall offshore.
Have the rates of these processes changed?	No changes detected.
Has the level of contaminants in the tissues of fish and shellfish around the outfall changed since discharge began?	No substantial change in flounder or lobster contaminant body burdens, with concentrations remaining very low. Detectable increases in concentrations of some contaminants in mussel arrays deployed at the outfall.
Do the levels of contaminants in the edible tissue of fish and shellfish around the outfall represent a risk to human health?	No 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, with concentrations being highest in Boston Harbor and lowest in Cape Cod Bay.
Has the incidence of disease and/or abnormalities in fish or shellfish changed?	No increases in disease or abnormalities in response to the outfall; long-term downward trend in liver disease in fish from near Deer Island and near the outfall.

*Table 2. Summary of contingency plan thresholds and exceedances as of 2006. (*NA *= not applicable,* ✓ *= no exceedance,* **C** *= caution level exceedance,* **W** *= warning level exceedance)*

Location/ Parameter Type	Parameter	2000	2001	2002	2003	2004	2005	2006
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**	✓	✓	✓	✓	**W**
	Chronic toxicity, sea urchin	✓	**W**	✓	✓	✓	**W**	✓
	PCBs	✓	✓	✓	✓	✓	✓	✓
	Plant performance	✓	✓	✓	✓	✓	✓	✓
	Flow	NA	✓	✓	✓	✓	✓	✓
	Total nitrogen load	NA	✓	✓	✓	✓	✓	✓
	Floatables	NA	NA	NA	NA	NA	NA	NA
	Oil and grease	✓	✓	✓	✓	✓	✓	✓

Location/ Parameter Type	Parameter	2000	2001	2002	2003	2004	2005	2006
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	✓	✓	✓	✓	✓	C
	Autumn	C	✓	✓	✓	✓	✓	✓
Nearfield nuisance algae *Phaeocystis pouchetii*	Winter/spring	NA	✓	✓	✓	C	✓	✓
	Summer	NA	✓	C	C	C	C	C
	Autumn	✓	✓	✓	✓	✓	✓	✓
Nearfield nuisance algae *Pseudonitzchia*	Winter/spring	NA	✓	✓	✓	✓	✓	✓
	Summer	NA	✓	✓	✓	✓	✓	✓
	Autumn	✓	✓	✓	✓	✓	✓	✓
Nearfield nuisance algae *Alexandrium*	Any sample	✓	✓	✓	✓	✓	C	C
Farfield shellfish	PSP toxin extent	✓	✓	✓	✓	✓	✓	✓
Plume	Initial dilution	NA	✓	Complete	Complete	Complete	Complete	Complete

Location/ Parameter Type	Parameter	2000	2001	2002	2003	2004	2005	2006
Sea Floor								
Nearfield sediment contaminants	Acenaphthene	NA	✓	✓	NA	NA	✓	NA
	Acenaphylene	NA	✓	✓	NA	NA	✓	NA
	Anthracene	NA	✓	✓	NA	NA	✓	NA
	Benzo(a)anthracene	NA	✓	✓	NA	NA	✓	NA
	Benzo(a)pyrene	NA	✓	✓	NA	NA	✓	NA
	Cadmium	NA	✓	✓	NA	NA	✓	NA
	Chromium	NA	✓	✓	NA	NA	✓	NA
	Chrysene	NA	✓	✓	NA	NA	✓	NA
	Copper	NA	✓	✓	NA	NA	✓	NA
	Dibenzo(a,h)anthracene	NA	✓	✓	NA	NA	✓	NA
	Fluoranthene	NA	✓	✓	NA	NA	✓	NA
	Fluorene	NA	✓	✓	NA	NA	✓	NA
	Lead	NA	✓	✓	NA	NA	✓	NA
	Mercury	NA	✓	✓	NA	NA	✓	NA
	Naphthalene	NA	✓	✓	NA	NA	✓	NA
	Nickel	NA	✓	✓	NA	NA	✓	NA
	p,p'-DDE	NA	✓	✓	NA	NA	✓	NA
	Phenanthrene	NA	✓	✓	NA	NA	✓	NA
	Pyrene	NA	✓	✓	NA	NA	✓	NA
	Silver	NA	✓	✓	NA	NA	✓	NA
	Total DDTs	NA	✓	✓	NA	NA	✓	NA
	Total HMW PAH	NA	✓	✓	NA	NA	✓	NA
	Total LMW PAH	NA	✓	✓	NA	NA	✓	NA
	Total PAHs	NA	✓	✓	NA	NA	✓	NA
	Total PCBs	NA	✓	✓	NA	NA	✓	NA
	Zinc	NA	✓	✓	NA	NA	✓	NA
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	✓	✓	✓	✓	✓	✓

Location/ Parameter Type	Parameter	2000	2001	2002	2003	2004	2005	2006
Fish and Shellfish								
Nearfield flounder tissue	Total PCBs	NA	✓	✓	✓	NA	NA	✓
	Mercury	NA	✓	✓	✓	✓	NA	✓
	Chlordane	NA	✓	✓	✓	NA	NA	✓
	Dieldrin	NA	✓	✓	✓	NA	NA	✓
	Total DDTs	NA	✓	✓	✓	NA	NA	✓
Nearfield flounder	Liver disease (CHV)	NA	✓	✓	✓	✓	✓	✓
Nearfield lobster tissue	Total PCBs	NA	✓	✓	✓	NA	NA	✓
	Mercury	NA	✓	✓	✓	NA	NA	✓
	Chlordane	NA	✓	✓	✓	NA	NA	✓
	Dieldrin	NA	✓	✓	✓	NA	NA	✓
	Total DDTs	NA	✓	✓	✓	NA	NA	✓
Nearfield mussel tissue	Total PCBs	NA	✓	✓	✓	NA	NA	✓
	Lead	NA	✓	✓	✓	NA	NA	✓
	Mercury	NA	✓	✓	✓	NA	NA	✓
	Chlordane	NA	C	C	✓	NA	NA	✓
	Dieldrin	NA	✓	✓	✓	NA	NA	✓
	Total DDTs	NA	✓	✓	✓	NA	NA	✓
	Total PAHs	NA	C	C	C	NA	NA	✓

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1. Introduction

Background

For more than 20 years, the Massachusetts Water Resources Authority (MWRA) has worked to minimize the effects of wastewater discharge on the marine environment. MWRA was created by an act of the Massachusetts State Legislature in December 1984 and in 1985 embarked upon what has become known as the Boston Harbor Project. Before then, 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 Quincy Bay in the southern part of the harbor. MWRA ended discharge of municipal sludge into 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 is a physical treatment process, which involves removal of solids through settling, followed by disinfection.) Batteries of secondary treatment (which includes bacterial decomposition as well as settling 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.

Efforts to improve treatment continued in 2005 when MWRA initiated studies aimed at maximizing flow through the secondary treatment systems. These studies followed on several capital projects, including improvements to the secondary treatment facilities and upgrades to the oxygen generation plant. Also in 2005, a tunnel connection opened between the Deer Island Treatment Plant and the Fore River Pelletizing Facility, where sludge is processed into fertilizer. Prior to opening the tunnel, sludge was centrifuged at Deer Island and barged to Fore River. The liquid removed by the centrifuge, known as centrate, was then sporadically added back at the head of the plant. With the opening of the tunnel, sludge is centrifuged at Fore River, and the centrate is returned to Deer Island by tunnel, resulting in a more stable process.

Better dilution was achieved in 2000, by diverting the effluent discharge from Boston Harbor to a 9.5-mile-long outfall and diffuser system, located offshore in Massachusetts Bay (Figure 1-1).

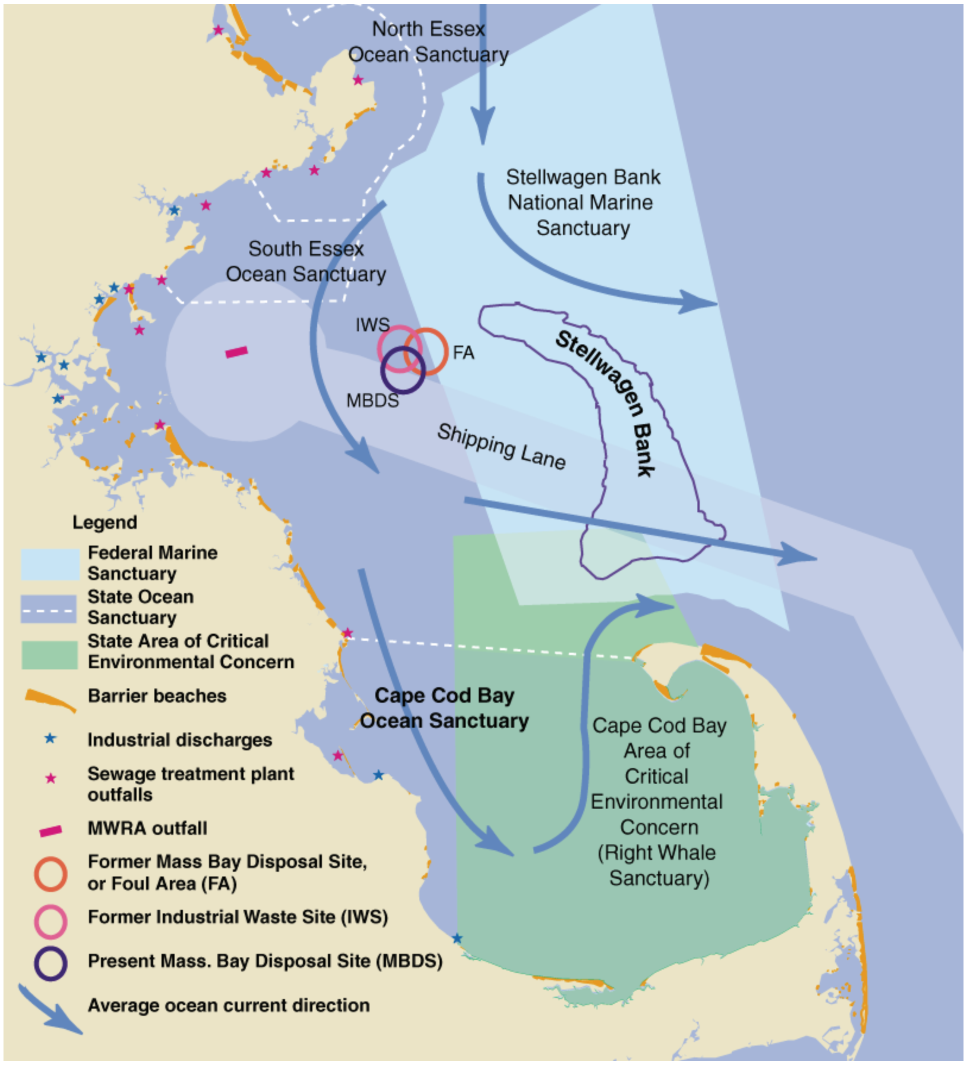


Figure 1-1. Massachusetts and Cape Cod bays, including areas of special consideration

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 that it replaced, which was located at a depth of 50 feet. The offshore location of the outfall 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. Moving the effluent outfall from the harbor to Massachusetts Bay did raise 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). The outfall monitoring program was established in MWRA's National Pollutant Discharge Elimination System (NPDES) permit to address these specific questions (see Table 1, page ix). Fifteen years (nine baseline, six during discharge) have provided extensive data that have answered these concerns.

Outfall Permit

The permit issued by EPA and MADEP under NPDES became effective on August 9, 2000 and continued until August 9, 2005. (Since expiration, MWRA continues to operate under the conditions of the permit until a new one is issued.) The permit 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 subcommittees 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. Rosters of panel and committee members

OMSAP as of December 2006

Andrew Solow, Woods Hole Oceanographic Institution (WHOI)
Marine Policy Center (chair)
Robert Beardsley, WHOI
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 Vakalopoulos,
MA Department of Environmental Protection (OMSAP staff)

IAAC as of December 2006

- US Geological Survey
  - Michael Bothner
- MA Coastal Zone Management
  - Todd Callaghan
  - Jan Smith (alternate)
- US Army Corps of Engineers
  - Thomas Fredette
- Stellwagen Bank National Marine Sanctuary
  - Ben Haskell
- MA Department of Environmental Protection
  - Russell Isaac
- MA Division of Marine Fisheries
  - Jack Schwartz
- US Environmental Protection Agency
  - Matthew Liebman
- National Marine Fisheries Service
  - David Dow

PIAC as of December 2006

- Patty Foley (chair, representative of Save the Harbor/Save the Bay)
- Save the Harbor/Save the Bay
  - Bruce Berman (alternate)
- Center for Coastal Studies
  - Peter Borrelli
- Wastewater Advisory Committee
  - Edward Bretschneider
- Conservation Law Foundation
  - Priscilla Brooks
- Massachusetts Audubon Society
  - Robert Buchsbaum
- New England Aquarium
  - Marianne Farrington
- MWRA Advisory Board
  - Joseph Favaloro
- Association for the Preservation of Cape Cod
  - Maggie Geist
  - Tara Nye (alternate)
- Safer Waters in Massachusetts
  - Salvatore Genovese
- The Boston Harbor Association
  - Vivian Li
- Cape Cod Commission
  - John Lipman
  - Steve Tucker (alternate)

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 monitoring program were approved by EPA and MADEP, and 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.

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. Monitoring program objectives and analyses

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 provided continuous oceanographic data until February 2006.	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

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 responses 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, 2005a, 2005b, 2006). 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.

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	Sediment contaminants 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 of 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, and Revision 1 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 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 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 on thresholds 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. 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 (Galya *et al.* 1996, 1997a, 1997b, Werme and Hunt 2000a, 2000b, 2001, 2002, 2003, 2004, 2005, 2006). The report includes a scientific summary for the year of monitoring. Overviews for 1994 through 1999 included only baseline information. With the outfall operational, subsequent reports have included information relevant to the Contingency Plan, such as threshold exceedances, 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 2006, marking six full years of post-discharge monitoring. It compares all results to Contingency Plan thresholds. The overview also includes sections on special studies and the Stellwagen Bank National Marine Sanctuary.

2. Effluent

Background

Pollution Prevention and Wastewater Treatment

Ensuring that the final 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 (TRAC) program 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 15% 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-dilution studies, which were completed in 2001, and water-column monitoring (see Section 3, Water Column).

Table 2-1. Monitoring questions related to the effluent

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,” such as 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 untreated 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 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 of constituents of the effluent and variability in those concentrations 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 measurements of 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	
Ammonium-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 prohibits discharge of nutrients in amounts that would cause eutrophication. It 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 and verified by field studies of outfall plumes in 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, ammonium, 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. Floatables are measured; threshold limits are 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.

Table 2-3. Monitoring plan parameters for effluent

Parameter	Sample Type	Frequency
Total Kjeldahl nitrogen	Composite	Weekly
Ammonium	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 to the Deer Island Treatment Plant was slightly lower in 2006 than in 2005, slightly above average for the monitoring period (Figure 2-1). Almost 98% of the flow received secondary treatment, a result of process improvements to maximize secondary flow. Most of the primary-only-treated effluent flow occurred during storms in May and June (Figure 2-2).

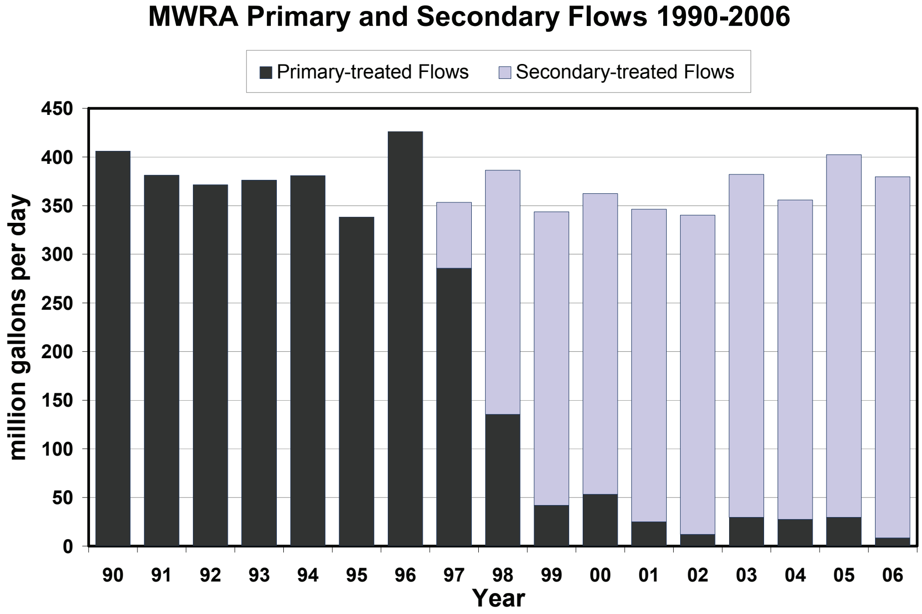


Figure 2-1. Annual effluent flows, 1990-2006

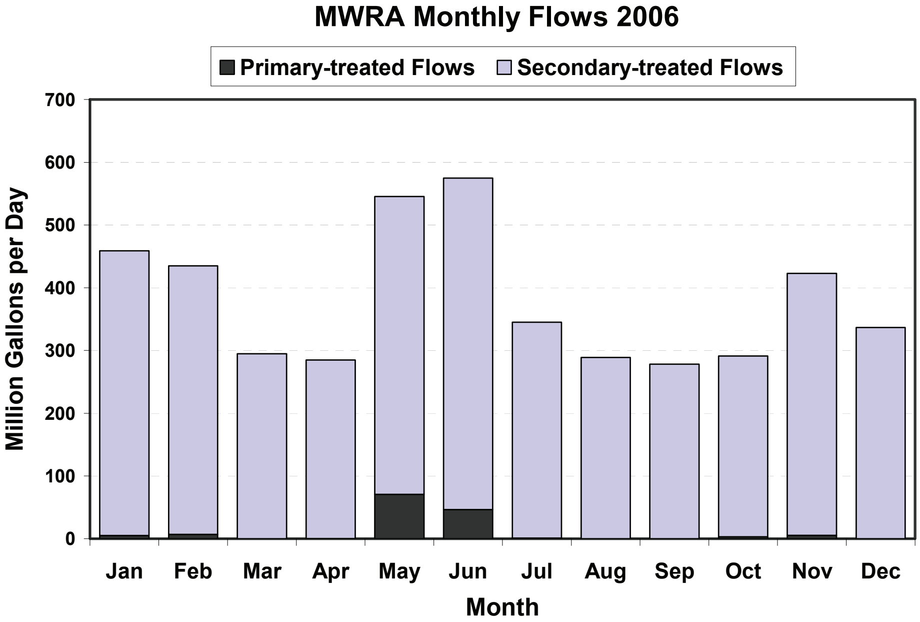


Figure 2-2. Monthly primary and secondary flows in 2006

Solids discharges continued to decrease in 2006 (Figure 2-3). Metals loads also decreased and for some metals are about one-sixth of what they were when the monitoring program began in 1991 (Figure 2-4). Mercury loads are about 5% of those discharged in the early 1990s. There were also decreases in loads of organic compounds, such as PCBs, chlordanes, and PAHs.

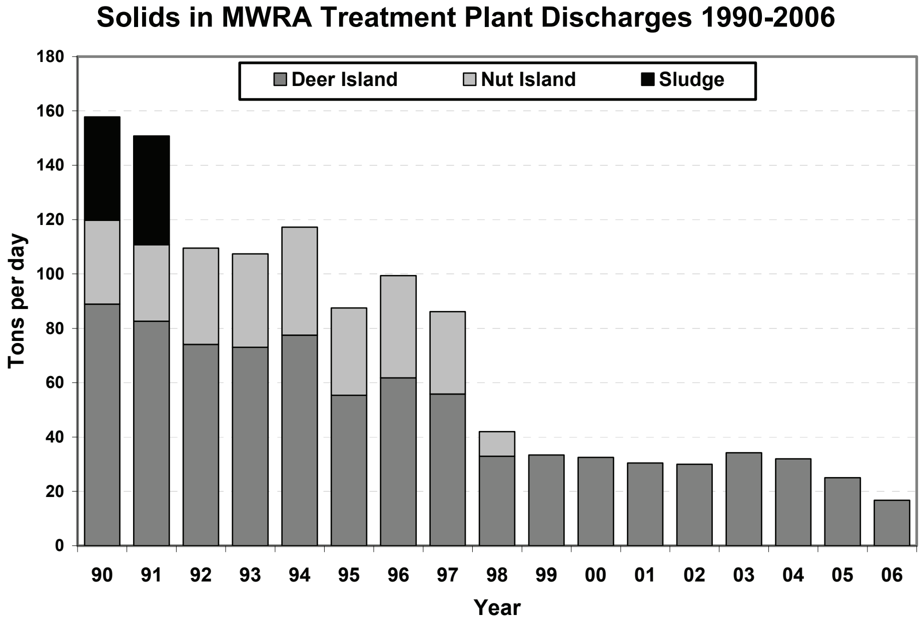


Figure 2-3. Annual solids discharges, 1990-2006

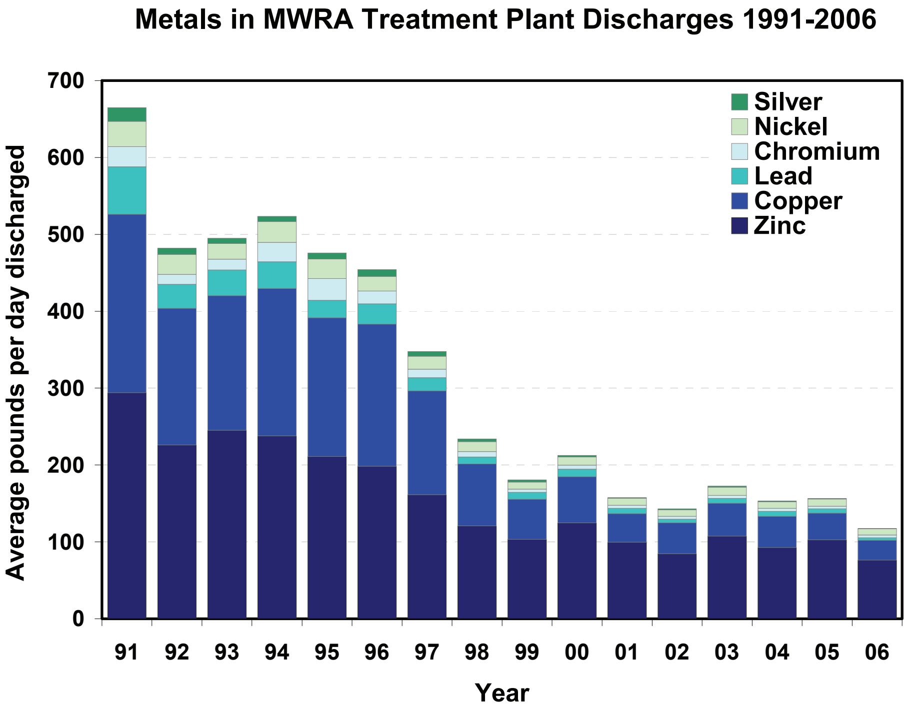


Figure 2-4. Annual metals discharges, 1991-2006

Total nitrogen loads remained about the same as in 2004 and 2005, but ammonium loads increased slightly compared to the previous year (Figure 2-5). Approximately 15,000-20,000 pounds of the 69,000 pounds of dissolved inorganic nitrogen (ammonium, nitrate, and nitrite) entering the treatment plant each day is introduced in the nutrient-rich centrate that is generated during the thickening process at the Fore River sludge-to-fertilizer pelletizing plant. The centrate is returned to Deer Island via tunnel from the pelletizing plant and is particularly rich in ammonium. While little of the total dissolved inorganic nitrogen is removed during treatment, secondary treatment appears to transform about 10% of the ammonium to nitrite and nitrate.

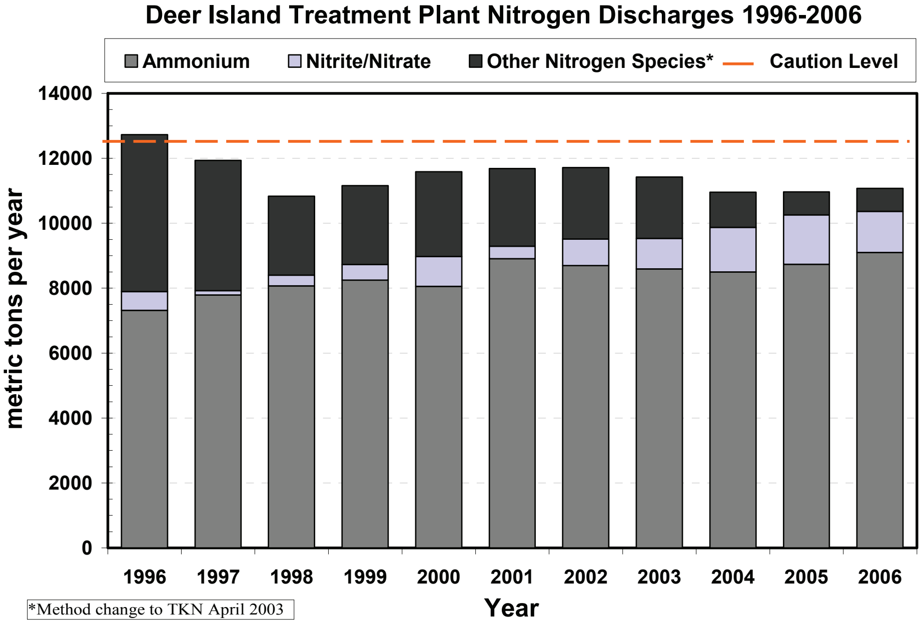


Figure 2-5. Annual nitrogen discharges, 1996-2006

Contingency Plan Thresholds

The Deer Island Treatment Plant had one permit violation during 2006 (Table 2-4). The permit requires that four tests for effluent toxicity be conducted each month. One of the tests, the fish chronic growth-and-survival test, did not meet the Contingency Plan warning threshold for series of samples collected on July 11-17. The test exposes *Menidia beryllina* (inland silverside) to effluent dilutions of 1.5%, 6.25%, 12.5%, 25%, 50%, and 100%. The fish in the 1.5% effluent dilution had lower survival than the control group of fish, constituting an exceedance of the warning level threshold. The test results were somewhat anomalous, as the next higher concentration, 6.5%, did not show toxicity. Ammonium in one effluent subsample was elevated, which may have been a factor in the test failure. The levels reached in the laboratory do not suggest a possible effect on animals in the ambient receiving waters.

Table 2-4. Contingency Plan threshold values and 2006 results for effluent monitoring

Parameter	Caution Level	Warning Level	2006 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)	Not exceeded
Chlorine, residual	None	631 µg/l daily, 456 µg/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	One exceedance of fish survival and growth test in July
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. A coastal current flows southwestward along the Maine and New Hampshire coasts; it may enter Massachusetts Bay at Cape Ann, which is north of Boston. This current drives an average counterclockwise circulation in Massachusetts Bay and (sometimes) Cape Cod Bay. Water flows back out of the bays at Race Point, located at the tip of Cape Cod. Whether the coastal current enters Massachusetts Bay and whether it continues south into Cape Cod Bay depends on the strength of the current and the direction, duration, 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, Jiang *et al.* 2006).

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. Transient gyres in Massachusetts and Cape Cod bays 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, strong 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 follow 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.

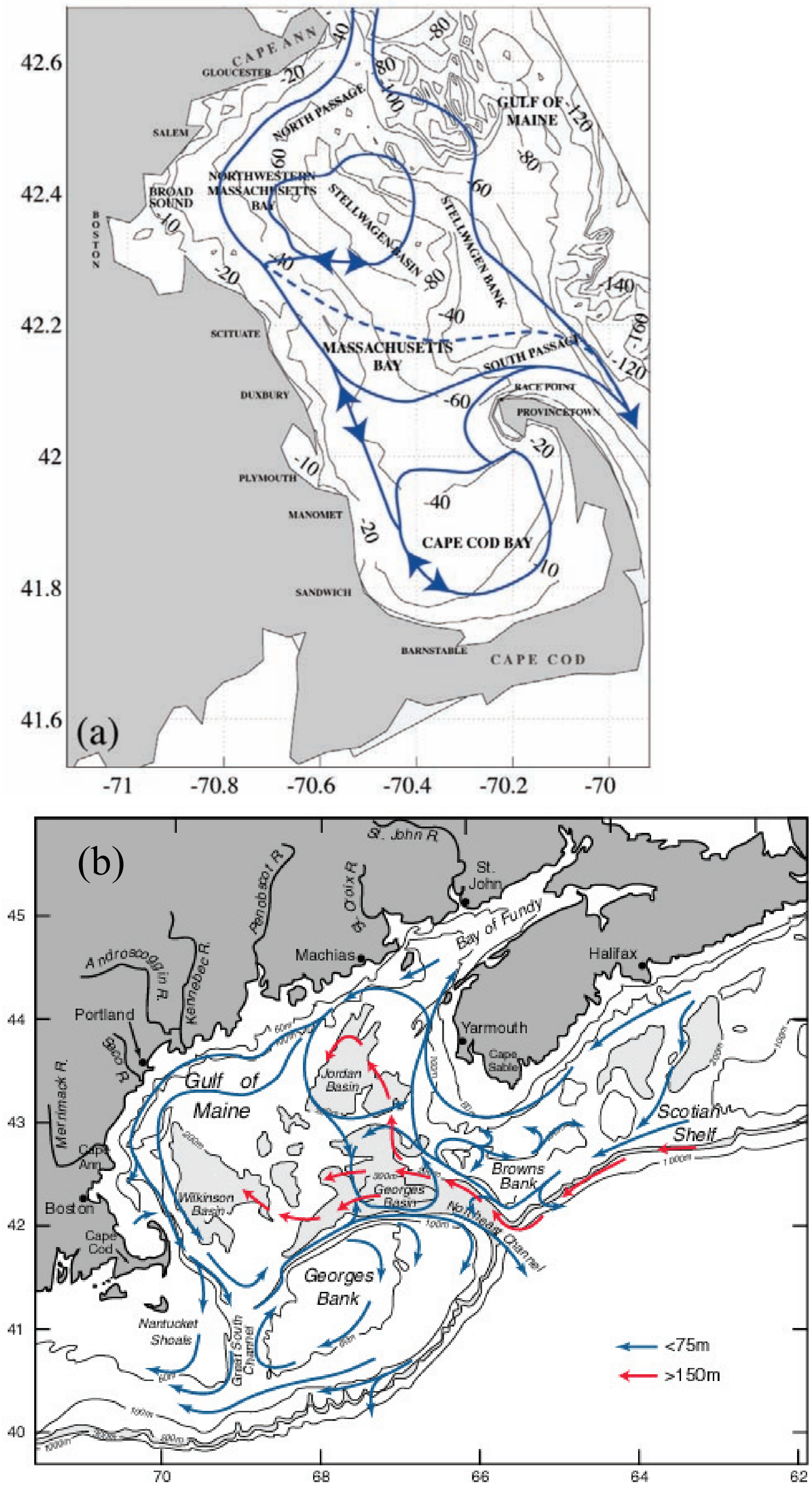


Figure 3-1. (a) General circulation within Massachusetts Bay. Reprinted from Journal of Marine Systems, Vol. 29, Author: PFJ Lermusiaux, "Evolving the subspace of the three-dimensional multiscale ocean variability: Massachusetts Bay," pp 385-422 © 2001 with permission from Elsevier. (b) General circulation within the Gulf of Maine (from Beardsley et al. 1997).

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 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, concentrations of toxic contaminants discharged in the MWRA effluent are so low that it is impractical to measure them in the water column. Because organic material, pathogens, and floatables are effectively removed by treatment at the Deer Island plant, but nutrients are not, nutrient issues caused the greatest concern prior to the start-up of the Deer Island Treatment facility.

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 in the bottom waters 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 or species groups are of particular concern: the dinoflagellate *Alexandrium fundyense* (*A. fundyense* and *A. tamarense* are now considered to be varieties of the same species), the diatom *Pseudo-nitzschia multiseries*, and the colonial flagellate *Phaeocystis pouchetii*.

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?

Alexandrium fundyense blooms are known in New England as red tides. They produce a toxin, which when sufficiently concentrated, causes paralytic shellfish poisoning (PSP), a condition that 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. *Phaeocystis pouchetii* is not toxic, but individual cells can aggregate in gelatinous colonies that may be aesthetically displeasing or provide poor food for zooplankton.

Dissolved oxygen concentrations in bottom waters naturally decrease during the stratified period as part of the natural seasonal pattern. If discharged nutrients were to stimulate large phytoplankton blooms, the conditions could lead to lower levels of dissolved oxygen when the cells sink to the bottom and decay.

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 departures 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, qualitatively verified the expected dilution at the outfall and confirmed predictions that bacteria and toxic contaminant concentrations in the discharged effluent are very low.

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	Provide continuous oceanographic data near outfall location
Remote sensing	Provides oceanographic data on a regional scale through satellite imagery

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 were 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). Twelve surveys of seven nearfield stations and six surveys of 25 farfield stations were conducted in 2006, with two additional stations sampled in February and April.

Parameters measured are listed in Tables 3-3 and 3-4. 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 most readily used by phytoplankton. The surveys also include observations and net tows in the outfall area to assess the presence of floatable debris.

The continuous recording components of the program capture temporal variations in water quality between nearfield surveys. Remote sensing by satellite captures spatial variations in water quality on a larger, regional scale.

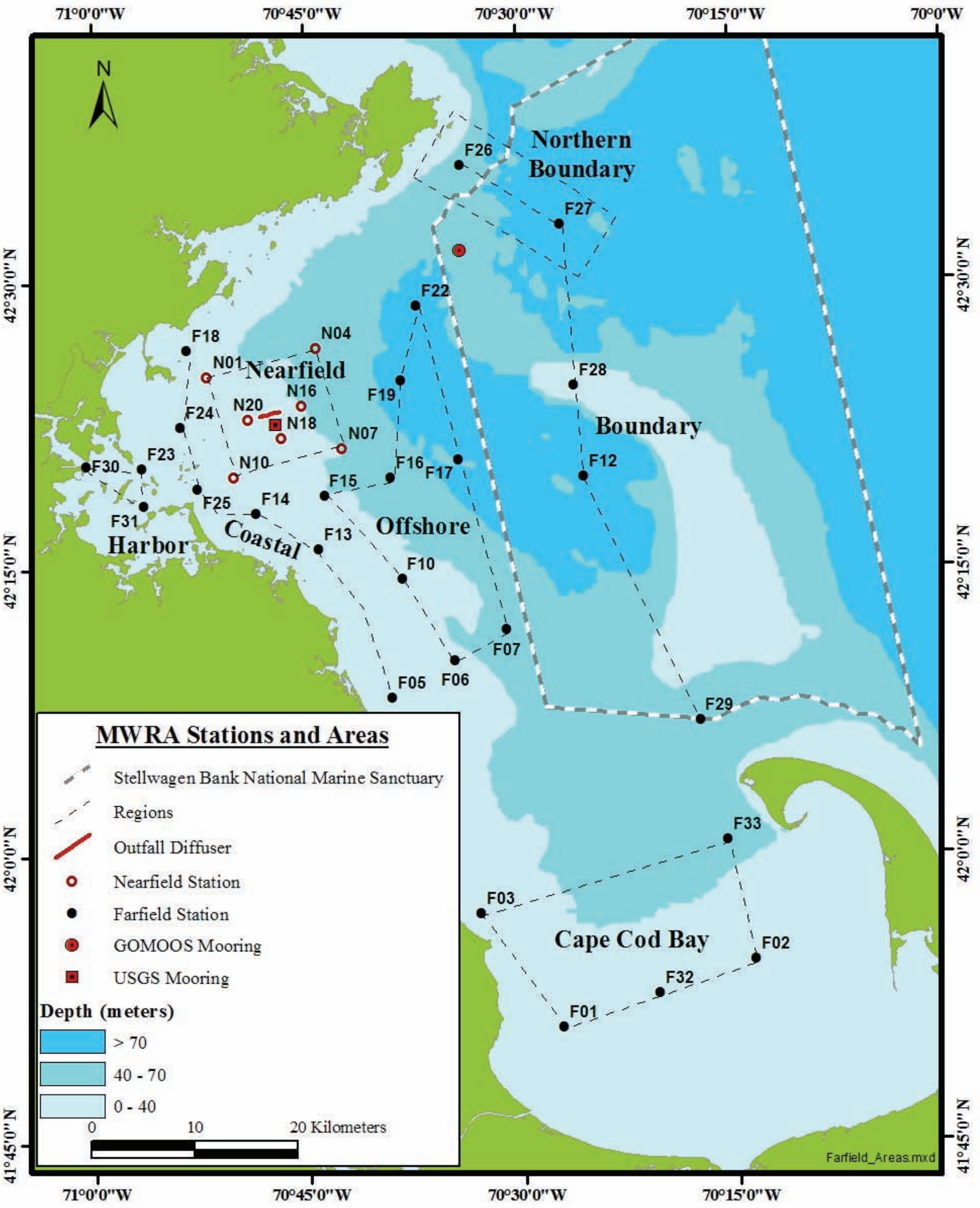


Figure 3-2. Water-column sampling stations and regions

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 shallow 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

Results

Physical Conditions

The Massachusetts Bay region was wetter in 2006 than in many other years, particularly during May, when there were late-season northeast storms. The flow from the rivers in the region during this period was the highest measured since the 1938 Hurricane (Libby *et al.* 2007). Flow of the Merrimack River was about twice that of low-flow years, with the highest spring flow and the second highest annual flow measured throughout the duration of the monitoring program (2005 had higher annual flow). Similarly, flow through the Charles River was higher than average (Figures 3-3, 3-4).

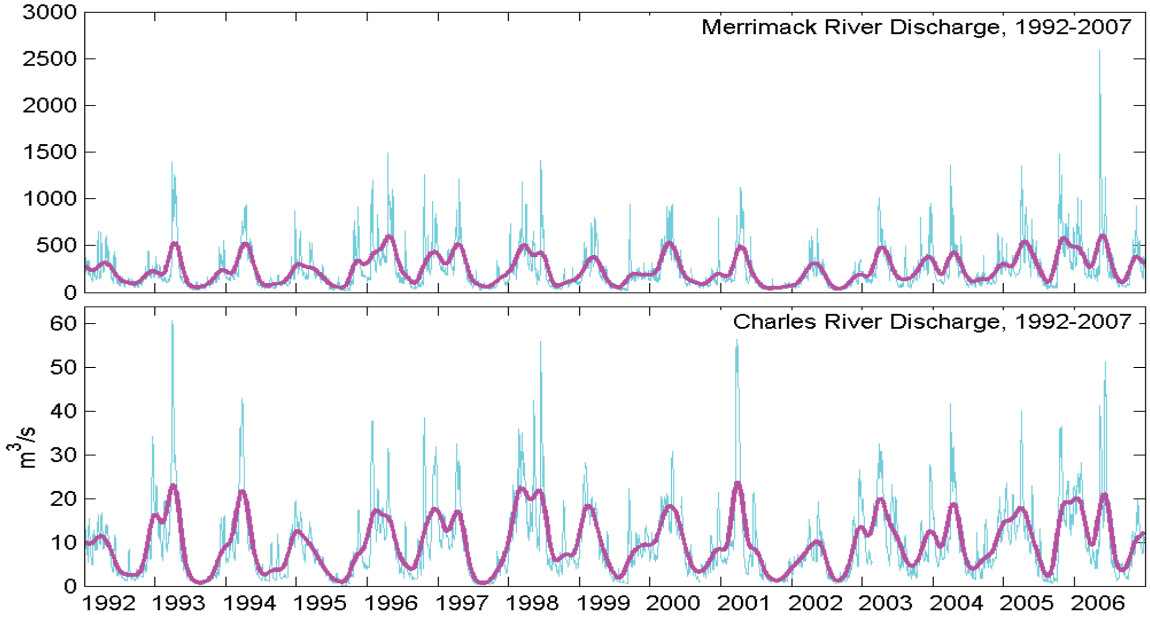


Figure 3-3. Merrimack River (top) and Charles River (bottom) discharges, 1992-early 2007 (data from gauges at Lowell and Waltham, Massachusetts; smooth lines are 3-month moving averages)

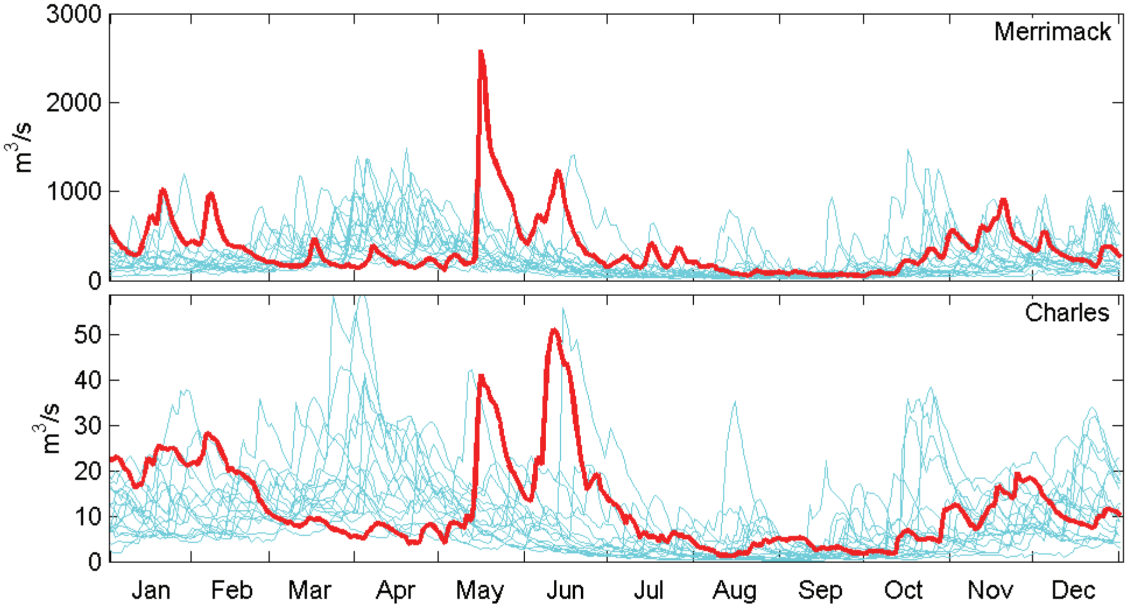


Figure 3-4. 2006 river discharges compared to observations since 1992

While May is usually a time of transition in the water column, with wind-stress conditions changing from winter downwelling to summer upwelling, the late-season storms promoted strong downwelling during May of 2006 (Figure 3-5). These conditions, similar to 2005, promoted inflow of water from the Gulf of Maine, a condition that can result in importing potentially harmful algal blooms. Strong upwelling conditions in July resulted in some of the coolest surface water temperatures measured during the monitoring program, while bottom water temperatures remained average.

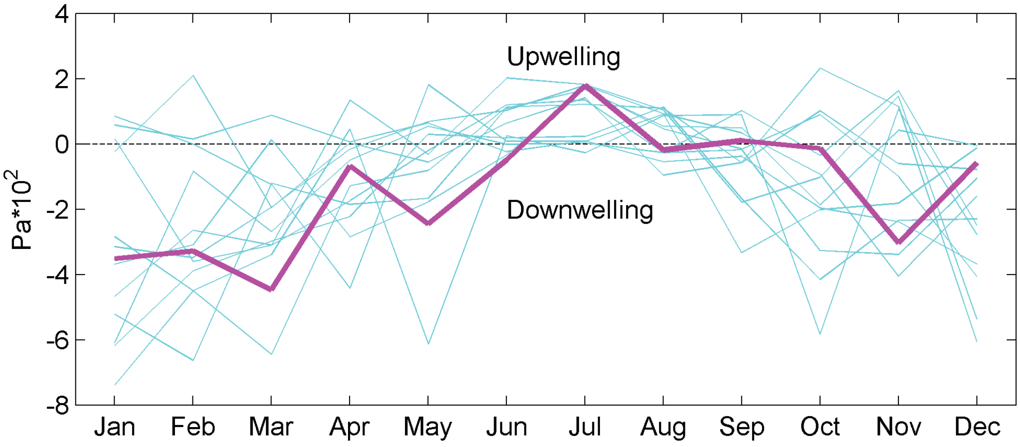


Figure 3-5. 2006 monthly average wind stress at the Boston Buoy compared with observations from the previous 12 years (Positive values indicate northward-directed, upwelling-favorable wind stress.)

Air temperatures were especially warm in January and December 2006, while summer temperatures were average. Near-surface water temperatures in the vicinity of the outfall were warmer than usual in the winter, but colder during the spring and early summer, when the northeast storms precluded rapid warming (Figure 3-6).

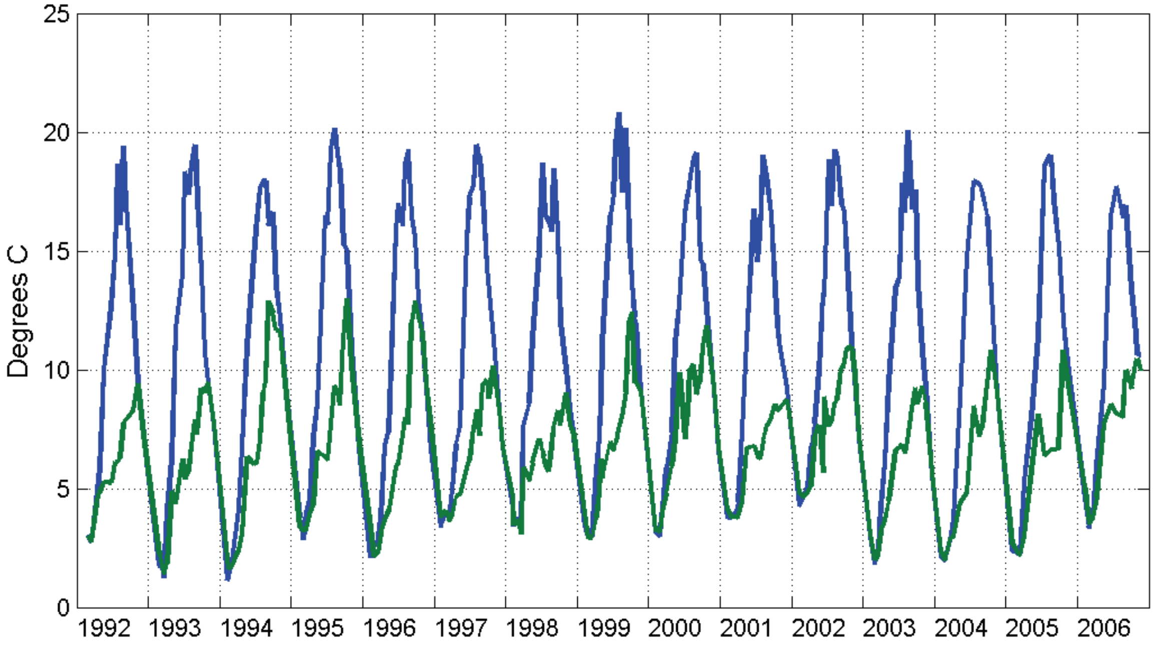


Figure 3-6. Nearfield surface and bottom water temperature (Surface measurements are the upper line.)

Salinities were also affected by the spring storms, with surface salinities reaching the lowest levels since 1998 (Figure 3-7). Spring bottom-water salinities were lower than any year except 2005, which was also subject to spring storms. Bottom-water salinities did not show a similar large dip, possibly because there was less mixing during the spring storm events than there had been in 2005.

The low surface salinity caused stronger than usual stratification during May and June. Stratification was weaker than usual during the summer, a result of the prevailing upwelling conditions.

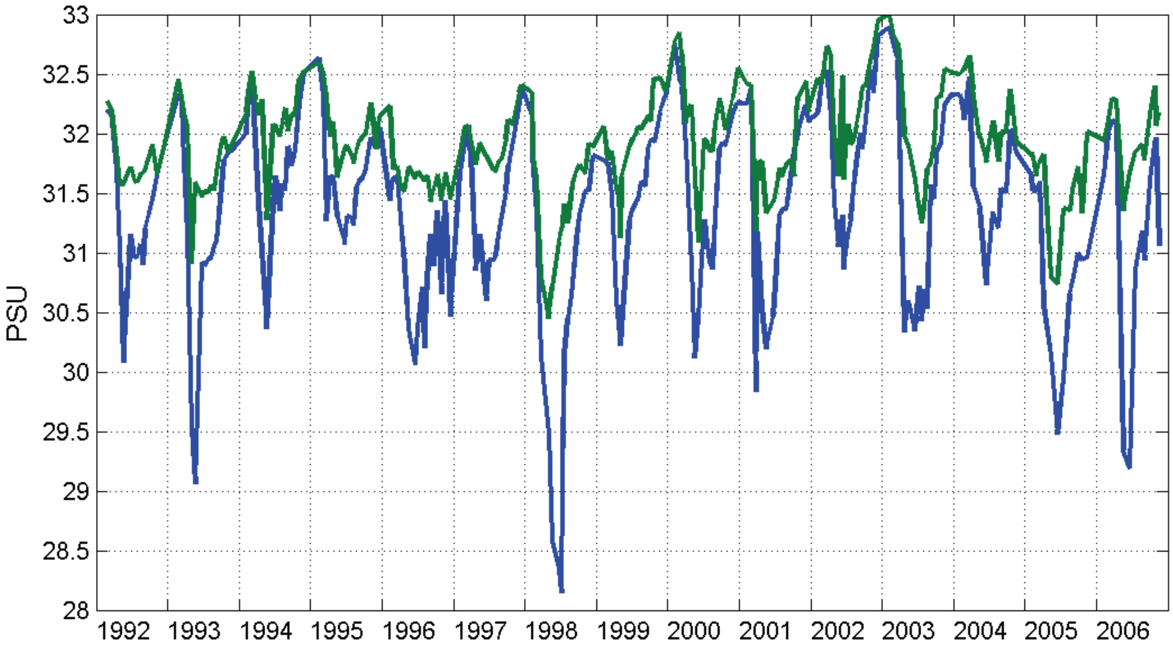


Figure 3-7. Nearfield surface and bottom water salinity (Surface measurements are the lower line.)

Water Quality

As in every year since the Massachusetts Bay outfall began operation, water quality measurements in 2006 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.* 2007). Trends in water quality parameters, including nutrients, phytoplankton biomass, and dissolved oxygen were generally similar to previous years. However, there were differences in the timing and magnitude of events, some of which were influenced by the spring northeast storms.

Localized, elevated concentrations of ammonium, the form of nitrogen most readily taken up by phytoplankton, have been observed in the nearfield since the outfall began operation, particularly during periods when biological uptake is low. These elevated levels had been anticipated, because a large portion of the dissolved inorganic nitrogen in treated effluent is ammonium.

In 2006, as expected, nearfield ammonium concentrations during the first survey of the year in early February were higher than the baseline range (Figure 3-8). However, for the remainder of the year, levels were within or even below the baseline range. Consequently, the annual average concentration of ammonium in the nearfield was the lowest measured since outfall diversion though not significantly different from the baseline period (Figure 3-9). The concentrations of ammonium in Boston Harbor, which dropped dramatically following effluent diversion to Massachusetts Bay, remained low, and concentrations in the other regions were also among the lowest measured in monitoring program.

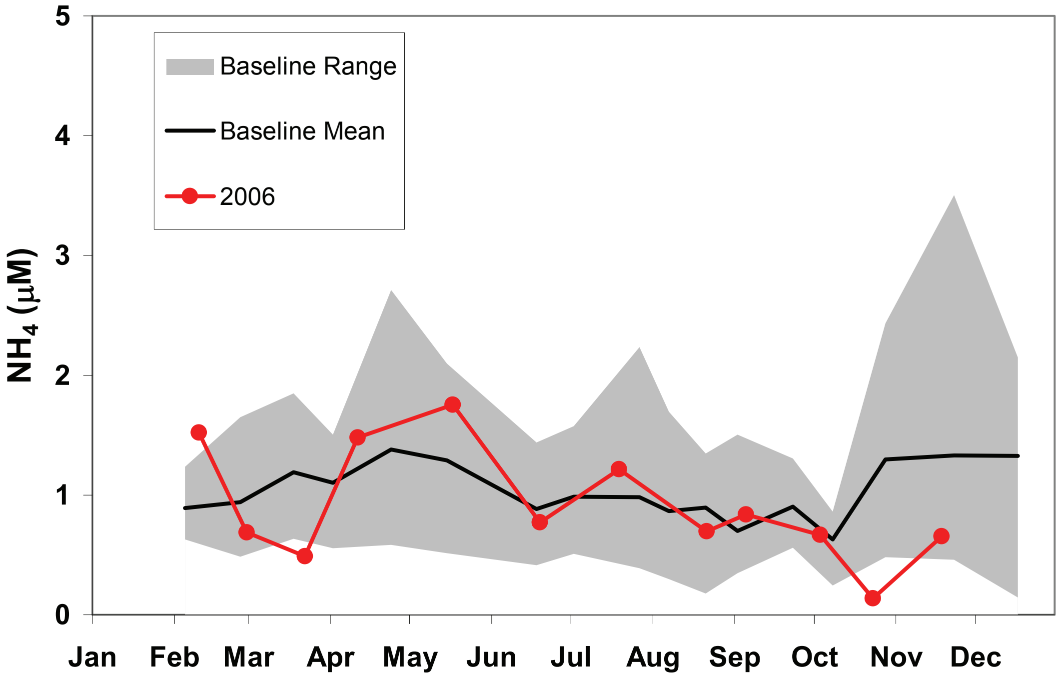


Figure 3-8. 2006 nearfield ammonium concentrations compared to the baseline range and mean

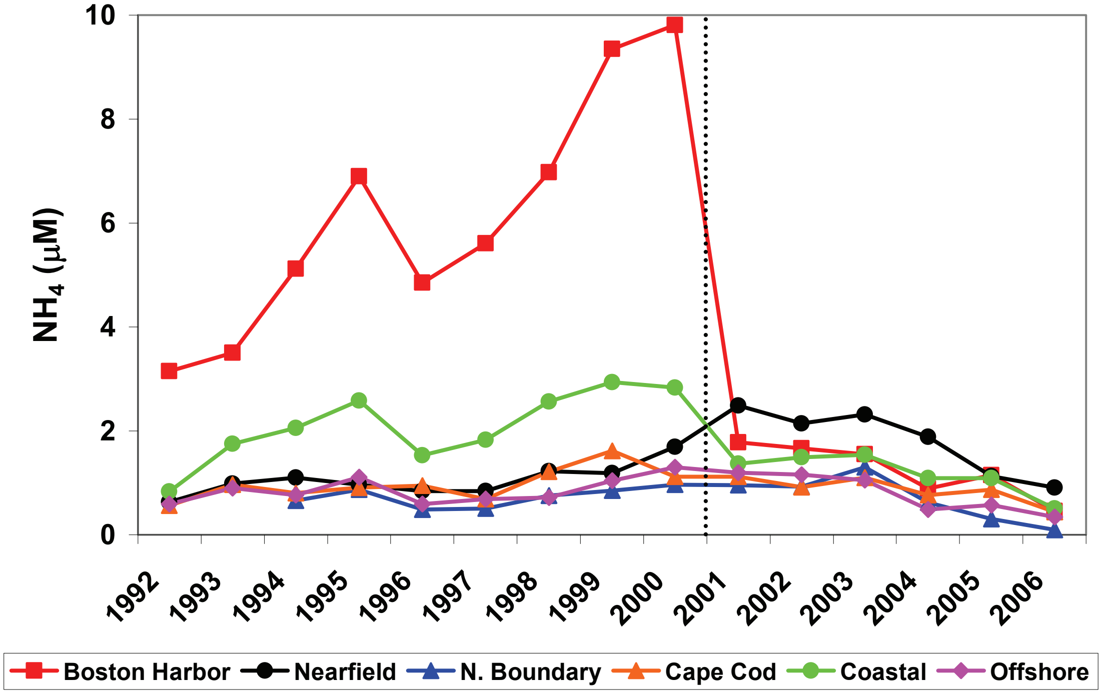


Figure 3-9. Annual mean ammonium concentrations in Massachusetts Bay regions

Concentrations of nitrate, another form of nitrogen readily used by phytoplankton and present in the effluent, continued to fall within the baseline range for most surveys and showed the same seasonal pattern as seen in baseline monitoring. However, concentrations were higher than the baseline range during several surveys (Figure 3-10), and the annual nearfield mean concentration increased to the highest level measured in the monitoring program (Figure 3-11). Annual concentrations were also higher in the other regions, except for Cape Cod Bay. Annual concentrations of nitrate are typically quite variable and reflect physical conditions and the timing and magnitude of phytoplankton blooms. The 2006 increase in nitrate, as well as the 2006 decrease in ammonium concentration, is thought to be related to regional conditions rather than to the outfall discharge.

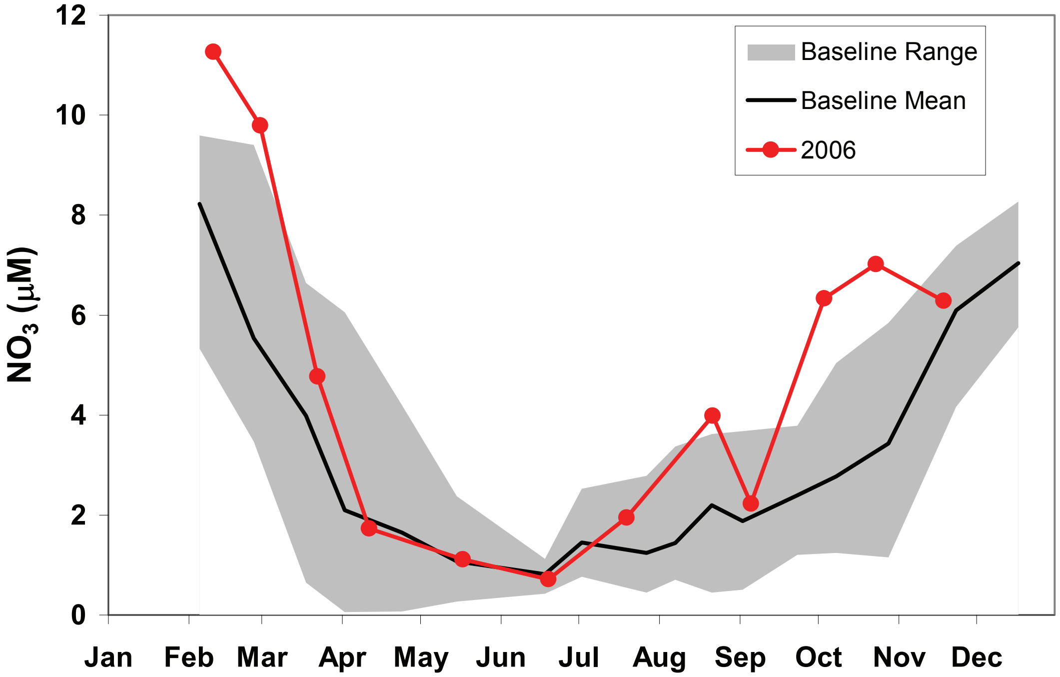


Figure 3-10. 2006 nearfield nitrate concentrations compared to the baseline range and mean

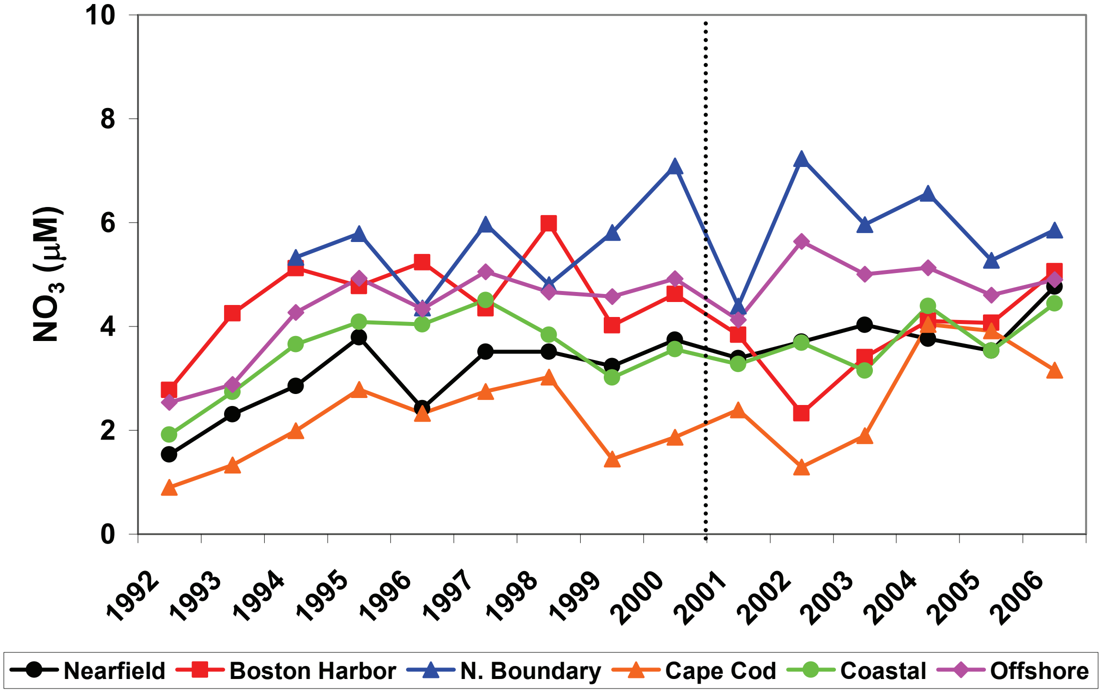


Figure 3-11. Annual mean nitrate concentrations in Massachusetts Bay regions

Nearfield phytoplankton biomass, as measured by chlorophyll (areal chlorophyll; mg per square meter), has shown apparent increases in the years since the outfall began discharge (Figure 3-12). Because the timing and sizes of phytoplankton blooms are varied, these chlorophyll data are highly variable, and none of the increases is statistically significant. The 2006 annual concentration was the highest measured in the post-discharge period, but lower than levels measured in 1999 and 2000, just before the outfall came on line. Nearfield concentrations during the winter and spring of 2006 were in the upper end of the baseline range, and concentrations in the summer were higher than baseline levels, the result of a July diatom bloom (Figure 3-13). Particulate organic carbon concentrations, another measure of phytoplankton biomass, were also high during the summer.

Summer and annual primary production rates, measured by the uptake of ^{14}C, have decreased in Boston Harbor since the outfall diversion, as the area shifts to a less nutrient-rich environment. In the nearfield, there have been only minor changes in production rates. Areal production rates at both nearfield stations and at the one station monitored within the harbor were low in 2006.

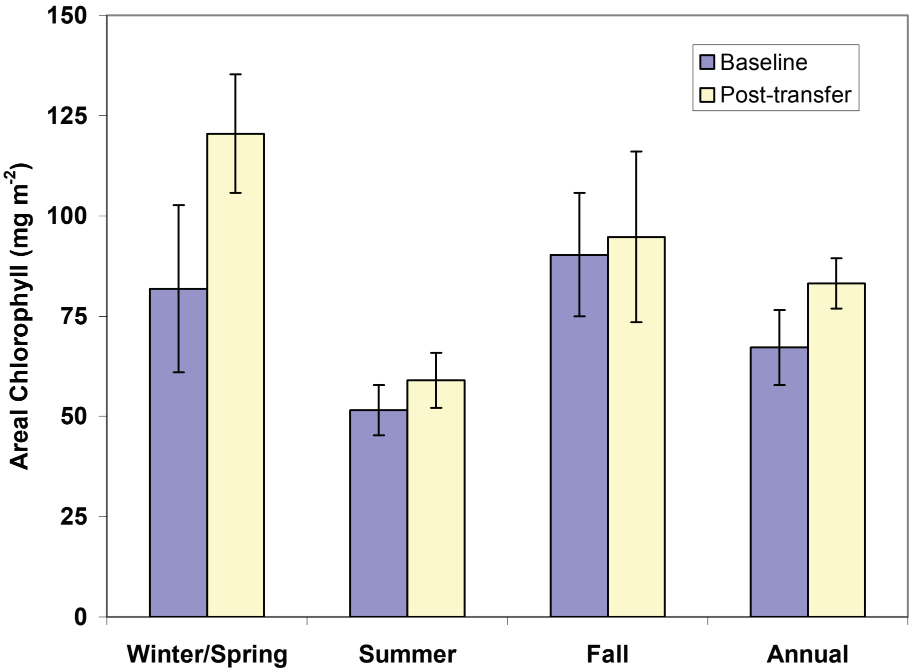


Figure 3-12. Comparison of baseline and post-transfer seasonal and annual mean areal chlorophyll in the nearfield (Error bars represent plus or minus one standard error.)

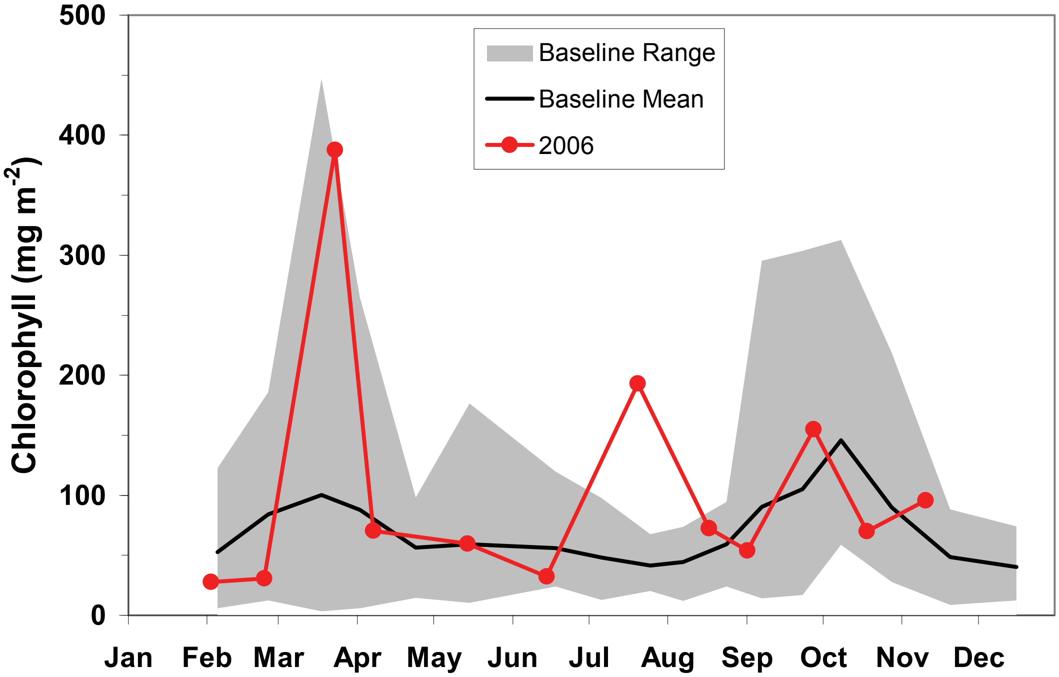


Figure 3-13. 2006 nearfield areal chlorophyll compared to the baseline range and mean

Measurements of concentrations (Figure 3-14) and percent saturation (not shown) of dissolved oxygen in the nearfield bottom waters have shown no response to nutrient enrichment or addition of organic matter from the outfall. As in other 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. Dissolved oxygen concentrations were relatively low throughout most of 2006, lower than the baseline range in February, and at the lower end of the range for the rest of the year. Although it is difficult to separate regional from local effects on oxygen, the rate of decline of oxygen concentrations from June to October may be a good indicator of community respiration; for 2006 the rate of decline was average. Rather, the oxygen concentration in June was relatively low, and that level carried through to low values in early October until mixing began to reventilate bottom waters.

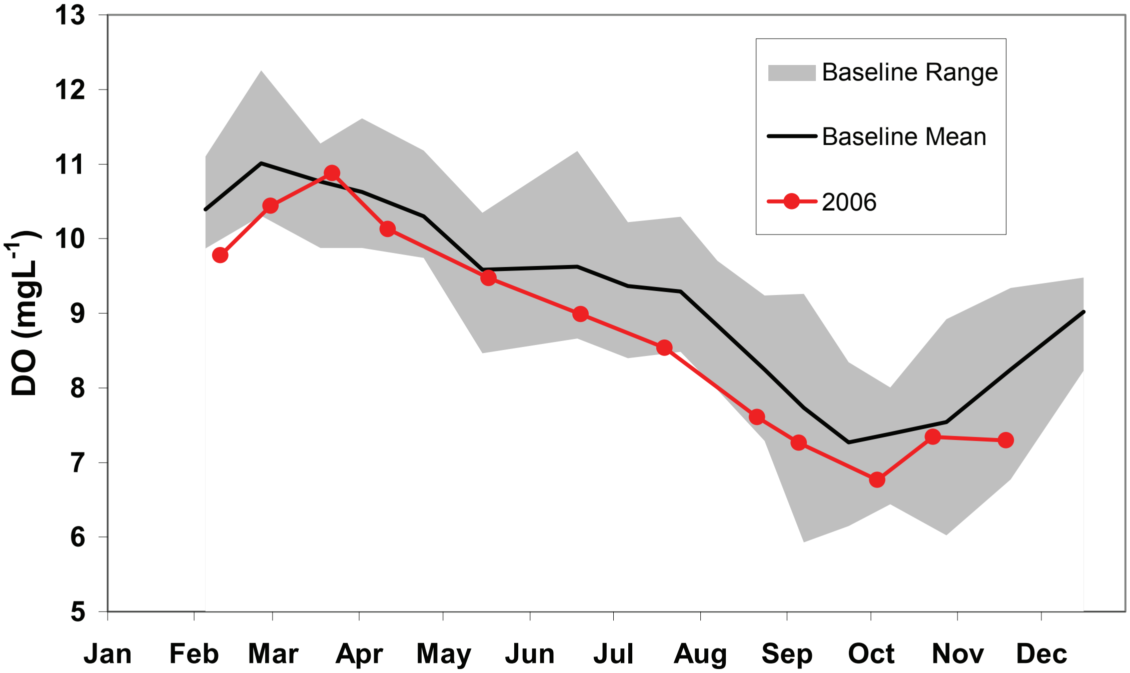


Figure 3-14. 2006 nearfield dissolved oxygen concentrations compared to the baseline range and mean

Phytoplankton Communities

Seasonal abundance of phytoplankton remained similar to the baseline mean for most survey dates in 2006 (Figure 3-15, top), as it has for other post-outfall diversion years (Libby *et al.* 2007). The year was marked by several diatom blooms, occurring in the winter/spring, summer, and fall. There was a bloom of the nuisance species *Phaeocystis pouchetii,* which was similar to 2005 in the nearfield but larger in the boundary and offshore areas. There was also a bloom of toxic dinoflagellates in the genus *Alexandrium*, which was significant but much smaller than the enormous red tide bloom that occurred in 2005.

The usual species assemblage in Massachusetts Bay includes small microflagellates and cryptomonads, which 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.

Two blooms of the diatom *Dactyliosolen fragilissimus*, a chain-forming species that is one of the dominant species in the region and not considered a nuisance, occurred during 2006, one in July and the second in early October (Figure 3-15, bottom). The blooms were coincident with peaks in chlorophyll and particulate organic carbon measurements and occurred throughout the region. *Dactyliosolen fragilissimus* is the only diatom species to increase in abundance in the years since the outfall began operation. Overall diatom abundance has decreased across all the regions and at every depth sampled in the monitoring program, while microflagellates have increased in abundance in every region except Boston Harbor.

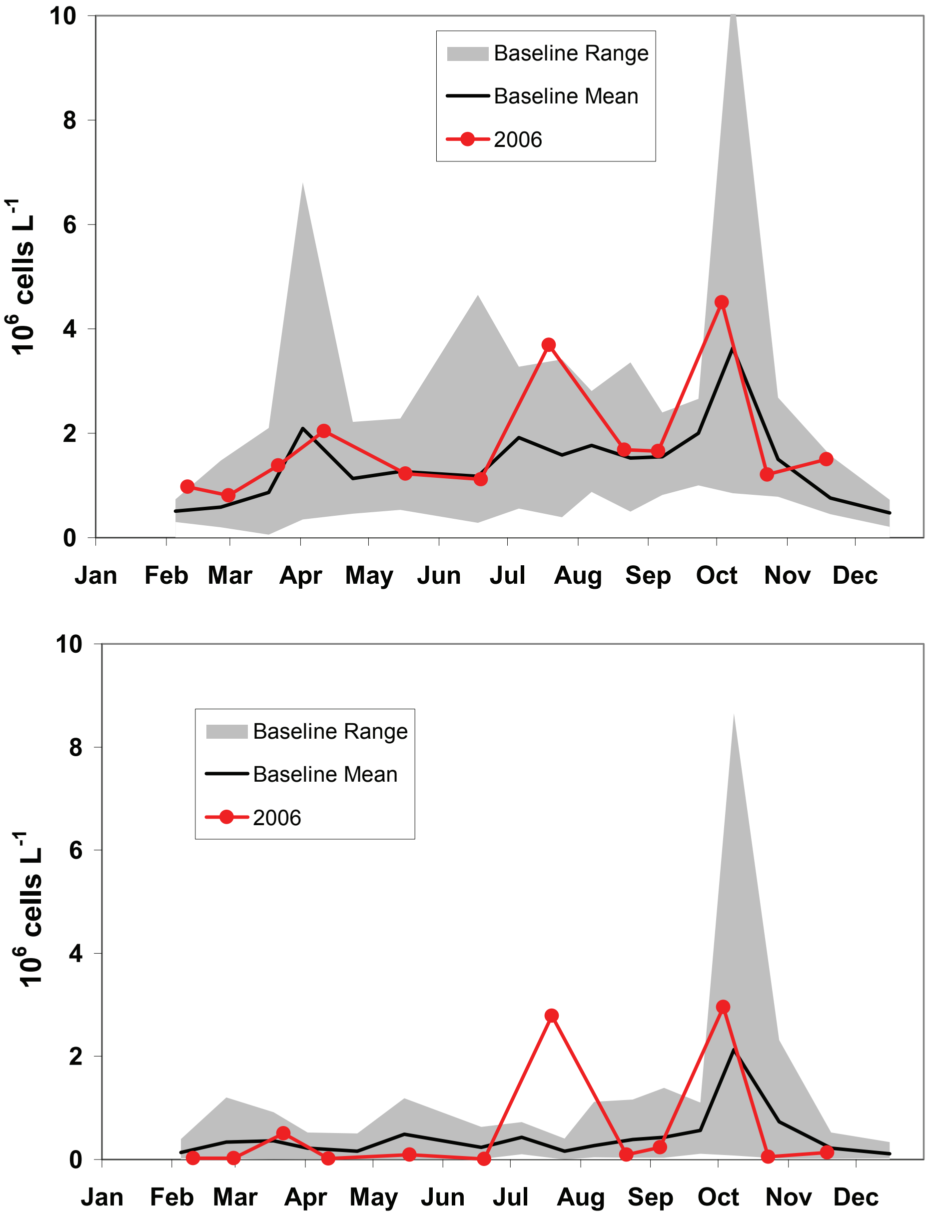


Figure 3-15. Top: 2006 nearfield phytoplankton abundance compared to baseline range and mean; Bottom: Time-series of survey mean total diatom abundance in the nearfield in 2006 compared against the baseline range and mean. Note the nearfield survey baseline mean and range are shown for 17 surveys vs. 12 in 2006. Data from stations N04, N16 and N18 only.

Although there have not been any major changes in the composition of the phytoplankton community over the past 15 years, there have been several variations in the timing and magnitude of various events in the seasonal succession. The most pronounced variations have been associated with the regional spring blooms of *Phaeocystis pouchetii* (Figure 3-16). From 1992 through 2000, there were spring *Phaeocystis* blooms approximately every three years, in 1992, 1994 (only recorded in the farfield), 1997, and 2000. Since 2001, the blooms have occurred annually and have increased in duration. In earlier years, *Phaeocystis* blooms occurred primarily in late March and April. Since 2002, they have begun earlier in March and persisted until early May. The 2006 bloom had largely ended by May, although *Phaeocystis* was still found at some stations.

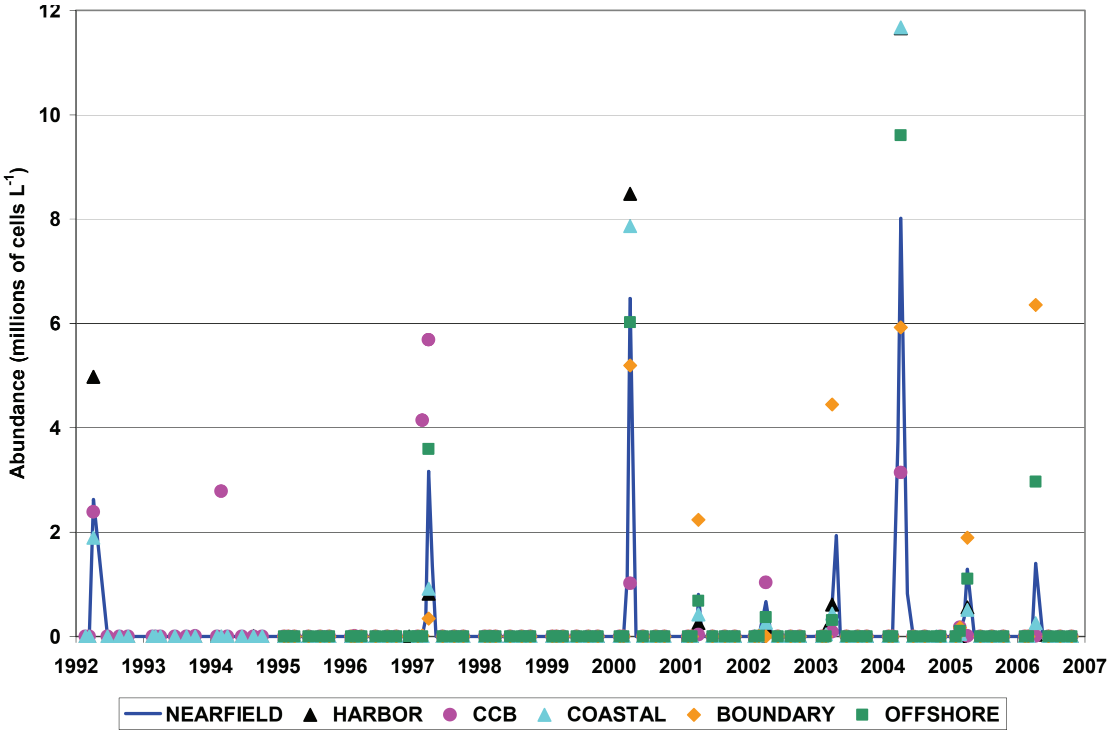


Figure 3-16. Abundance of Phaeocystis pouchetii*, 1992-2006*

As in other years, the 2006 bloom occurred well beyond the boundaries of Massachusetts and Cape Cod bays, and there have been no obvious associations with the outfall. Rather, the blooms appear to be affected by physical conditions. For example, the extended duration of the blooms fits into a pattern noted in previous years: the duration of the bloom corresponds to the calendar date at which water temperatures reach 14°C (Figure 3-17).

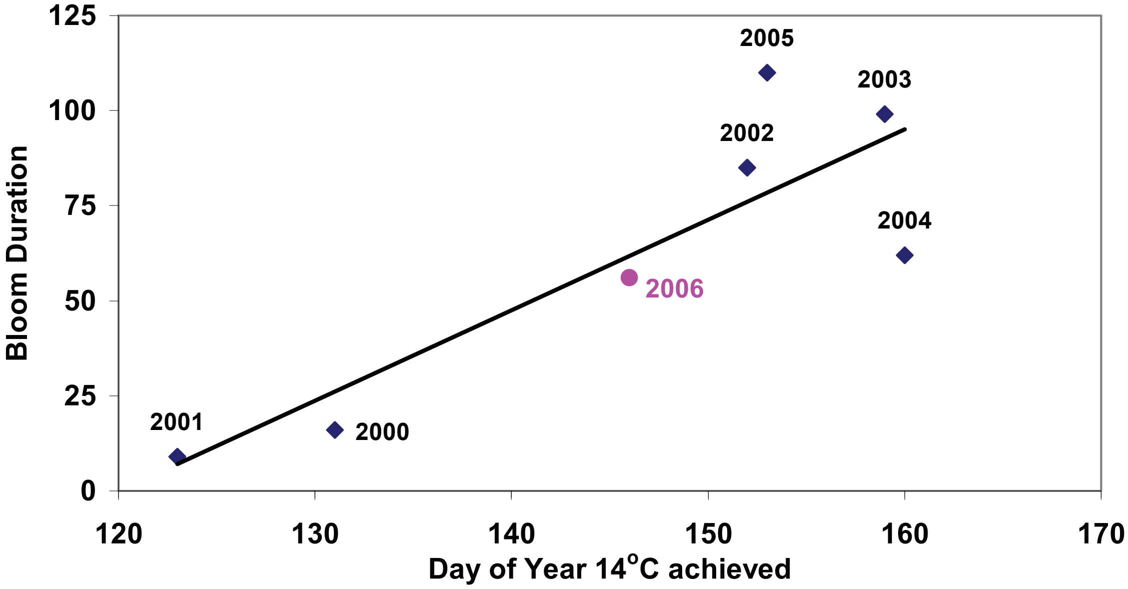


Figure 3-17. Phaeocystis *bloom duration related to the date at which temperatures reached 14°C (Data from years prior to 2000 were insufficient to be included in the analysis.)*

The 2006 *Alexandrium* red tide bloom was significant in size and extended into Massachusetts Bay, but cell abundances and toxicity were lower than those observed in 2005, when the largest bloom since 1972 occurred. Cell abundances in 2006 were about 25% of those observed in 2005 (Figure 3-18). The bloom resulted in closure of shellfish beds along the entire coasts of Maine and New Hampshire, extending to the Marshfield/Duxbury line within Massachusetts Bay.

Evaluation of three factors important to the development of *Alexandrium* blooms—high river flow, winds from the northeast, and abundance of cysts in seedbeds—has suggested that the high abundance of cysts in the western Gulf of Maine sediments in 2004 was the factor most responsible for the 2005 bloom (Anderson *et al.* 2007; see Section 6, Special Studies for additional discussion). Winds are also important, as downwelling-favorable, episodic winds from the northeast move the algal populations toward the shore and into Massachusetts Bay; however the analysis suggested that a bloom would have occurred in 2005 even without favorable wind conditions. Anomalously high river runoff appeared to have no region-wide effect on the 2005 bloom.

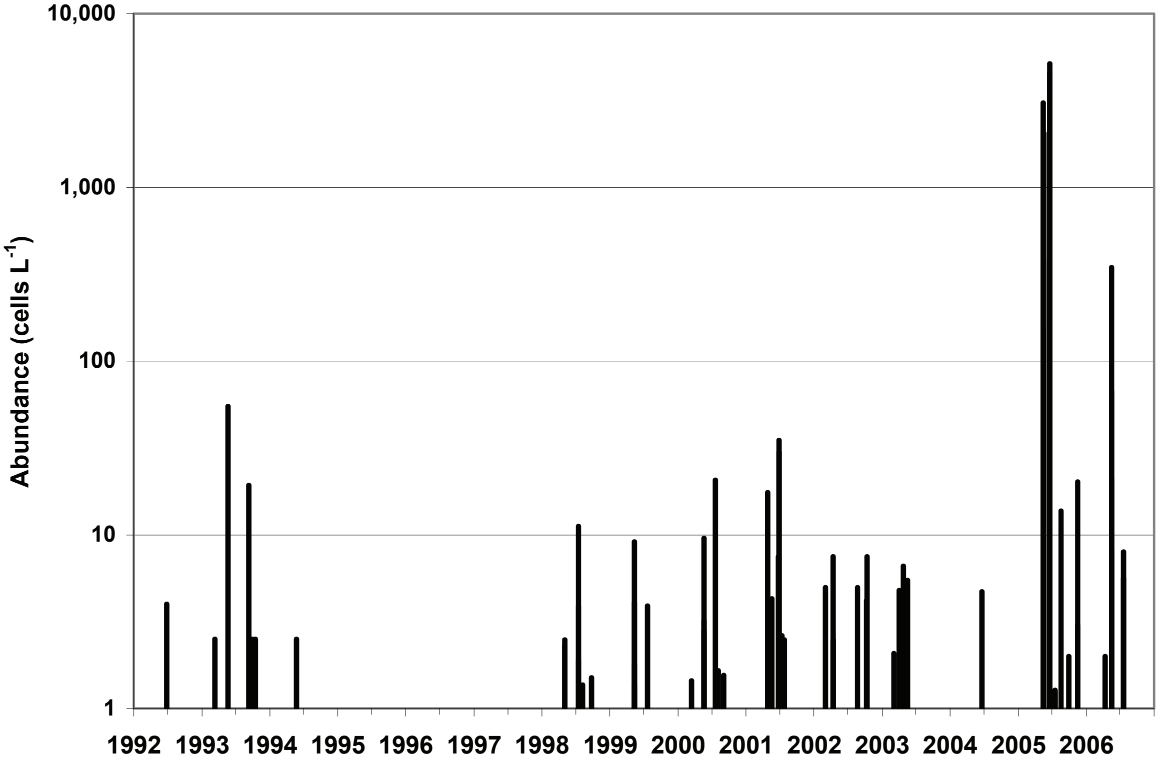


Figure 3-18. Abundance of Alexandrium *species in the nearfield, 1992-2006*

Zooplankton Communities

The structure of the zooplankton community in 2006 was similar to that of many earlier years and continued to show no effects of the outfall (Libby *et al.* 2007). Abundance was dominated by copepod nauplii and copepodites and adults of the small copepods *Oithona similis* and *Pseudocalanus* spp. Other, less dominant, copepods typically include *Calanus finmarchicus*, *Paracalanus parvus*, *Centropages typicus*, and *Centropages hamatus*.

The planktonic early life stages of bivalves, gastropods, barnacles, and polychaetes occur in sporadic pulses, which can sometimes dominate the community. For example, in 1992, there was a pulse of polychaete larvae; the summer of 1999 was marked by several pulses of various species; and in June of 2000, many samples were dominated by bivalve veligers.

There has, however, been a measurable decrease in total zooplankton abundance during 2001 through 2006 in comparison to the baseline years, 1992 through 2000. In particular, total copepod abundance has been lower during the late spring and early summer and during the fall (Figure 3-19). Similar decreases have been observed across Massachusetts Bay, including the northern boundary to the Gulf of Maine, the offshore, and the coastal stations.

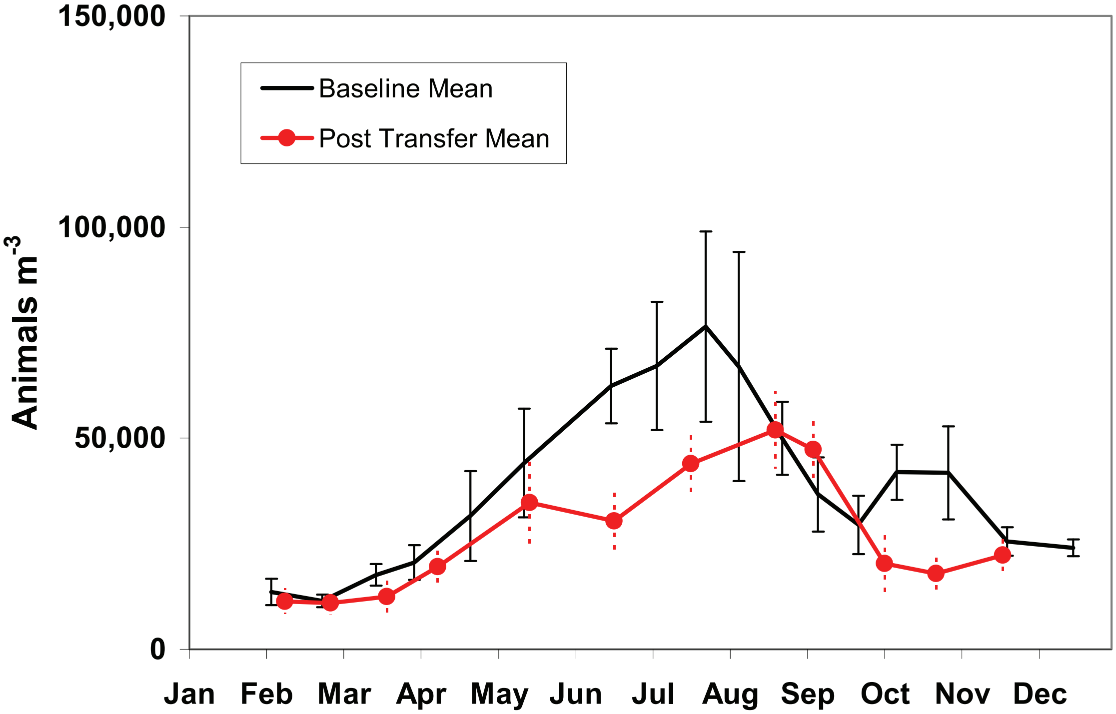


Figure 3-19. Nearfield copepod abundance during the baseline and post-transfer periods. (Data are from Stations N04, N16, and N18, and error bars represent plus or minus one standard error.)

Oithona similis, the small copepod that is consistently the most abundant species, has shown the most dramatic decreases in abundance, particularly during February through August in the nearfield and also in the boundary and offshore regions. Not all copepod taxa have exhibited this decrease. One species, the relatively large *Calanus finmarchicus*, has been present at abundances approximating the baseline mean and within the baseline range during most of the year, with a large increase in nearfield abundance observed in May (Figure 3-20). *Calanus finmarchicus* has also shown post-transfer increases in the boundary, Cape Cod Bay and the offshore regions.

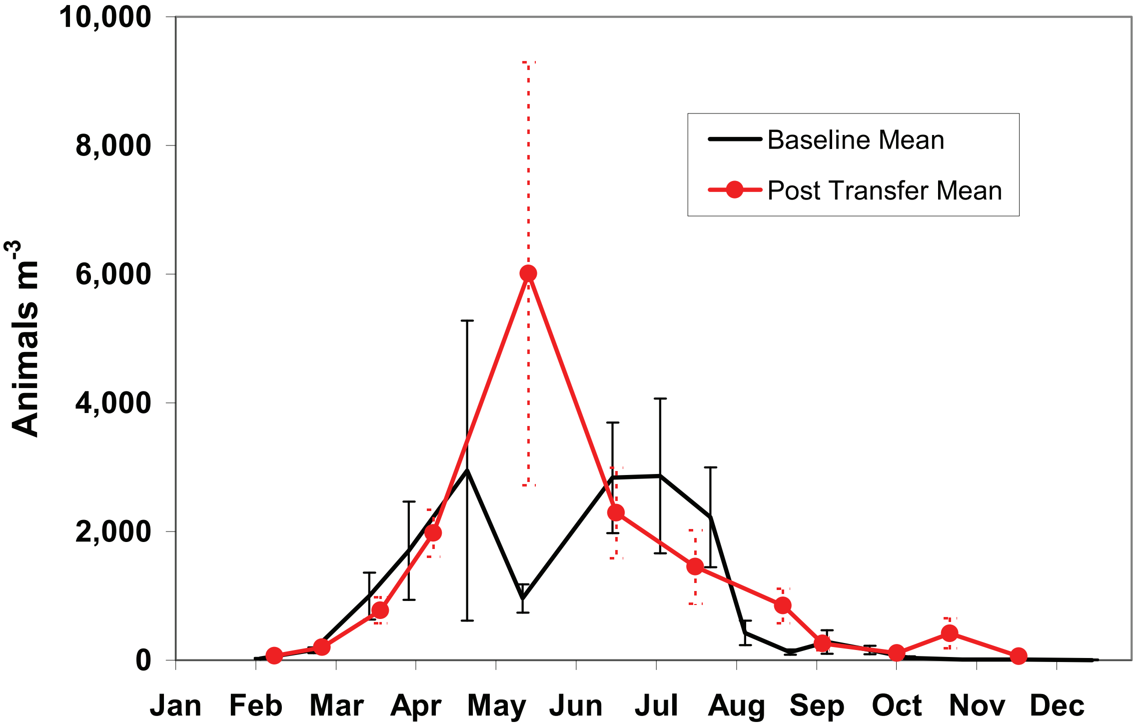


Figure 3-20. Nearfield Calanus *abundance during the baseline and post-transfer periods. (Error bars represent plus or minus one standard error.)*

The region-wide decline in zooplankton abundance is not well-understood. In some years, high numbers of ctenophores (comb jellies), which are predators on zooplankton, have been observed. Physical oceanographic factors and biological interactions (for example, the nuisance alga, *Phaeocystis*) may also be affecting zooplankton abundances.

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. There were three exceedances of thresholds in 2006—the summer chlorophyll threshold, the summer *Phaeocystis* threshold, and the *Alexandrium* threshold.

The reported mean nearfield chlorophyll value for May through August was 97 mg/m^2, an exceedance of the caution level threshold of 93 mg/m^2. The high level came during the summer bloom of the chain-forming diatom *Dactyliosolen fragilissimus*, stimulated by unusual upwelling in July which brought bottom-water nutrients (including outfall ammonium and ambient nitrate) closer to the surface where light is available for plant growth. This species is not considered to be a harmful or nuisance species. The exceedance is not thought to be a cause for environmental concern. Similar levels were recorded before the outfall began operation in 2000 (Figure 3-21). Further, there was no decline in oxygen levels in the nearfield bottom waters that could be attributed to over-abundant algae.

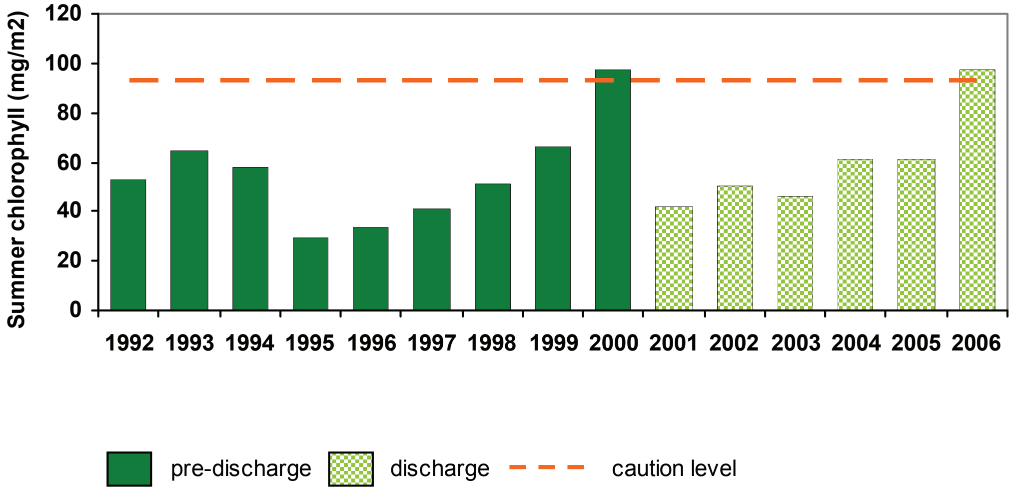


Figure 3-21. Summer nearfield chlorophyll levels in 1992-2006, compared to the caution level threshold

The summer *Phaeocystis* caution level threshold has been exceeded each year since 2002, due to the extended duration of the spring blooms that have occurred in recent years and to the extremely low summer threshold. The peak of the 2006 bloom, which occurred in April, was relatively low. The termination of spring *Phaeocystis* blooms appears to be related to the speed with which the surface waters warm in the spring (see Figure 3-17).

The *Alexandrium* threshold of 100 cells per liter was exceeded during the May red tide, with 5,667 cells per liter measured during a nearfield survey. In Massachusetts, shellfish beds were closed from the New Hampshire border to Duxbury, but the threshold for PSP toxin extent was not exceeded, because the spatio-temporal pattern of the red tide was consistent with past blooms, beginning in the north and progressing to the south.

Table 3-5. Contingency plan threshold values and 2006 results for water-column monitoring

Location/ Parameter	Specific Parameter	Baseline	Caution Level	Warning Level	2006 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 = 6.76 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 = 72.1%
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 = 6.56 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 = 69.5%
Bottom water nearfield	DO depletion rate (June-October)	0.024 mg/l/d	0.037 mg/l/d	0.049 mg/l/d	0.015 mg/l/d
Chlorophyll nearfield	Annual	79 mg/m^2	118 mg/m^2	158 mg/m^2	107 mg/m^2
	Winter/spring	62 mgml^2	238 mg/m^2	None	129 mg/m^2
	Summer	51 mg/m^2	93 mg/m^2	None	97 mg/m^2, caution exceedance
	Autumn	97 mg/m^2	212 mg/m^2	None	93.6 mg/m^2
Nuisance algae nearfield *Phaeocystis pouchetii*	Winter/spring	468,000 cells/l	2,020,000 cells/l	None	382,588 cells/l
	Summer	72 cells/l	357 cells/l	None	18,045 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	0 cells/l
	Summer	14,600 cells/l	43,100 cells/l	None	0 cells/l
	Autumn	9,940 cells/l	24,700 cells/l	None	222 cells/l
Nuisance algae nearfield *Alexandrium fundyense*	Any nearfield sample	Baseline maximum = 163 cells/l	100 cells/l	None	5,667 cells/l, caution exceedance
Farfield	PSP toxin extent	Not applicable	New incidence	None	Not exceeded

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.

Modeling and long-term monitoring have confirmed that sediment transport in the region occurs primarily during storms (Butman *et al.* 2005). 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. Tidal currents, wind-driven currents, and currents associated with spring runoff are insufficient to resuspend sediments.

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 sediment transport caused concern about increased 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).

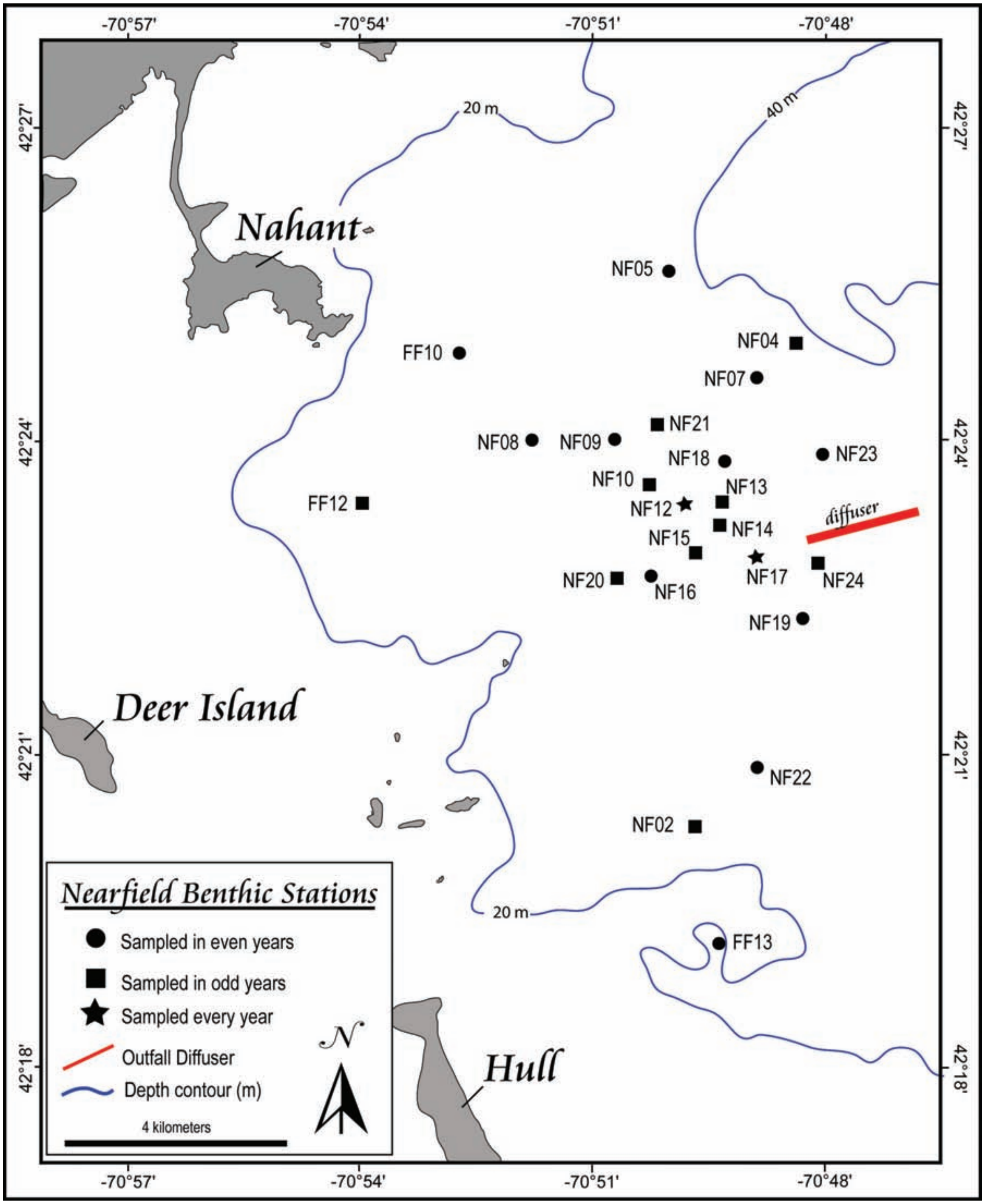


Figure 4-1. Locations of nearfield soft-bottom stations

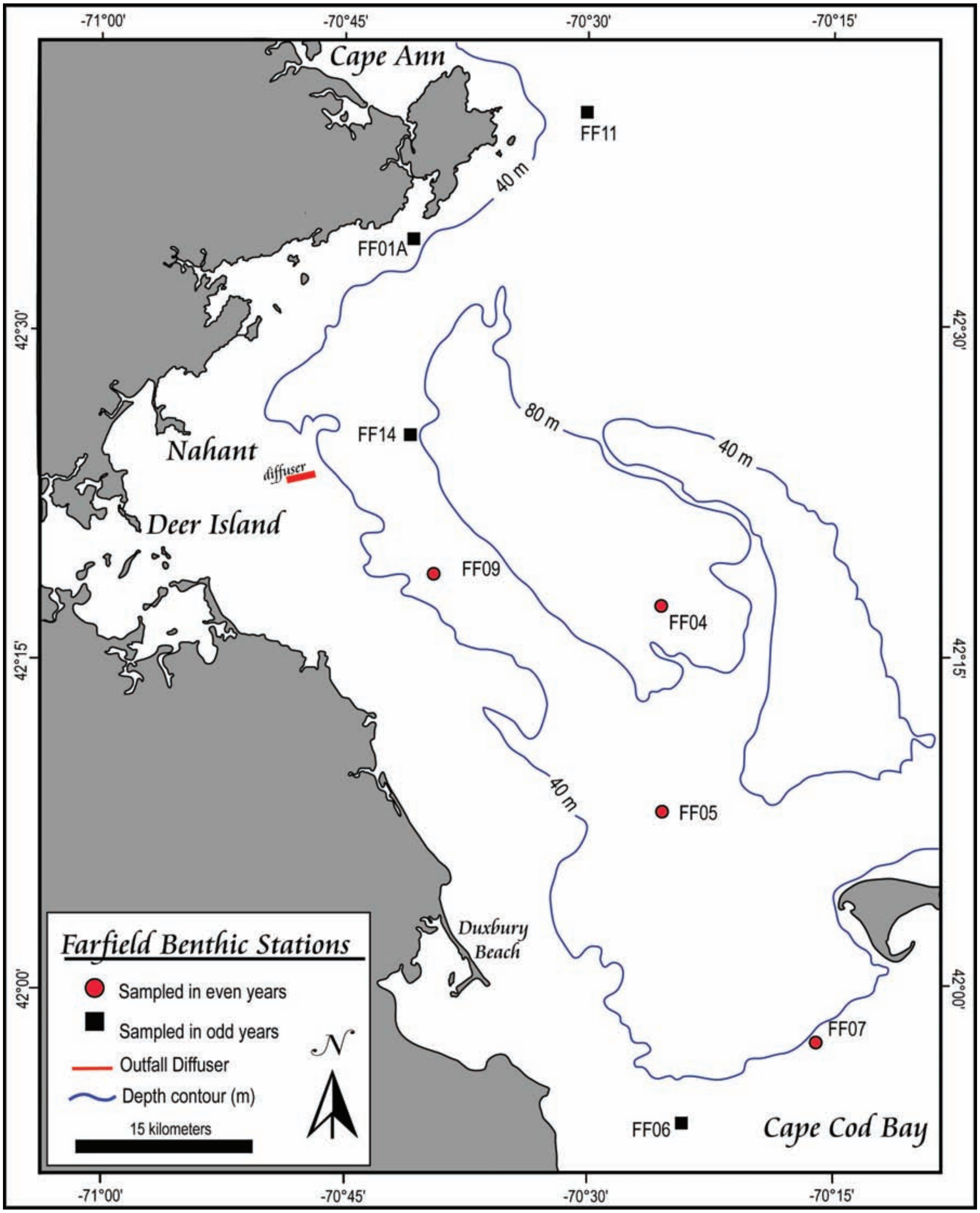


Figure 4-2. Locations of farfield soft-bottom stations

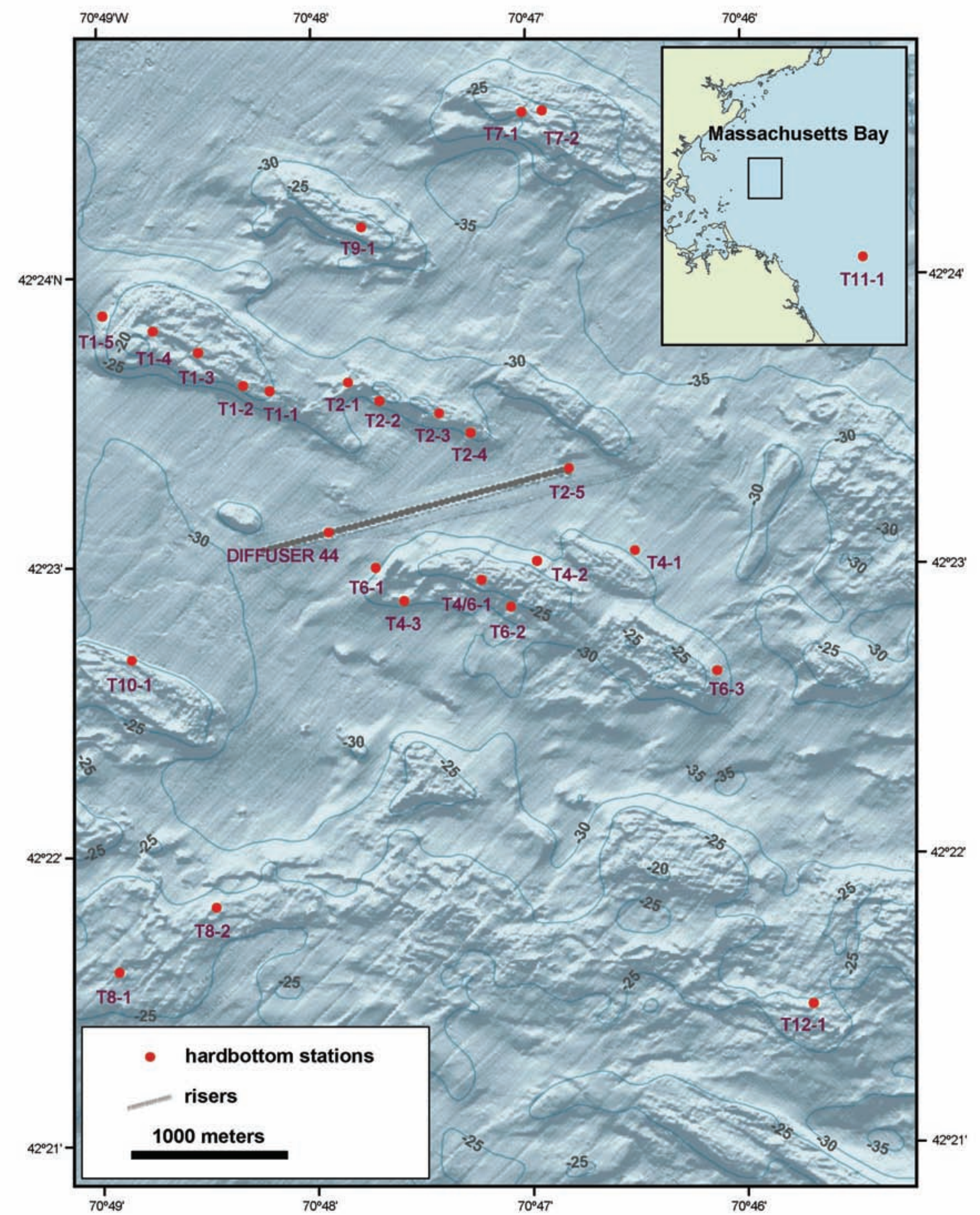


Figure 4-3. Locations of hard-bottom stations

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, primarily in association with USGS (for example, Bothner and Butman 2007).

Sediment-profile-image monitoring is conducted each August and results in area-wide assessments of sediment quality and benthic community status. A sharp-edged prism is used to cut into sediment surfaces at each station; a camera mounted to the prism records images of the sediment-water interface and the surface-sediment profiles. At each station, the camera is lowered to the sea floor three or four times, and a series of two to four replicate images is taken, generally within the first 12 seconds after bottom contact. A video feed allows real-time monitoring and ensures that adequate still photographs are obtained. The sediment-profile images provide more rapid assessments of benthic habitat conditions than is possible from traditional faunal analyses.

Monitoring the soft-bottom benthic infauna also includes annual sampling 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).

Beginning in 2003 and 2004, 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 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 those measurements most recently occurring in 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.

Analyses in 2006 included sediment grain-size distribution, total organic carbon content, and enumeration of *Clostridium perfringens* spores in samples from the even-year stations and analysis of chemical contaminants in samples from two stations. Sediment grain-size distributions and total organic carbon content were consistent with results from most years of the monitoring program. The coarse sediments, observed in 2005 and believed to have resulted from transport during severe storms, were not seen in 2006.

Abundance of the sewage tracer *Clostridium perfringens* decreased with increasing distance from Boston Harbor (Figure 4-4). Farfield stations, located more than 20 km from the harbor, had the lowest abundances. In the area near the outfall, abundances had declined during the 1990s and then increased in 2001, the year after the outfall began to discharge. Levels remained elevated through 2005, but then decreased in 2006.

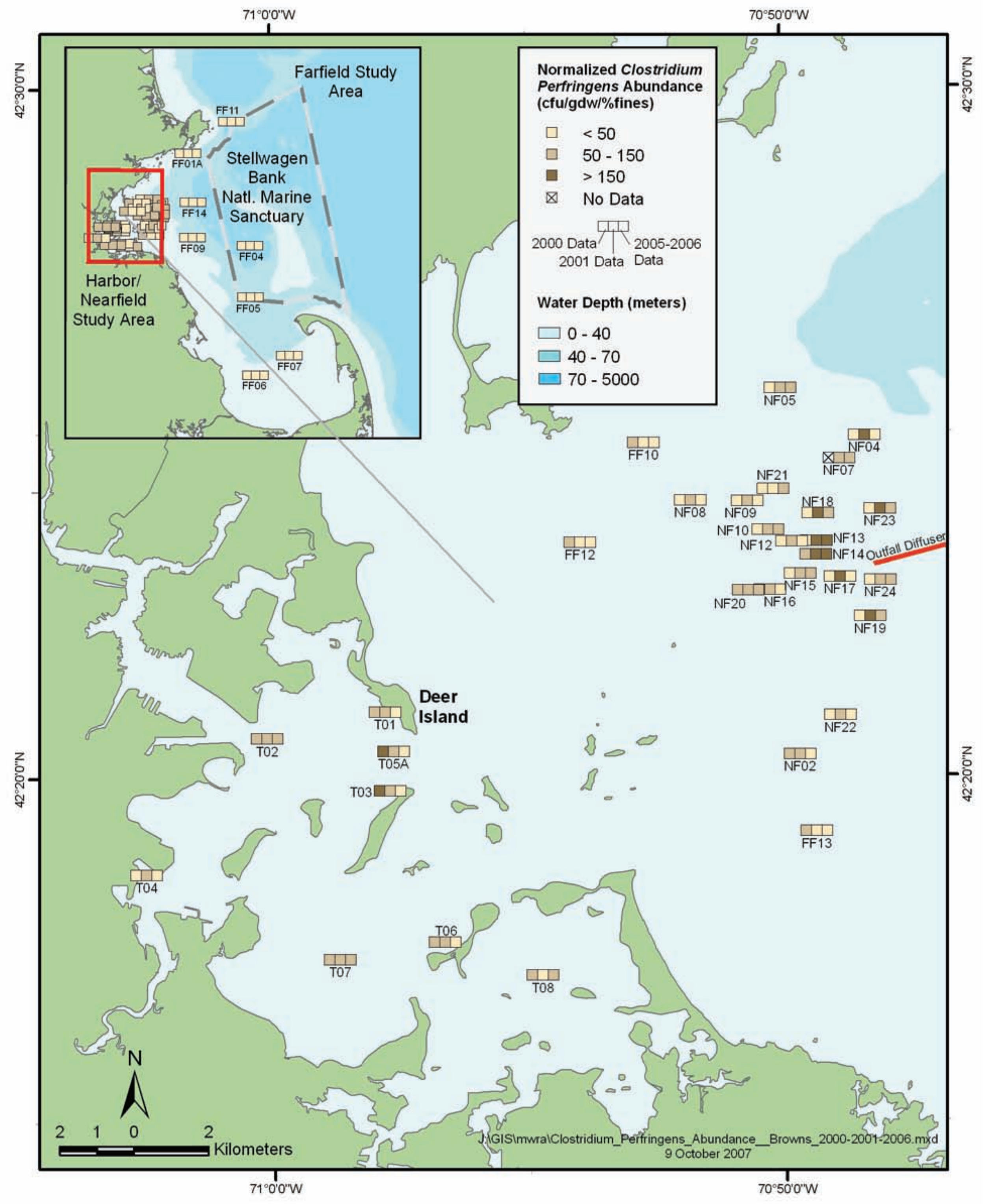


Figure 4-4. Clostridium perfringens *spore counts, normalized to percent fine fraction in the sediments, in the harbor, the nearfield, and the farfield in 2000, 2001, and 2006*

Concentrations of chemical contaminants continued to slowly decrease over time, but were variable, as has been typical throughout the monitoring program. Sediment grain size, particularly the percentage of sand, has been the primary factor associated with the variance.

Sediment-Profile Imaging

Sediment-profile imaging measurements in 2006 showed no adverse changes from the baseline to the post-baseline period (Maciolek *et al.* 2007; Figure 4-5). The mean RPD depth in 2006 was the deepest measured in the post-discharge period, reflecting continued healthy conditions in the nearfield. No relationship between RPD depth and outfall operation has been detected; yearly patterns appear to be acting across broad regional scales, and there has been no indication of increased organic matter accumulating in surface sediments. Some sediment-profile images showed evidence of increased layering at some stations north and south of the outfall. Coarser sediments were layered on top of finer sediments, reflecting physical processes.

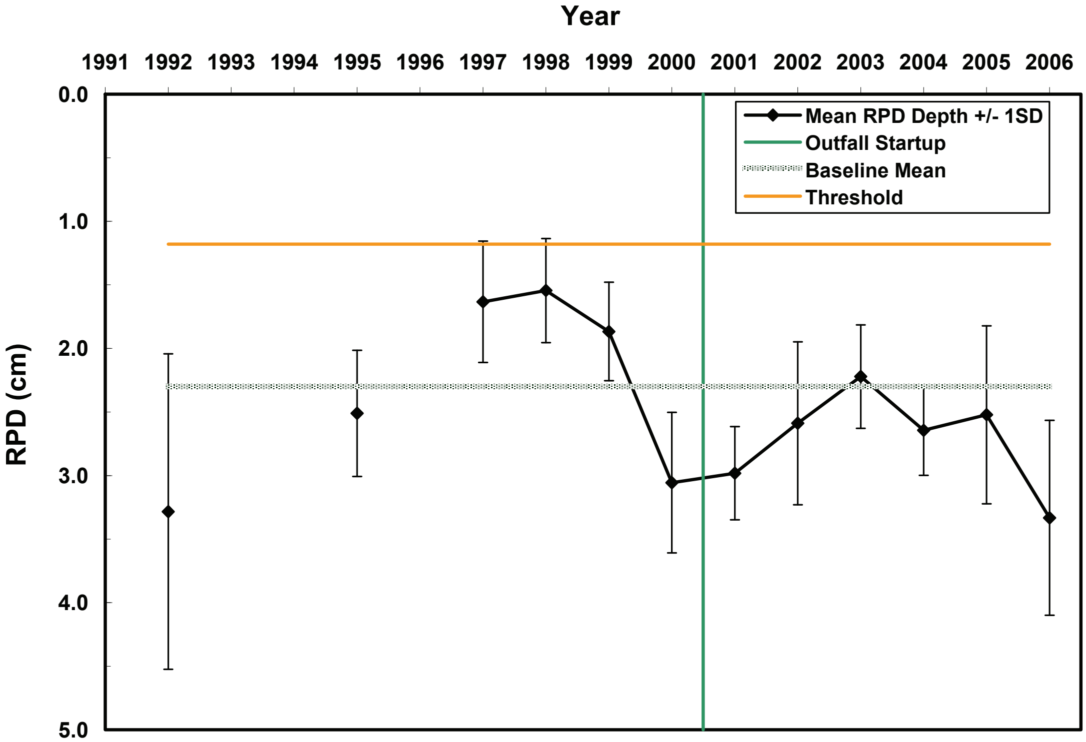


Figure 4-5. Apparent color RPD for data from nearfield stations sampled in 2006

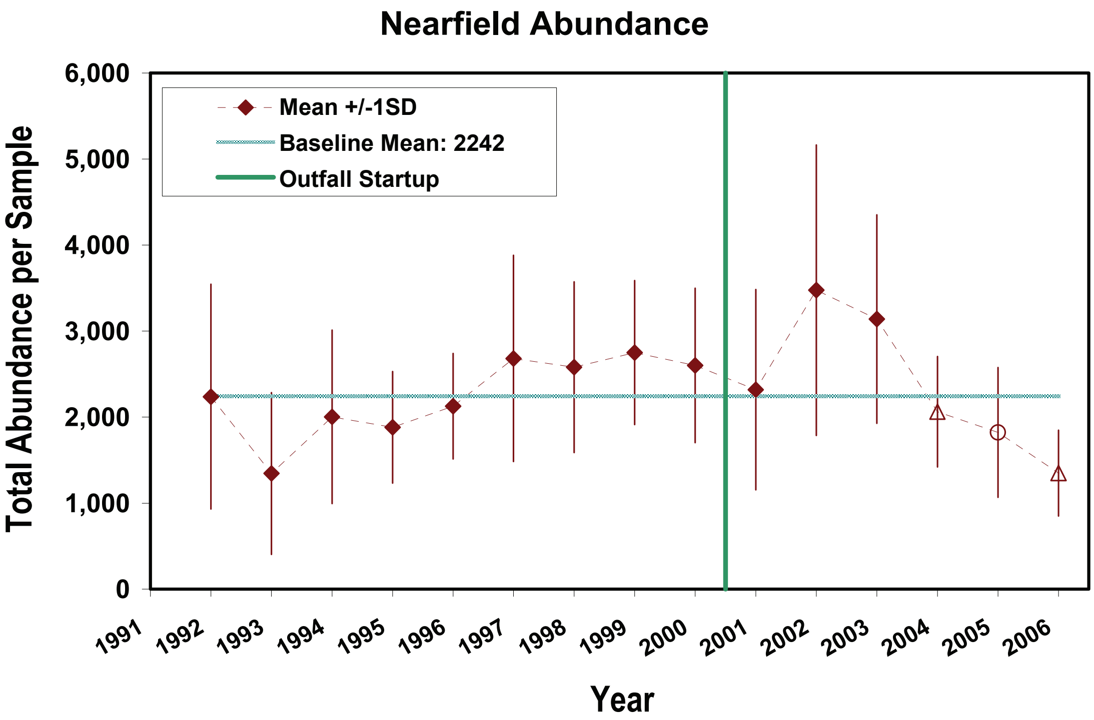
Soft-bottom Communities

The soft-bottom communities have also shown no response to the outfall (Maciolek *et al.* 2007). 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 2006, mean total abundance per sample continued to fall in the nearfield (Figure 4-6, top) and the farfield (not shown) after record high densities in 2002 and 2003. Annual fluctuations in the populations of several species and the occasional scouring of the bottom by storms contribute to the annual changes in numbers of animals per sample. The total number of species per sample (not shown), was approximately the same as in 2005 and near the baseline mean. Diversity, measured by indices such as log-series alpha (Figure 4-6, bottom), and evenness (not shown) showed small but insignificant increases in comparison to 2005.



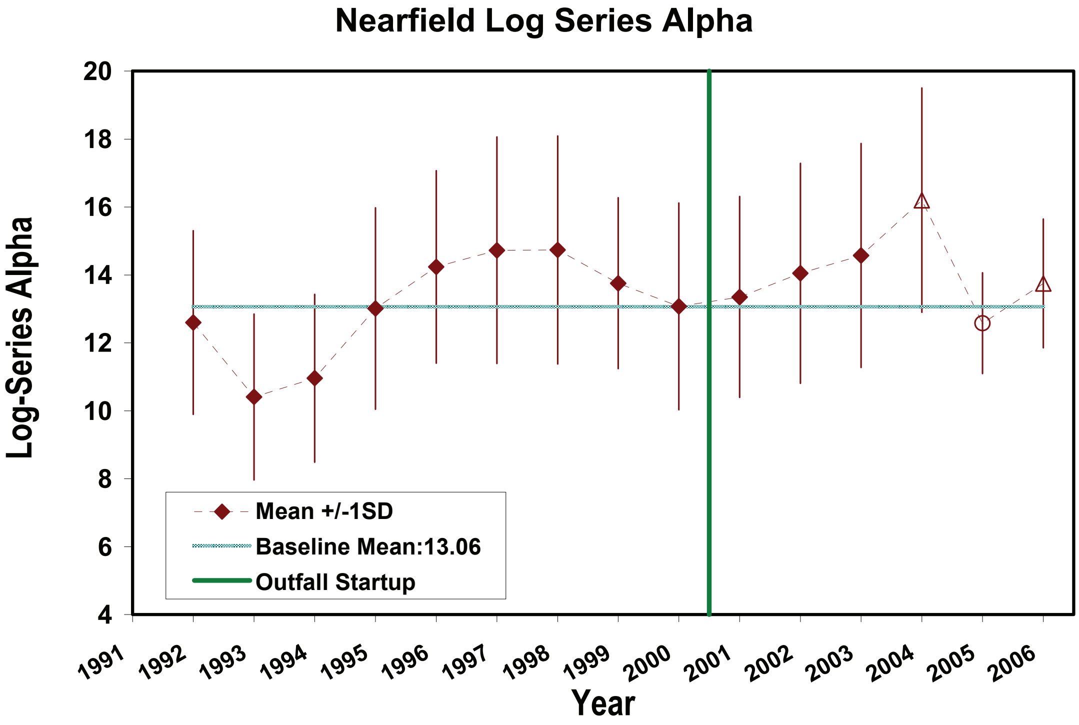


Figure 4-6. Community parameters in the nearfield, 1992-2006. Open symbols indicate new sampling schedule of alternating station groups. Top: abundance per sample, Bottom: log-series alpha

The polychaete *Prionospio steenstrupi* has continued to be the numerically dominant species at nearfield stations with 5-70% fine sediments, although there have been changes in their absolute numbers. At stations with sandier sediments, bivalves, ascidians, amphipods, and the sand dollar *Echinarachnius parma* have predominated. There have been no detectable changes in response to the outfall, even at stations that prior to 2006 showed elevated concentrations of the sewage tracer *Clostridium perfringens*.

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 (Maciolek *et al.* 2007). For example, there has been a slight decrease in the number of upright algae at many stations, but these decreases began in the 1990s before the outfall went on-line, and the trend appears to be reversing. Other species, such as *Cancer* crabs, also appear to exhibit cycles of abundance.

At several stations, there have been increases in sediment drape and concurrent decreases in abundance of coralline algae, conditions that might suggest an outfall effect. However, those changes have been evident at the most northern stations, which were not predicted to be susceptible to outfall effects. An alternative explanation is that the northern stations are affected by tanker traffic; since September 11, 2001, tankers bearing liquefied natural gas (LNG) have frequently been seen to be anchored in the area, sometimes affecting MWRA survey schedules. During the 2006 survey, anchor scars and turned-over boulders, with coralline algae on the bottom rather than the top surfaces, were observed at one of these most northern stations (Figure 4-7). Such physical disturbances could be compromising the effectiveness of these sites as reference stations for the MWRA program. Lush epifaunal growth, particularly sea anemones, continues to thrive on the diffuser heads.

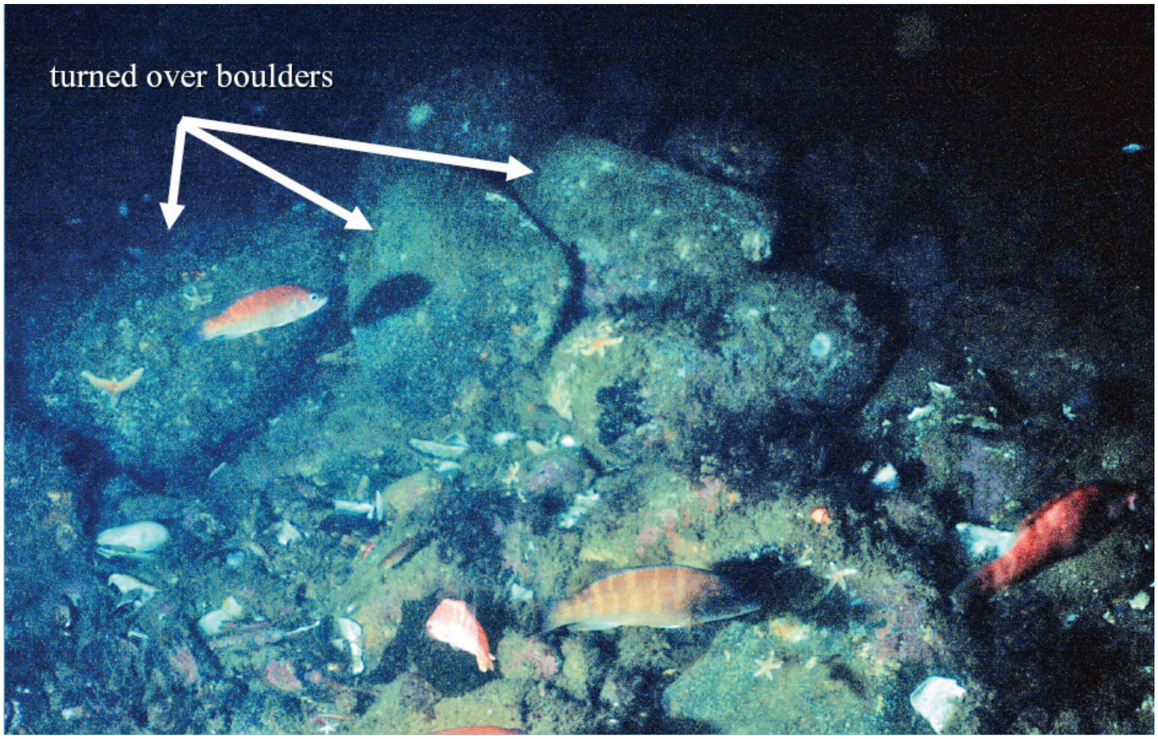


Figure 4-7. Anchor scarring at the most northern hard-bottom transect, T7-2, in 2006

Contingency Plan Thresholds

No Contingency Plan thresholds for sea-floor monitoring were exceeded in 2006 (Table 4-2). RPD depth was deeper than the baseline mean, rather than shallower, as had been a concern. Soft-bottom community parameters were within normal ranges, and the percent of the soft-bottom community composed of opportunistic species remained low, more than an order of magnitude below the caution threshold.

Table 4-2. Contingency Plan threshold values and 2006 results for sea-floor monitoring

Location	Parameter	Caution Level	Warning Level	2006 Results
Sediments, nearfield	RPD depth	1.18 cm	None	2.96 cm
Even years, Benthic diversity, nearfield	Species per sample	<48.41 or >82.00	None	61.76
	Fisher’s log-series alpha	<9.99 or >16.47	None	13.72
	Shannon diversity	<3.37 or >4.14	None	3.77
	Pielou’s evenness	<0.58 or >0.68	None	0.64
Benthic opportunists	% opportunists	>10%	>25%	0.37%

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.

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?

The concerns for fish and shellfish were that the discharge of sewage effluent into the relatively clean waters of Massachusetts Bay could result in chemical contamination of the fisheries or that contaminants in the effluent could cause direct damage to health of the fishery stocks. Because many toxic contaminants adhere to particles, which settle, animals that live on the bottom, in contact with sediments, and animals that eat bottom-dwelling organisms were considered to be the most likely species to be affected. Exposure to contaminated sediments could result in fin erosion, 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 (*Pseudopleuronectes americanus*), lobster (*Homarus americanus*), and blue mussel (*Mytilus edulis*). Winter flounder and lobster are important resource species in the region. Like all flatfish, winter flounder live and feed on the bottom, often lying partially buried in the sediments. Lobsters live on a variety of surfaces within the region, including mud, sand, gravel, and rock outcrops. Like other filter feeders, blue mussels process large volumes of water and can concentrate toxic metals and organic compounds in their tissues. Mussels are also resource species. They can be readily maintained in fixed cages, so they are convenient monitoring tools.

Flounder and lobster are sampled from Deer Island Flats, near the outfall site, and Cape Cod Bay (Figure 5-1). Flounder are also taken near Nantasket Beach and until 2005, at Broad Sound. Mussels are deployed at the edge of the mixing zone, one kilometer south of the diffuser line, in Cape Cod Bay, at Deer Island Light, and in the Inner Harbor.

Winter Flounder

Flounder are collected annually. Whole fish are examined for external lesions or other abnormalities, and 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. Vacuolation and neoplasia have been associated with chronic exposure to contaminants.

Since 2004, chemical analyses for flounder are completed every third year, including 2006, to determine tissue burdens 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.

Lobster

Commercial lobstermen collect lobsters for the monitoring program. Since 2004, lobsters have been studied every third year, including 2006. All lobsters are examined for external conditions, and 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.

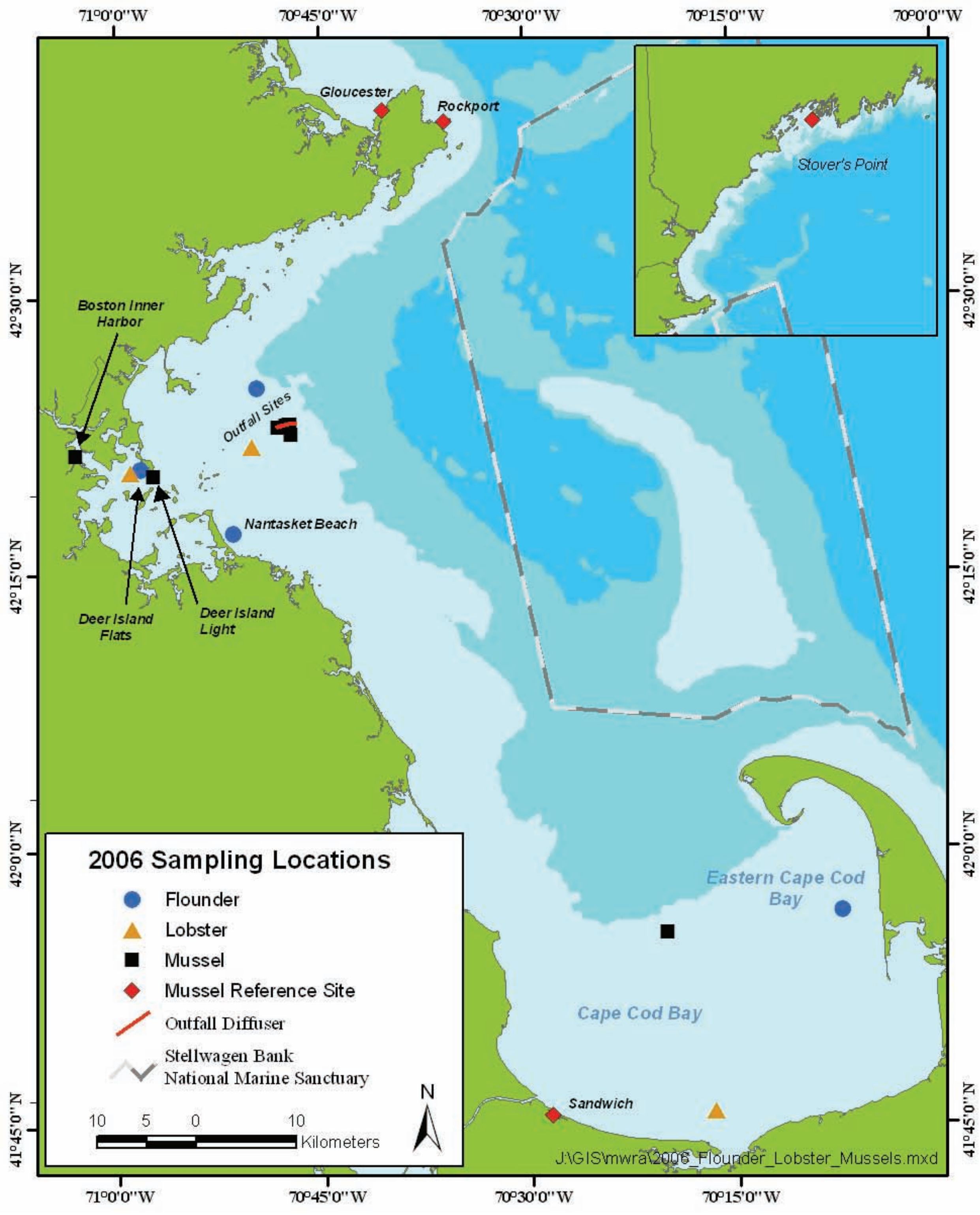


Figure 5-1. Sampling areas for fish and shellfish monitoring

Blue Mussel

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. Since 2004, mussel deployments and analyses have been carried out every third year, including 2006.

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

Results

Winter Flounder

Sampling for winter flounder occurred during late April 2006. Fifty sexually mature fish were collected at each of the four sampling sites, except the area off Nantasket Beach where only 29 flounder were obtained after three hours of bottom trawling (Nestler *et al.* 2007). Catch per unit effort declined at all stations, despite adjustments in exact trawling locations to maximize catch. The declines reflect a recent regional decline in the Gulf of Maine stock (Massachusetts Division of Marine Fisheries (MADMF) data, available at www.nefcs.noaa.gov).

Each of the fish was examined for physical characteristics and external condition, and all fish were used for histological and age analyses. The first 15 fish caught were designated for chemical analysis, with tissues from five individual fish from each area composited into three fillet samples and three liver samples per area.

All fish were at least 30 cm in length, and almost all were female, as has been typical in recent years. The average age was between four and five years. Prevalence of undesirable external conditions, such as fin erosion or blind-side ulcers, was typically highest in fish taken from Deer Island Flats and lowest in those from eastern Cape Cod Bay. Fin erosion occurred in more than half the fish taken from Deer Island Flats, the highest incidence seen since the early days of the monitoring program but within the historic range. The incidence of blind-side skin ulcers, which had been first detected in western Massachusetts Bay in 2003, was low, only 2% in 2006, compared to a high of 24% at the outfall site in 2004.

No neoplasia was observed in any fish from any site. The incidence of the least severe and most common form of vacuolation, centrotubular hydropic vacuolation (CHV), remained low (Figure 5-2). Incidence of CHV in fish from the outfall site was comparable to levels observed in 2001 and 2005 and lower than the incidence in the years before the outfall began to discharge.

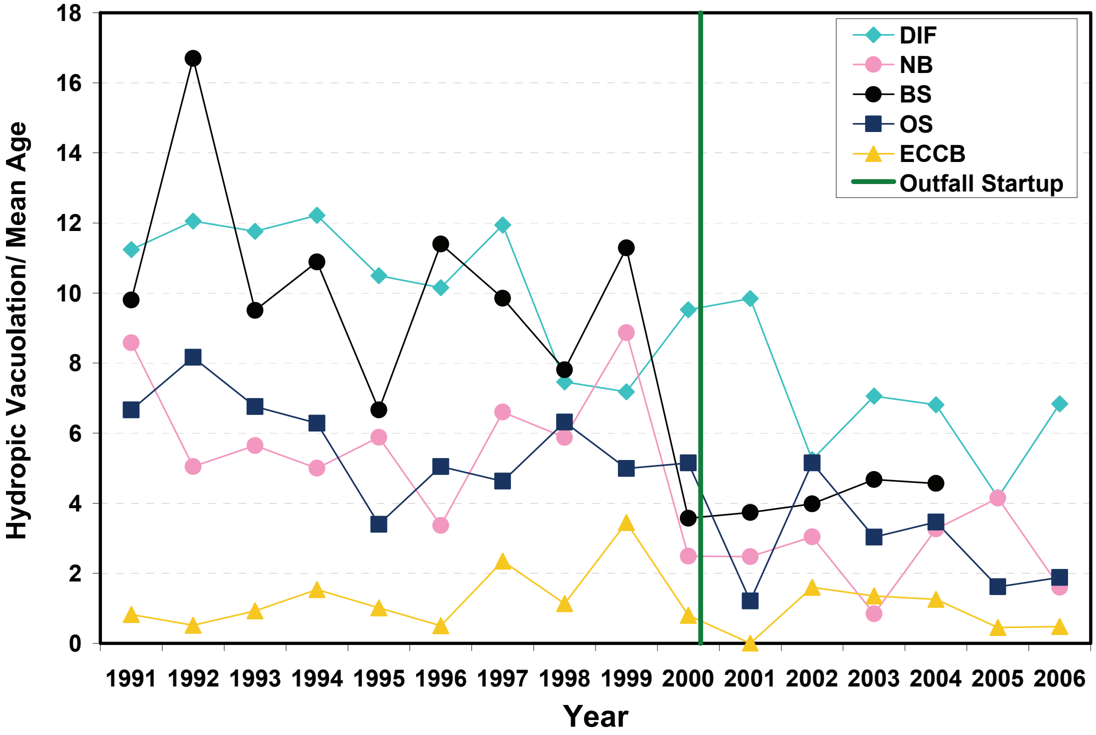


Figure 5-2. Prevalence of centrotubular hydropic vacuolation (CHV), corrected for age (DIF = Deer Island Flats, OS = Outfall Site, ECCB = Eastern Cape Cod Bay, NB = Nantasket Beach, and BS = Broad Sound)

Concentrations of contaminants in flounder fillets remained low, with the highest levels of most contaminants observed in fish from Deer Island Flats. Concentrations of contaminants in flounder livers showed similar patterns. Statistical analyses of data from the years immediately prior to the outfall coming on line (1998-2000) in comparison to those from post-discharge years (2001-2003 and 2006) found no increase in contaminant levels in fillets. Chlordane levels (alpha-chlordane + trans-nonachlor) have significantly decreased in the years following outfall start-up. There were increases in PCB concentrations, measured as congeners 138+153, in flounder livers from fish from the outfall site and Deer Island flats, but the levels were within the historic ranges.

Lobster

Twenty-one lobsters were collected from each of three areas—Deer Island Flats (sampled in July), the outfall site (sampled in September), and eastern Cape Cod Bay (sampled in October). All samples were trapped by commercial lobstermen, accompanied by fisheries technicians who verified sampling locations and conducted field sample processing (Nestler *et al.* 2007). The lobsters from Cape Cod Bay and Deer Island Flats were approximately the same size; those caught near the outfall were slightly smaller. Only males were collected from eastern Cape Cod Bay, mostly males were taken at Deer Island Flats, and mostly females were taken at the outfall site. No black gill disease or deleterious external conditions were noted.

Within each site, tissues from three to seven lobsters were composited for chemical analysis, so that there were three meat samples and three hepatopancreas samples for each area. For most compounds, contaminant concentrations in lobster tissues were low, at the lower end of the historic ranges at all sampling sites. Statistical analyses of data from 1998-2000 compared to data from 2001-2003 and 2006 indicated that no contaminant levels in lobster meat or hepatopancreas had increased since the outfall came on line. In hepatopancreas samples, concentrations of some organic compounds were higher than they had been in 2003, although these increases were more evident in samples from other stations rather than in those from the outfall site. In general, metals concentrations were within the historic ranges, although in some instances (nickel in samples from Deer Island Flats and zinc in samples from the outfall site), concentrations were at the upper end of that range.

Blue Mussel

Blue mussels were collected from Stover's Point, Maine, and deployed at Deer Island Light, the outfall site, Boston Inner Harbor, and Cape Cod Bay. Five arrays were deployed at or near the outfall, four just south of the diffuser heads and one approximately one kilometer away at the "B" buoy. Recovery of mussel arrays was scheduled for 40 and 60 days. A subset was collected at 40 days and archived. Collections at 60 days were sufficient for analysis at all stations, except one station at the outfall site (designated M1), at which no mussels were retrieved (and for which there were no 40-day samples). Survival was high in all recovered arrays (Nestler *et al.* 2007).

Composites, consisting of varying numbers of mussels, were made for chemical analyses, resulting in four of five replicates per location. Historically, samples from the Boston Inner Harbor and Deer Island sites have shown the highest concentrations of contaminants, and samples from Cape Cod Bay and the outfall area have been the lowest. The inner harbor site continued to show the greatest degree of bioaccumulation in 2006.

Loss of the arrays at the M1 station of the outfall site precluded some comparisons of data from 2006 to earlier years, as that specific location had frequently resulted in the highest concentrations of contaminants within the outfall area. The increase in alpha-chlordane levels in mussels deployed at the outfall, which had been noted in the years since the outfall began operation, was not evident, with 2006 values being at or near historic low levels at all stations. Average concentrations of total high molecular weight PAHs, which had increased in mussels from the outfall site during the post-diversion years of 2001-2003, were significantly lower in 2006, possibly due to decreases in PAH concentrations in the effluent but also possibly because of the lack of data from the M1 deployments.

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. No thresholds were exceeded in samples from 2006.

Table 5-3. Contingency Plan threshold values and 2006 results for fish and shellfish monitoring

Parameter Type/ Location	Parameter	Baseline	Caution Level	Warning Level	2006 Results
Flounder tissue nearfield	PCB	0.033 ppm	1 ppm wet weight	1.6 ppm wet weight	0.030 ppm
	Mercury	0.074 ppm	0.5 ppm wet weight	0.8 ppm wet weight	0.080 ppm
Flounder tissue, lipid normalized, nearfield	Chlordane	242 ppb	484 ppb	None	102 ppb
	Dieldrin	63.7 ppb	127 ppb	None	31.6 ppb
	DDT	775.9 ppb	1552 ppb	None	816 ppb
Flounder nearfield	Liver disease (CHV)	24.4%	44.9%	None	10%
Lobster tissue nearfield	PCB	0.015 ppm	1 ppm wet weight	1.6 ppm wet weight	0.014 ppm
	Mercury	0.148 ppm	0.5 ppm wet weight	0.8 ppm wet weight	0.067 ppm
Lobster tissue, lipid normalized, nearfield	Chlordane	75 ppb	150 ppb	None	3.2 ppb
	Dieldrin	161 ppb	322 ppb	None	71.4 ppb
	DDT	341.3 ppb	683 ppb	None	225 ppb
Mussel tissue nearfield	PCB	0.011 ppm	1 ppm wet weight	1.6 ppm wet weight	0.00467 ppm
	Lead	0.415 ppm	2 ppm wet weight	3 ppm wet weight	0.274 ppm
	Mercury	0.019 ppm	0.5 ppm wet weight	0.8 ppm wet weight	0.0116 ppm
Mussel tissue, lipid normalized, nearfield	Chlordane	102.3 ppb	205 ppb	None	76 ppb
	Dieldrin	25 ppb	50 ppb	None	10.8 ppb
	DDT	241.7 ppb	483 ppb	None	125 ppb
	PAH	1080 ppb	2160 ppb	None	2010 ppb

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 2006, special studies included studies of nutrient flux at the sediment-water interface, marine mammal observations, and continued studies related to the *Alexandrium* blooms known as red tides.

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 and at a station in Stellwagen Basin, which is considered to be out of the range of any sewage influence.

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?

Monitoring in 2006 continued to show the patterns of previous years, with improved conditions in Boston Harbor and little or no indication of any effect of the outfall discharge in the vicinity of the outfall (Figure 6-1; Tucker *et al.* 2007).

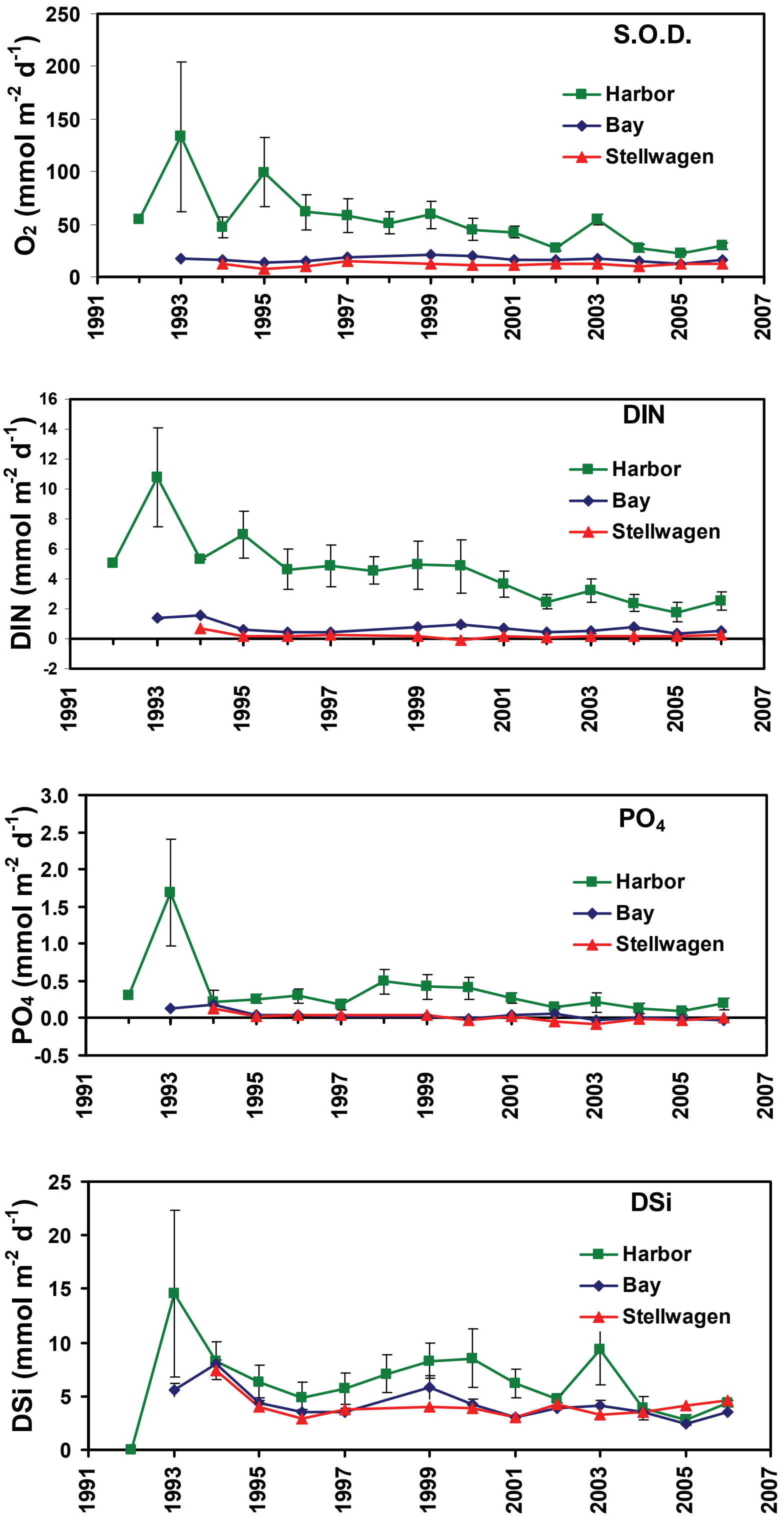


Figure 6-1. Annual survey averages (from top to bottom): sediment oxygen demand (S.O.D.), dissolved inorganic nitrogen flux (DIN), phosphate flux (PO_4), and dissolved silica flux (DSi) in Boston Harbor, Massachusetts Bay, and Stellwagen Basin. (Data are May, July, August, and October averages.)

Sediment oxygen demand and nutrient fluxes have decreased at the four Boston Harbor stations to levels that approach those in Massachusetts Bay. As the magnitude of the fluxes has declined, so has the temporal and spatial variability. Sediment oxygen demand and dissolved inorganic nitrogen flux at the three stations in the nearfield are slightly higher than the comparable values for Stellwagen Basin, but these measurements do not reflect any change since the outfall discharge began.

Prior to the outfall diversion, Boston Harbor had high rates of sediment oxygen demand compared to those in other coastal systems (Figure 6-2). 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 not increased.

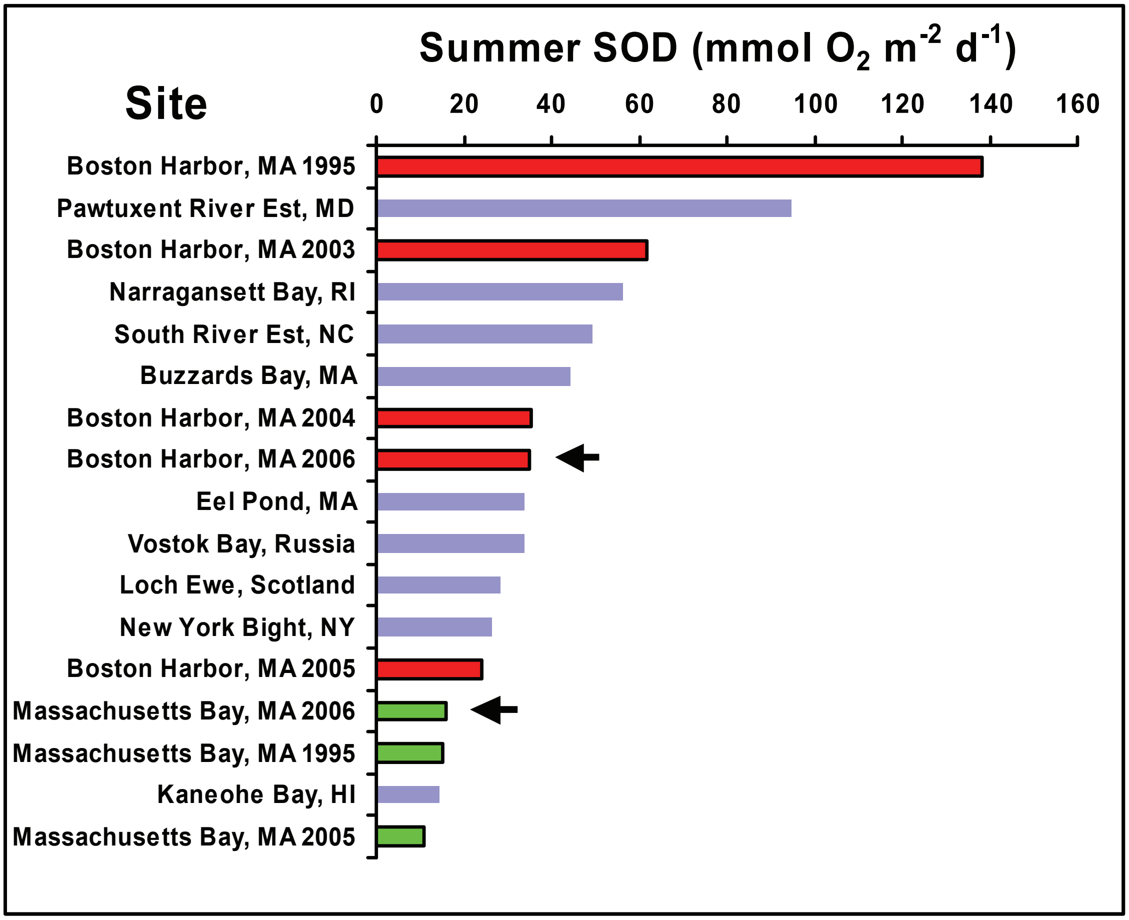


Figure 6-2. Sediment oxygen demand in Boston Harbor and the nearfield of Massachusetts Bay during pre- and post-diversion periods compared to other coastal ecosystems. Data for Boston Harbor and Massachusetts Bay are July and August averages; data for the other systems are summer rates from Nixon 1981. Arrows point to 2006 data.

Marine Mammal Observations

Several species of endangered or threatened whales and turtles visit Massachusetts and Cape Cod bays, including the right, humpback, finback, sei, and rarely, 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 2006, observers were included on twelve nearfield water quality surveys and three farfield surveys (Short *et al.* 2007). 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 2006 surveys, from 53 to more than 57 individual whales, more than 22 harbor porpoise, two unidentified porpoises, and 24 to 31 Atlantic white-sided dolphins were directly observed by the trained observers and other members of the monitoring team. One right whale was included in the whale sightings, which were concentrated within Massachusetts Bay. No whales were sighted in the vicinity of the outfall.

The total number of whales sighted by a dedicated observer was relatively high and in the same range as the numbers sighted during 1998-2001, higher numbers than the sightings in 2002-2004. Records of the Whale Center of New England (www.whalecenter.org) have also indicated an increase from the sparse sightings they had reported in recent years. Many adult humpback and fin whales were seen feeding on schools of sand lance over the shallow waters of Stellwagen Bank. Humpback whale mother-calf pairs were also more abundant than they had been in recent years. Northern Atlantic right whales were sighted feeding over the shallow waters of Stellwagen Bank and the deeper waters of Massachusetts Bay in late April and May.

Since 1998, there have been almost 300 whale sightings on MWRA surveys, including 19 right whale sightings. The most common species has been the humpback whale. More than half the sightings have occurred within the Stellwagen Bank National Marine Sanctuary, and almost one quarter have taken place in Cape Cod Bay.

Alexandrium Blooms

Blooms of the toxic *Alexandrium* species (*A. tamarense* and *A. fundyense*, which both occur in the Gulf of Maine and are indistinguishable in routine monitoring) occurred in Massachusetts Bay in 2005 and 2006. *Alexandrium* is one of the nuisance species groups of concern in water-column monitoring, because its blooms, known as red tides, produce a toxin that can concentrate in shellfish, causing paralytic shellfish poisoning (PSP) in birds and mammals, including humans, who consume shellfish.

The 2005 bloom was unprecedented, with cell concentrations exceeding those ever measured in southern New England and causing toxicity at locations farther south than had been observed in the past. The 2006 bloom was also significant in size, although cell abundances and toxicity were less than in 2005.

A conceptual model was developed by the Ecology of Harmful Blooms (ECOHAB) Gulf of Maine program, a project that addresses issues regarding the harmful algal blooms. The conceptual model developed by ECOHAB explains many aspects of *Alexandrium* blooms in the Gulf of Maine (Anderson *et al.* 2005; Figure 6-3).

Cyst seedbeds in the Bay of Fundy and south of the mouth of the Penobscot River in Maine produce the beginnings of the blooms. Currents transport the blooms to the southwest, where they may enter or bypass Massachusetts Bay. Recent modeling suggests that high cyst abundance in the western Gulf of Maine seedbeds is the most important factor affecting blooms in Massachusetts Bay (Anderson *et al.* 2007).

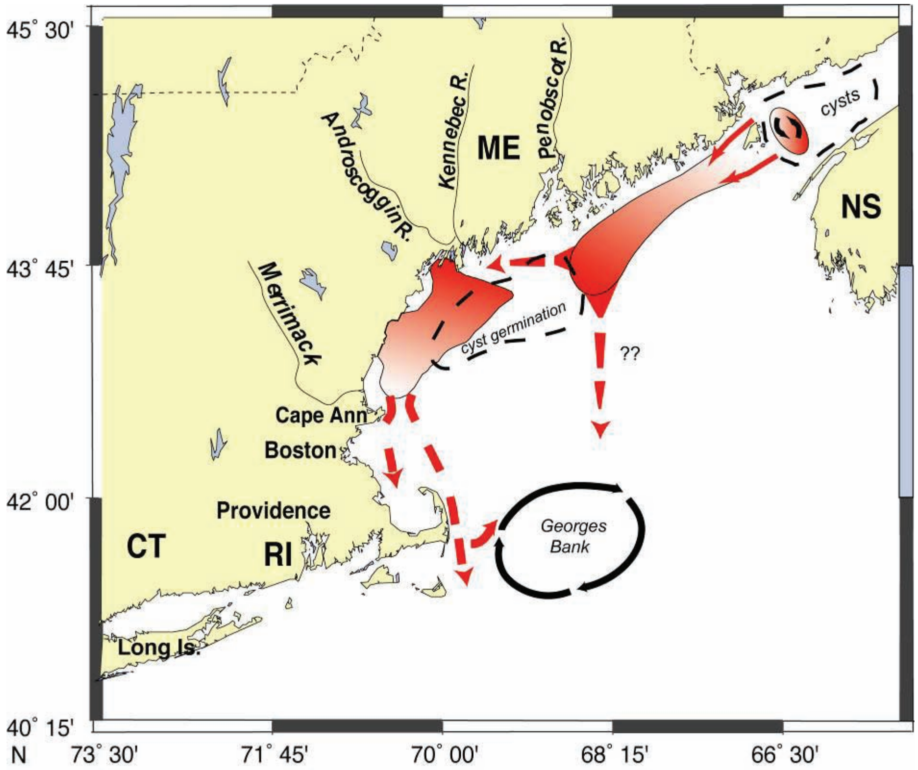


Figure 6-3. Conceptual model of red tide blooms in the Gulf of Maine. Dashed black lines outline cyst germination sites, red areas depict the extent of bloom development within a given area, and red arrows represents episodic transport pathways (from Anderson et al., 2005)

The MWRA outfall is not suspected to be a factor in the region-wide size or extent of the blooms. Localized effects have also not been definitively measured, but are a possibility. To supplement regular water-quality monitoring surveys, MWRA conducted four *Alexandrium* Rapid Response Surveys during 2006. Water-column data from MWRA regular and rapid-response surveys, the Woods Hole Oceanographic Institution, and the Center for Coastal Studies, in conjunction with shellfish toxicity data from the MADMF, were used to evaluate the effects, if any, of the outfall on the bloom (Libby *et al*. 2007). A similar analysis had determined that physical conditions alone were sufficient to explain the patterns of toxicity for the 2005 bloom. High toxicity in samples from Cohasset over a two-week period in 2006, when toxicities were lower at stations to the north and south, could imply some effect from the outfall, because the expectation is that toxicity would be highest at most northern locations. However, current monitoring and modeling efforts have not been able to conclude that nutrient stimulation played a role in the geographic pattern.

7. Stellwagen Bank National Marine Sanctuary

Background

The Gerry E. Studds Stellwagen Bank National Marine Sanctuary (SBNMS) comprises 842 square miles located at the boundary between Massachusetts Bay and the rest of the Gulf of Maine. Its 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 most prominent pressures on the sanctuary according to a condition report released in 2007 (available at http://sanctuaries.noaa.gov), are shipping; discharges from the MWRA outfall and dumping at the dredged material disposal site located adjacent to the sanctuary boundary; a fiber-optic cable laid across the sanctuary; the likelihood of development of a deepwater port approximately two miles west of the sanctuary for off-loading of liquefied natural gas; noise pollution that adversely affects marine mammals; commercial fishing; commercial whale watching; recreational fishing and boating; and climate change.

The National Centers for Coastal Ocean Science (NCCOS) recently published an ecological characterization report for the sanctuary (NCCOS 2006; available at http://ccma.nos.noaa.gov/products/biogeography/stellwagen). The report describes the physical and oceanographic setting, chemical contaminants, fishes, seabirds, and mammals in the sanctuary and the Gulf of Maine. The report finds that there has been no indication that the relocation of the MWRA outfall to Massachusetts Bay has exerted any effect on the magnitude of contaminants reaching the sanctuary.

Although these positive findings were anticipated, MWRA's discharge permit requires an annual assessment of possible outfall effects. This section of the outfall monitoring overview is included to meet that requirement.

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 "northern boundary" or "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 water-quality 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. The water-column programs and results for 2006 are described in Libby *et al.* (2007) and Pala and Libby (2007).

Two MWRA sea-floor stations are within the sanctuary, one at the southern boundary and one within Stellwagen Basin (FF04 and FF05, Figure 7-2). 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. Stations FF04 and FF05 were sampled in 2006 (Maciolek *et al.* 2007).

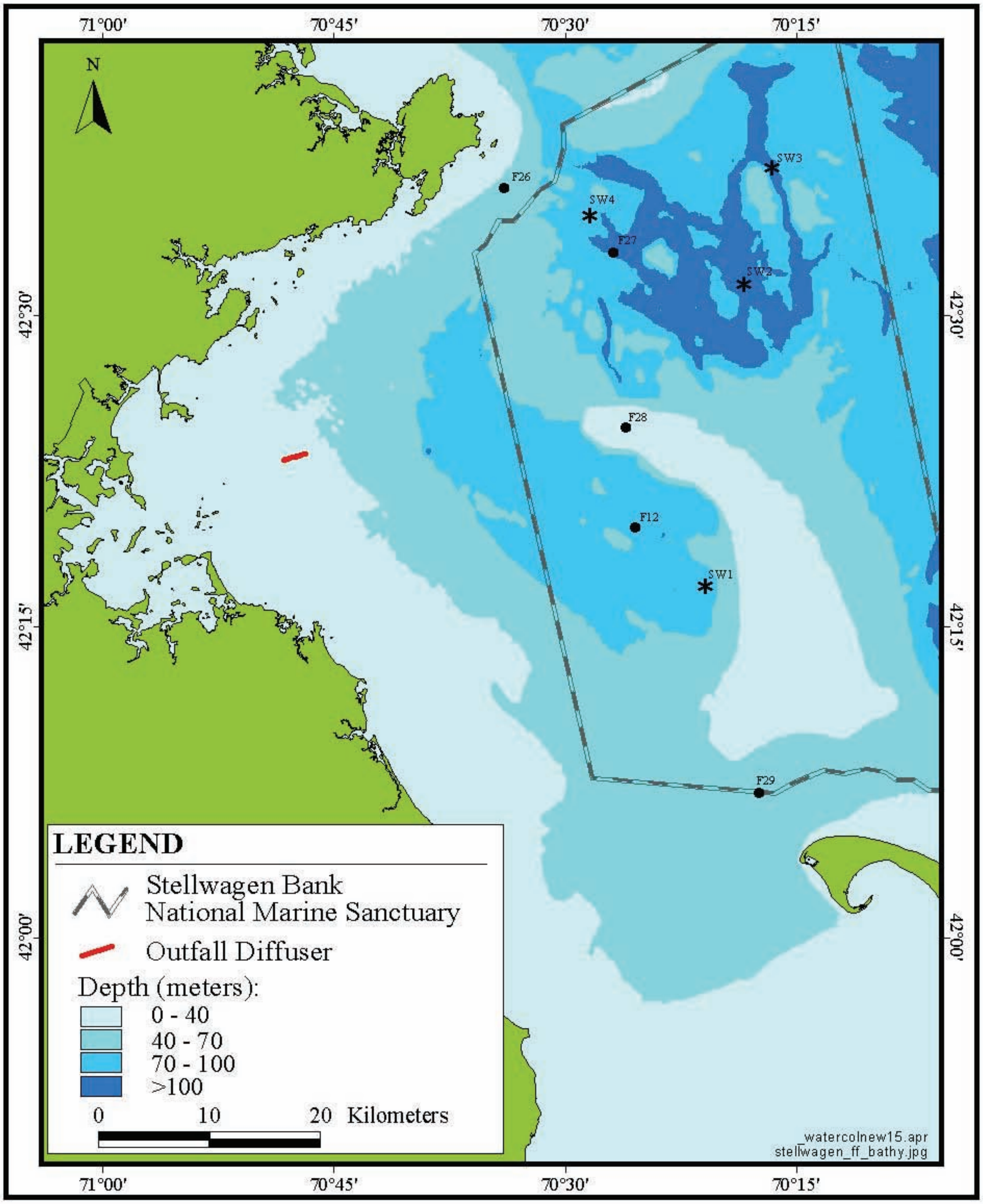


Figure 7-1. Water column stations in and near the Stellwagen Bank National Marine Sanctuary, including MWRA and supplemental stations

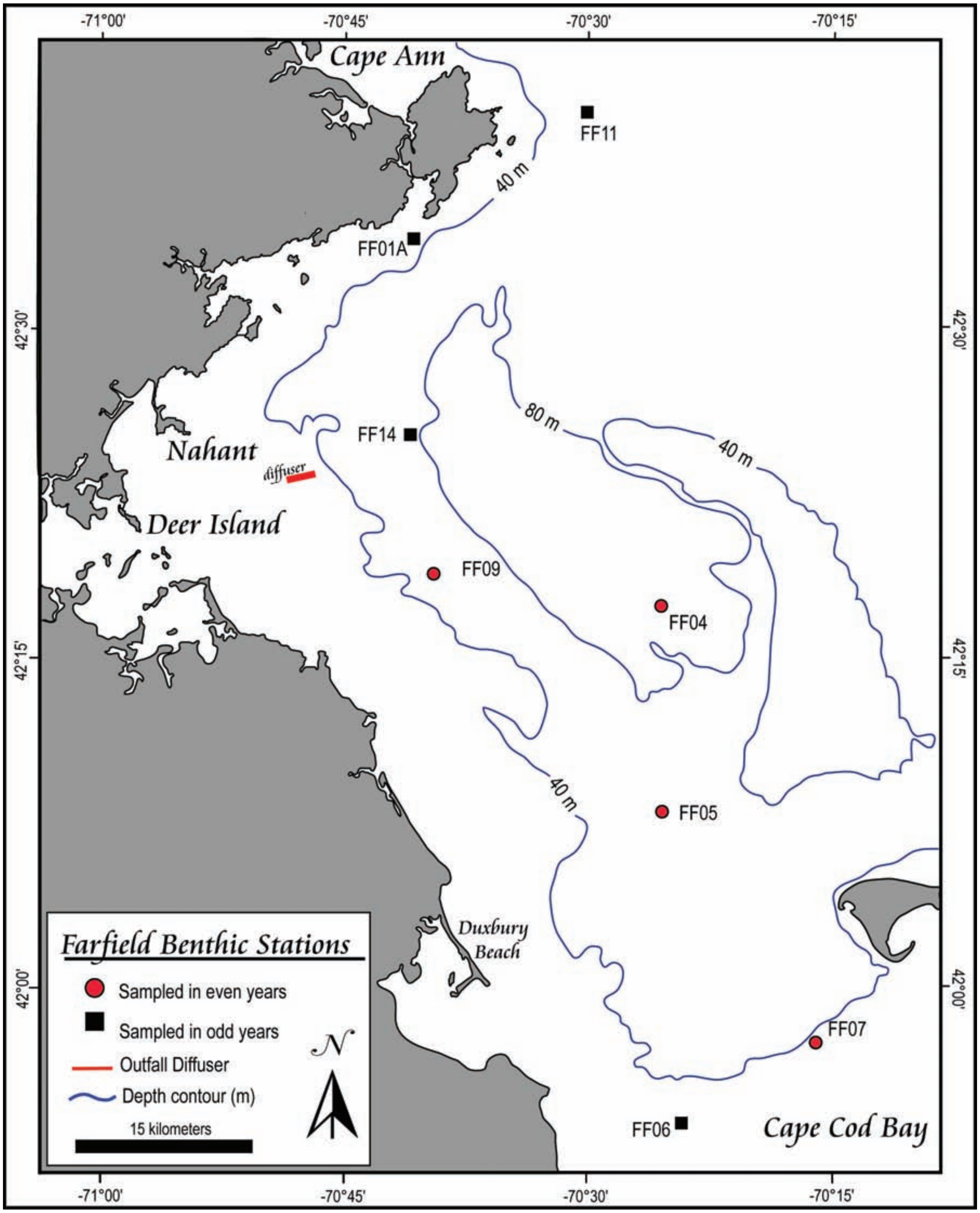


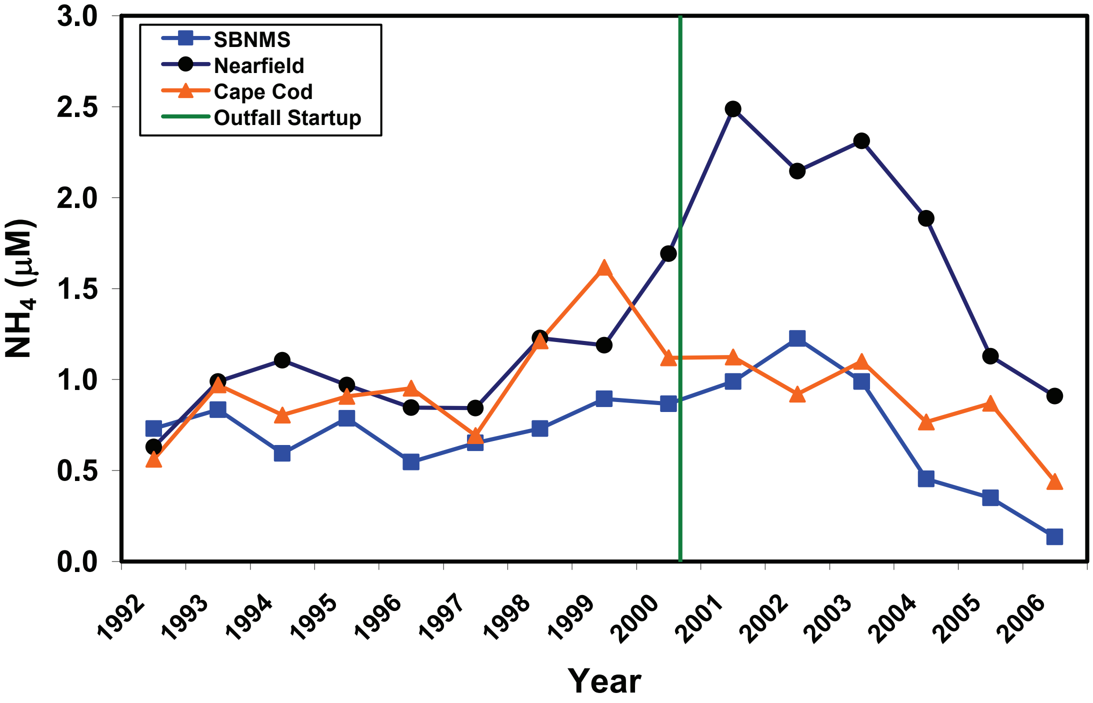
Figure 7-2. Farfield benthic stations (Stations FF04 and FF05 are in or at the border of Stellwagen Bank Marine Sanctuary and were sampled in 2006.)

Results

Water Column

Overall, water quality within the sanctuary is excellent, and the 2007 condition and characterization reports noted that chemical contaminant concentrations are low, that water-quality conditions are favorable for habitat and living resources, and that human activities are not having adverse effects. The 2006 MWRA and supplemental monitoring efforts confirmed those findings. Water quality continued to be good, with dissolved oxygen, nutrient concentrations, and plankton community measures and abundances within expected ranges for this region of Massachusetts Bay. There was no indication of any effect of the MWRA outfall, and the supplemental data collected within the sanctuary were consistent with the data collected from the MWRA stations located within and adjacent to the sanctuary (Libby *et al.* 2007, Pala and Libby 2007).

Annual mean concentrations of nutrients in water samples from the sanctuary have not changed substantially since the outfall began operation. While ammonium concentrations rose in the nearfield following the outfall diversion, they fell to within the pre-discharge range in 2005 and 2006. There was no parallel annual increase in Stellwagen Bank or Cape Cod Bay (Figure 7-3, top). Nitrate concentrations (Figure 7-3, bottom) continue to show a long-term upward trend in offshore Massachusetts Bay and in the nearfield, a regional phenomenon that predates the outfall diversion. The general upward trend is also evident in Cape Cod Bay, although there was a decline in nitrate concentrations in the late 1990s through 2003. Other measurements of nitrogen (Figure 7-4) and dissolved phosphate (not shown) also show long-term trends, unrelated to outfall operation.



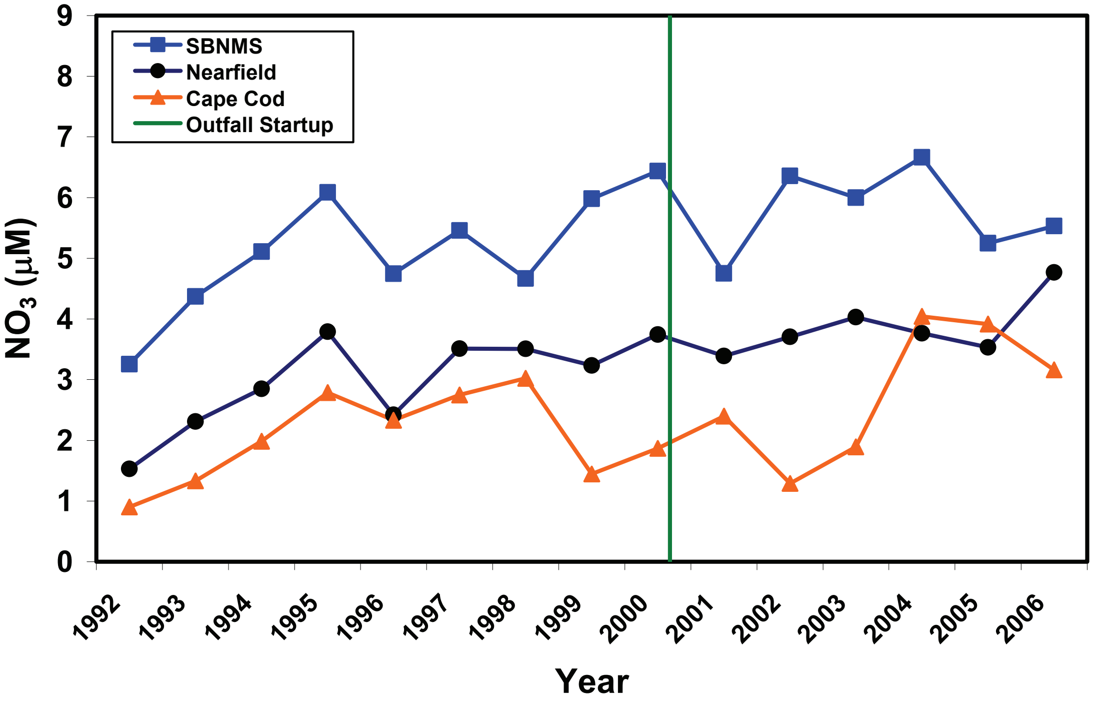


Figure 7-3. Annual mean ammonium (top) and nitrate (bottom) in the Stellwagen Bank National Marine Sanctuary, the nearfield, and Cape Cod Bay

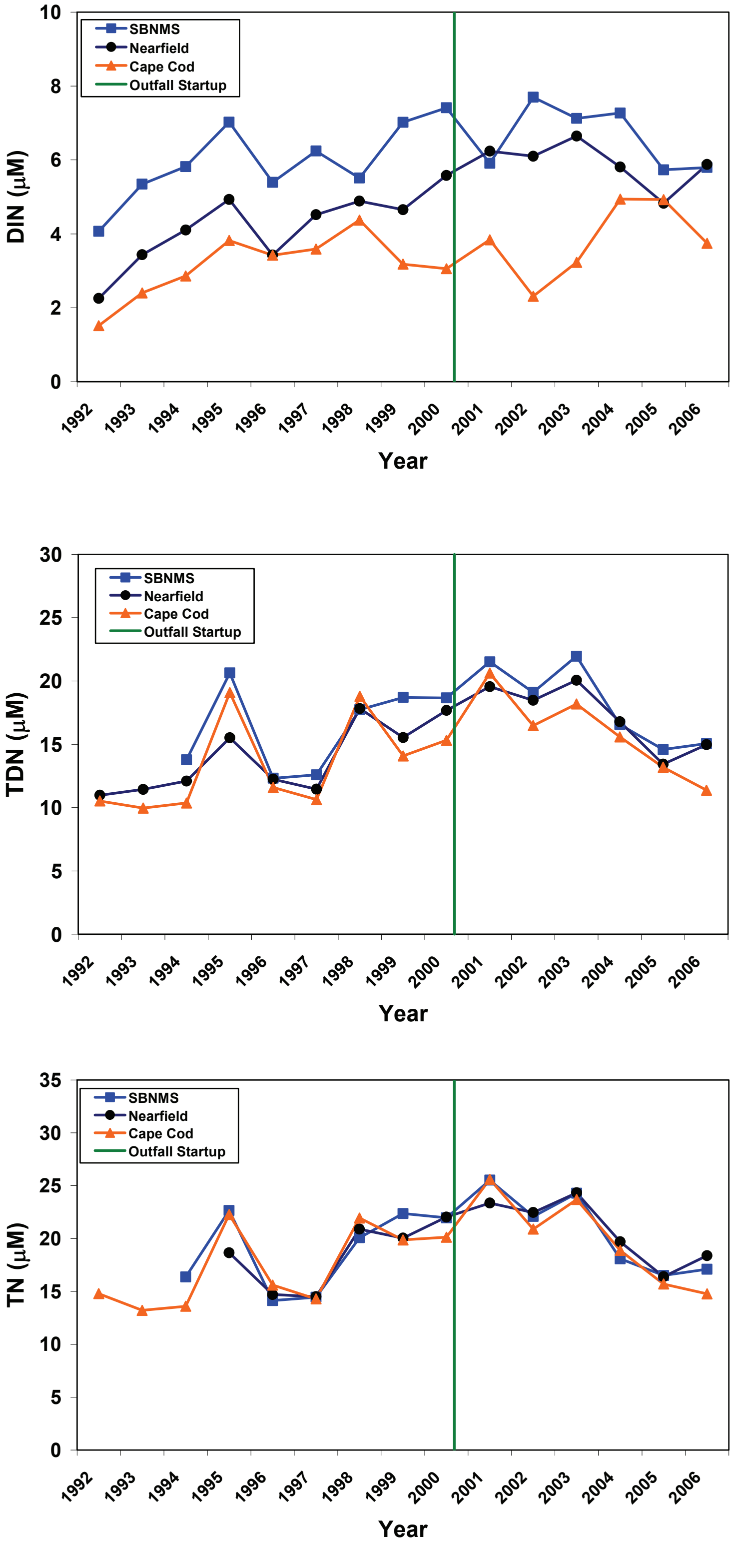
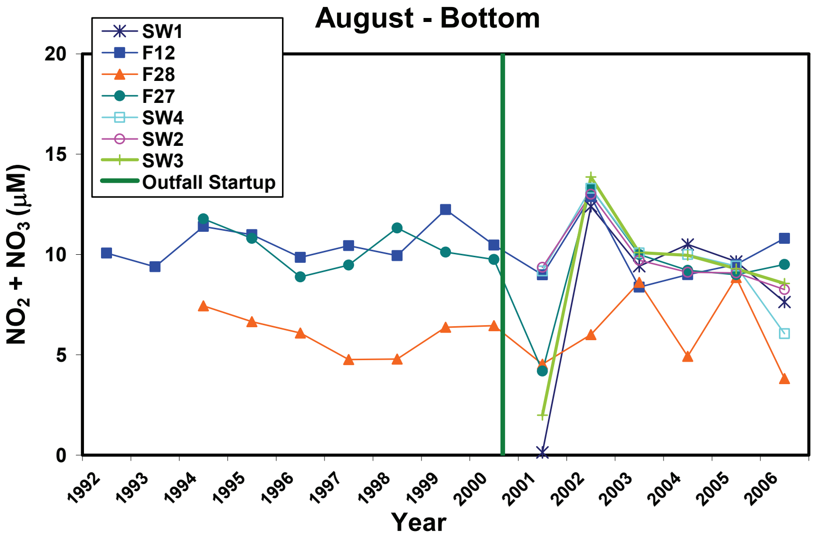


Figure 7-4. Annual mean dissolved inorganic nitrogen (DIN; top), total dissolved nitrogen (TDN; middle), and total nitrogen (TN; bottom) in Stellwagen Bank National Marine Sanctuary, the nearfield, and Cape Cod Bay

Six years of August and October sampling by the sanctuary continue to show that levels of nutrients at individual stations are generally similar, although there is some variation among stations and by year. Much of the variability is explained by variability in specific nutrient species. For example, Station F28, which is located on Stellwagen Bank, typically shows lower concentrations of nitrite plus nitrate in the bottom waters than other stations (Figure 7-5), reflecting the shallow depth of this station rather than any influence of the MWRA outfall.



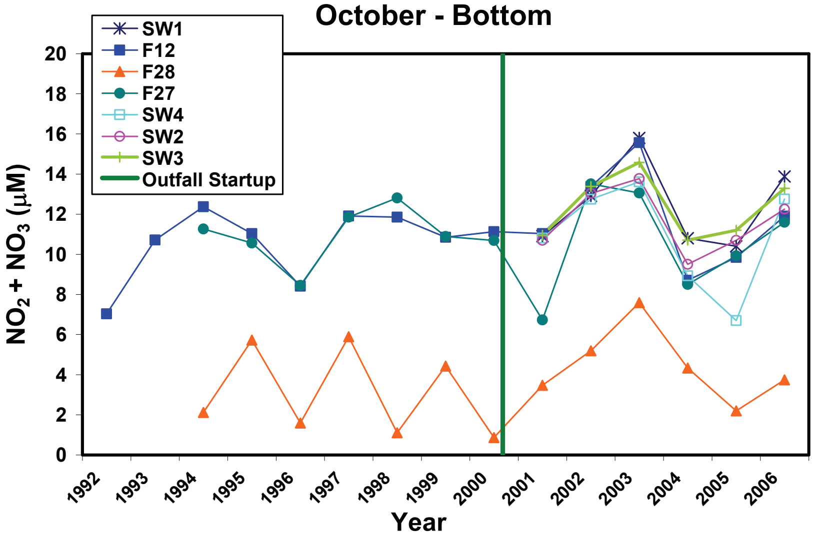


Figure 7-5. Total nitrite plus nitrate in August (top) and October (bottom) bottom waters at individual stations in Stellwagen Bank National Marine Sanctuary

The mean annual chlorophyll levels have not changed in response to the outfall discharge (Figure 7-6). Annual chlorophyll levels were similar in the nearfield, Cape Cod Bay, and Stellwagen Bank.

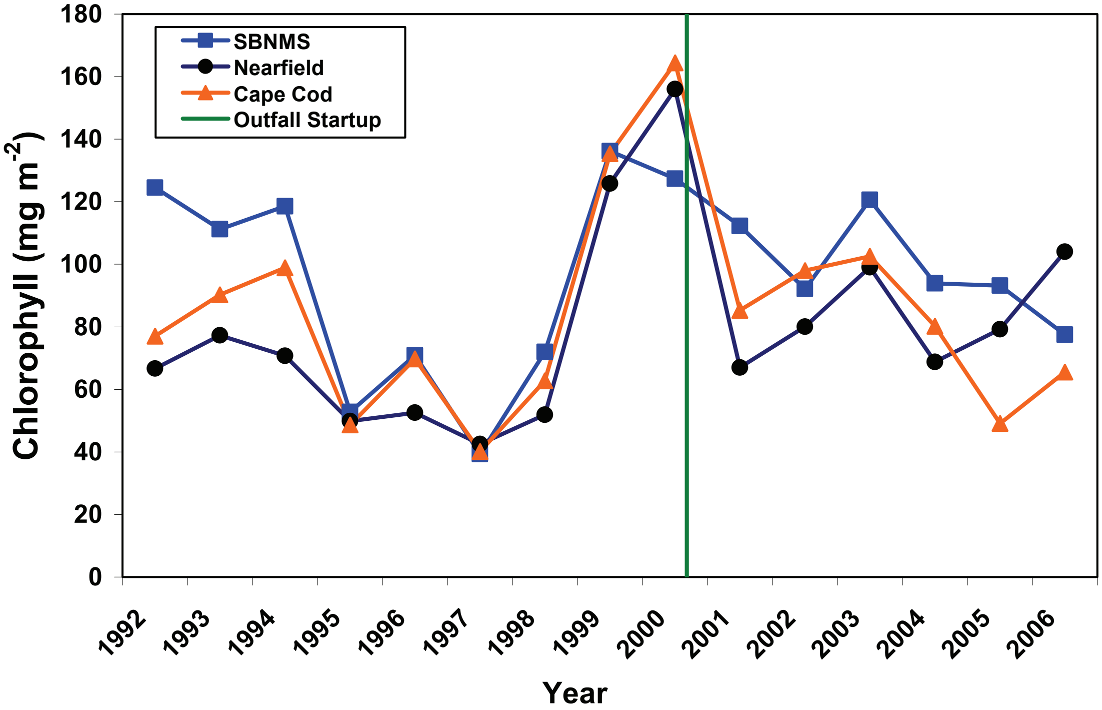


Figure 7-6. Annual mean chlorophyll in Stellwagen Bank National Marine Sanctuary and other regions

As in other years, the MWRA monitoring program documented a spring *Phaeocystis pouchetii* bloom throughout Massachusetts and Cape Cod bays (Libby *et al.* 2007; discussed in Section 3, Water Column). Similar to 2005, a major *Alexandrium* bloom occurred in May and June of 2006, although the 2006 bloom was smaller and of shorter duration (discussed in Section 3, Water Column, and Section 6, Special Studies). No blooms of toxic or harmful phytoplankton species occurred during August through October.

Concentrations of dissolved oxygen and percent saturation have remained unchanged in Stellwagen Basin as well as in the nearfield, although due to physical factors, dissolved oxygen levels were relatively low in 2006. Within 2006 survey dates, concentrations of dissolved oxygen were similar for all sanctuary stations (Figure 7-7).

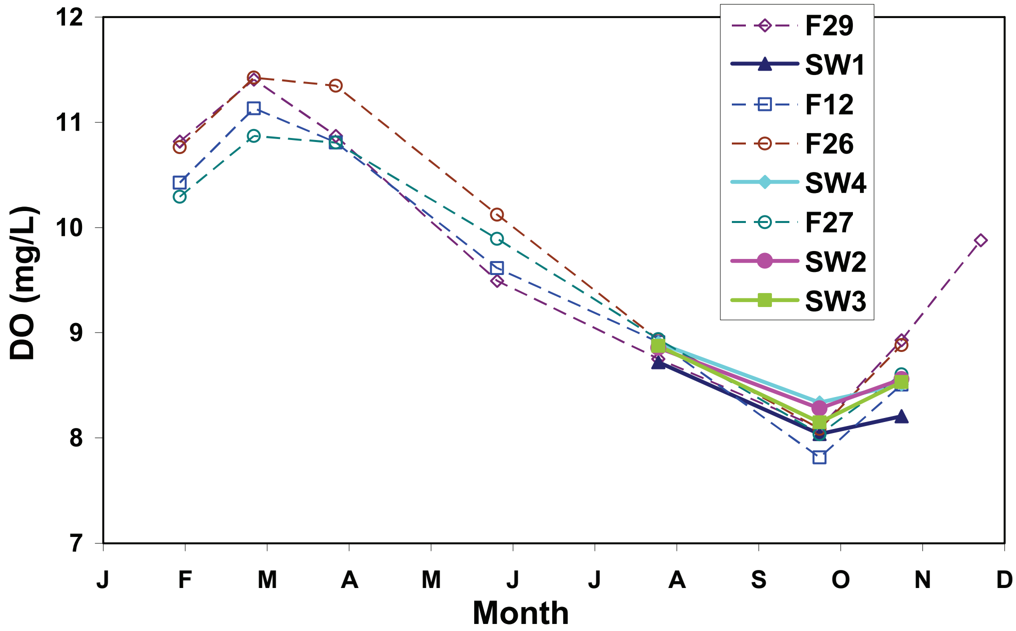


Figure 7-7. 2006 dissolved oxygen concentrations at individual stations within Stellwagen Bank National Marine Sanctuary

Sea Floor

No changes in concentrations of sewage tracers or sewage-related contaminants were observed in the sediment samples from stations within the sanctuary, and there have been no changes in community parameters since the outfall began operation (Maciolek *et al.* 2007).

The deep-water stations sampled in 2006 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 7-8). The numbers of individual organisms and species per sample decreased in 2006, following increases in recent years, paralleling results from throughout Massachusetts Bay. No consistent pattern has been found that relates to outfall operation.

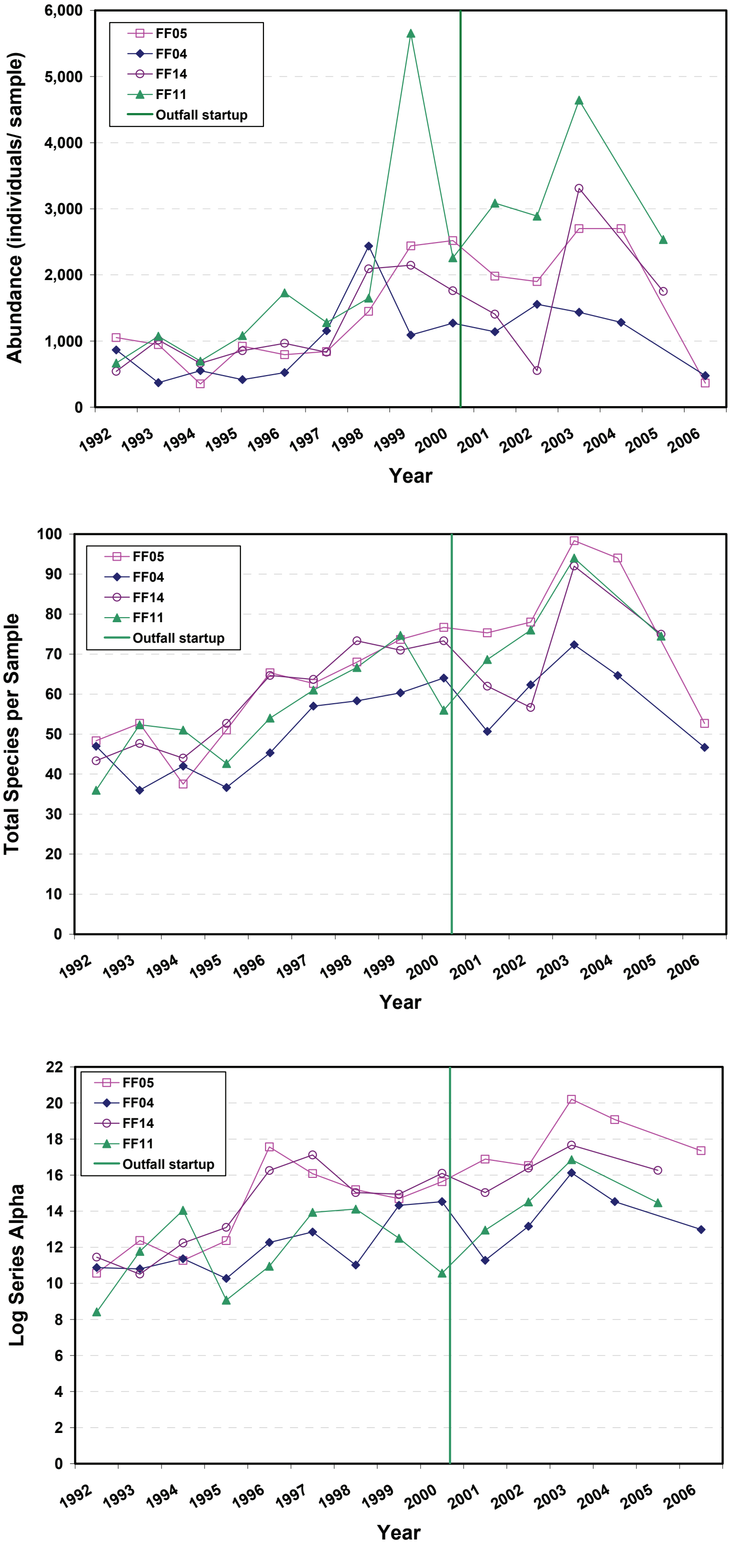


Figure 7-8. Benthic community parameters at stations in or near the Stellwagen Bank National Marine Sanctuary, 1992-2006. (Stations FF05 and FF04 are currently sampled in even years; Stations FF14 and FF11 are sampled in odd years.)

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List of Acronyms

BOD	Biochemical oxygen demand
BS	Broad Sound
cBOD	Carbonaceous biochemical oxygen demand
CCB	Cape Cod Bay
CFU	Colony forming units
CHV	Centrotubular hydropic vacuolation
C-NOEC	Chronic test, no observable effect concentration
CSO	Combined sewer overflow
DDE	Dichlorodiphenylethylene
DDT	Dichlorodiphenyltrichloroethane
DIF	Deer Island Flats
DIN	Dissolved inorganic nitrogen
DO	Dissolved oxygen
DSi	Dissolved silica
DW	Dry weight
ECCB	Eastern Cape Cod Bay
ECOHAB	Ecology of harmful algal blooms
EPA	U.S. Environmental Protection Agency
FDA	U.S. Food and Drug Administration
FA	Foul Area
FF	Farfield
GoMOOS	Gulf of Maine Ocean Observation System
HMW	High molecular weight
IAAC	Inter-agency Advisory Committee
IWS	Industrial Waste Site
LC50	50% mortality concentration
LMW	Low molecular weight
LNG	Liquefied natural gas
MADEP	Massachusetts Department of Environmental Protection
MADMF	Massachusetts Division of Marine Fisheries
MBDS	Massachusetts Bay Disposal Site
MGD	Million gallons per day
MIT	Massachusetts Institute of Technology
NCCOS	National Centers for Coastal Ocean Science
MWRA	Massachusetts Water Resources Authority
NA	Not analyzed/not applicable
NB	Nantasket Beach
ND	Not detected
NERACOOS	Northeastern Regional Association of Coastal Ocean Observing Systems
NF	Nearfield
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
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
PCB	Polychlorinated biphenyl
PPB	Parts per billion
PPM	Parts per million
PIAC	Public Interest Advisory Committee
RPD	Redox potential discontinuity
PSP	Paralytic shellfish poisoning
PSU	Practical salinity units
ROC	Receiver operating characteristic
SBNMS	Stellwagen Bank National Marine Sanctuary
SD	Standard deviation
SEIS	Supplemental Environmental Impact Statement
SOD	Sediment oxygen demand
SPI	Sediment-profile imaging
TDN	Total dissolved nitrogen
TN	Total nitrogen
TOC	Total organic carbon
TRAC	Toxic Reduction and Control Program
TSS	Total suspended solids
USGS	U.S. Geological Survey
WHOI	Woods Hole Oceanographic Institution

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