2003 outfall monitoring overview

Massachusetts Water Resources Authority

Environmental Quality Department
Report ENQUAD 2004-13

Citation:
Werme C, Hunt CD. 2004. 2003 Outfall monitoring overview. Boston: Massachusetts Water Resources Authority. Report ENQUAD 2004-13. 97p.

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Summary

During 2003, the third full year of discharge from the Massachusetts Bay outfall, the Deer Island treatment plant operated as designed, with no detectable negative effects on the ecosystem of Massachusetts and Cape Cod bays. Total loads of many parameters measured within the effluent, including solids and metals, were low. The treatment plant earned the Association of Metropolitan Sewerage Agencies Gold Peak Performance Award for facilities that had no permit violations during the year.

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

There were two contingency plan exceedances during the year (Table 2). As in 2002, summer concentrations of the nuisance algal species *Phaeocystis pouchetii* exceeded the caution level. As has been the case each year since the outfall began operation, concentrations of total polycyclic aromatic hydrocarbons (PAHs) exceeded the caution level for mussels deployed in cages at the outfall. These exceedances have been reviewed and are not considered to indicate environmental problems caused by outfall discharge.

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

During 2003, MWRA completed a review of the monitoring program and revised the monitoring plan to focus it on the potential for long-term chronic effects.

Table 1. Summary of monitoring questions and status as of the end of 2003

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

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

Monitoring Question	Status
How do the sediment oxygen demand, the flux of nutrients from the sediment to the water column, and denitrification influence the levels of oxygen and nitrogen in the water near the outfall?	Described by baseline monitoring; conditions do not suggest adverse changes have resulted from moving outfall offshore.
Have the rates of these processes changed?	No short-term changes.
Has the level of contaminants in the tissues of fish and shellfish around the outfall changed since discharge began?	No short-term changes in flounder or lobster contaminant body burdens. Detectable increases in PAHs and chlordane in mussels deployed at the outfall.
Do the levels of contaminants in the edible tissue of fish and shellfish around the outfall represent a risk to human health?	No short-term changes that would pose a threat to human health.
Are the contaminant levels in fish and shellfish different between the outfall, Boston Harbor, and a reference site?	Differences documented during baseline monitoring. Regional patterns have persisted since the diversion.
Has the incidence of disease and/or abnormalities in fish or shellfish changed?	Blind-side skin lesions were found on flounder collected in 2003. No changes in liver disease.

Table 2. Summary of contingency plan thresholds and exceedances as of 2003. (NA = not applicable, ✓ = no exceedance, **C** *= caution level exceedance,* **W** *= warning level exceedance)*

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

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

1. Introduction

Background

Since its creation in 1985, the Massachusetts Water Resources Authority (MWRA) has worked to end long-standing violations of the Clean Water Act and to minimize the effects of wastewater discharge on the marine environment. In 1991, MWRA ended discharge of municipal sludge into Boston Harbor. Steps to minimize effects of effluent discharge have included source reduction to prevent pollutants from entering the waste stream, improved treatment before discharge, and better dilution once the effluent enters the marine environment.

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

Improved treatment began in 1995, when a new primary treatment plant at Deer Island was brought on line, and disinfection facilities were completed. (Primary treatment involves removal of solids through settlement and disinfection.) The first and second batteries of secondary treatment (which includes bacterial decomposition as well as settlement and disinfection) went on line in 1997 and 1998. 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. A final battery of secondary treatment became operational in 2001.

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

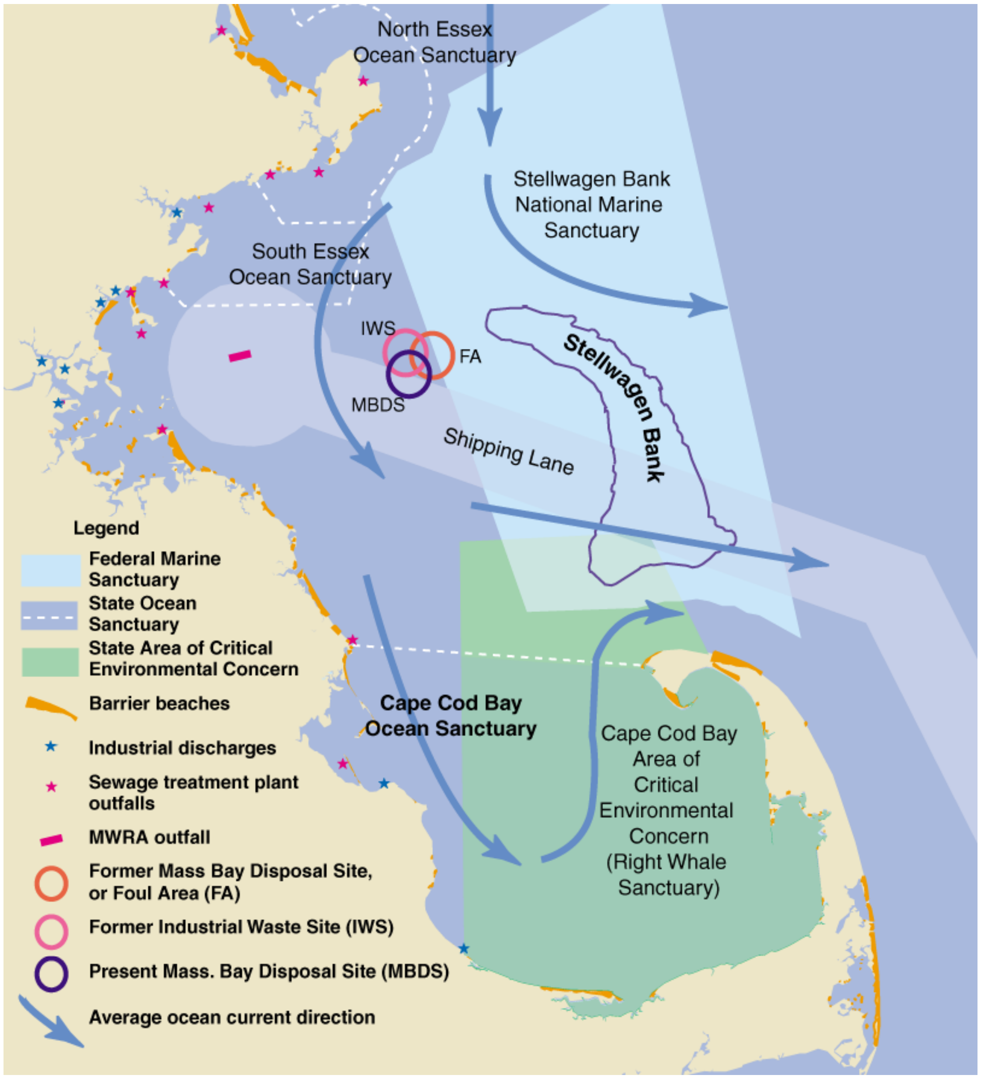


Figure 1-1. Map of Massachusetts and Cape Cod bays

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 5 times that of the Boston Harbor outfall, which was shallower, in 50 feet of water. The offshore location of the outfall diffuser ensures that effluent will not reach beaches or shellfish beds within a tidal cycle, even if currents are shoreward.

For many of the components of MWRA's work, there was little or no argument that the project benefited the marine environment and the people of the region. One aspect of the project, moving the effluent outfall from the harbor to Massachusetts Bay, raised some concerns, which were expressed as general 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 joint permit for the outfall issued by the U.S. Environmental Protection Agency (EPA) and the Massachusetts Department of Environmental Protection (MADEP).

Outfall Permit

The permit issued by EPA and MADEP under the National Pollutant Discharge Elimination System (NPDES) became effective on August 9, 2000. It limits discharges of pollutants and requires reporting on the treatment plant operation and maintenance. The permit requires MWRA to continue its ongoing pollution prevention program, which encompasses industrial, commercial, and residential users of the system, 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) developed in response to the EPA Supplemental Environmental Impact Statement (SEIS, EPA 1988). The permit requires MWRA to update, maintain, and run the three-dimensional Bays Eutrophication Model and to measure the dilution at the discharge. It requires that MWRA implement a contingency plan (MWRA 1997b, 2001), which identifies relevant environmental quality parameters and thresholds, which, if exceeded, would require a response.

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

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

Table 1-1. Roster of panel and committee members

<table>
<tr><td colspan="2">OMSAP as of December 2003
Andrew Solow, Woods Hole Oceanographic Institution (chair)
Robert Beardsley, Woods Hole Oceanographic Institution
Norbert Jaworski, retired
Robert Kenney, University of Rhode Island
Scott Nixon, University of Rhode Island
Judy Pederson, MIT Sea Grant
Michael Shiaris, University of Massachusetts, Boston
James Shine, Harvard School of Public Health
Juanita Urban-Rich, University of Massachusetts, Boston
Catherine Coniaris, MA Department of Environmental Protection (OMSAP staff)
Winifred Donnolly, MA Department of Environmental Protection (staff)</td></tr>
<tr><td>IAAC as of December 2003
MA Coastal Zone Management
Todd Callaghan
Jan Smith (alternate)
MA Department of Environmental Protection
Russell Isaac
Catherine Coniaris
MA Division of Marine Fisheries
Jack Schwartz
James Fair (alternate)
National Marine Fisheries Service
David Dow
Stellwagen Bank National Marine Sanctuary
Ben Haskell
US Army Corps of Engineers
Thomas Fredette
US Environmental Protection Agency
Matthew Liebman
US Geological Survey
Michael Bothner</td><td>PIAC as of December 2003
Patty Foley (chair, representative of Save the Harbor/Save the Bay)
Association for the Preservation of Cape Cod
Maggie Geist
Tara Nye (alternate)
Bays Legal Fund
Wayne Bergeron
The Boston Harbor Association
Vivian Li
Cape Cod Commission
John Lipman
Steve Tucker (alternate)
Center for Coastal Studies
Peter Borrelli
Conservation Law Foundation
Priscilla Brooks
New England Aquarium
Marianne Farrington
Massachusetts Audubon Society
Robert Buchsbaum
MWRA Advisory Board
Joseph Favaloro
Safer Waters in Massachusetts
Salvatore Genovese
Polly Bradley (alternate)
Save the Harbor/Save the Bay
Bruce Berman (alternate)
Wastewater Advisory Committee
Edward Bretschneider</td></tr>
</table>

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 by MWRA, 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 in 1998.)

The outfall ambient monitoring plan expands the general questions of public concern by translating them into possible "environmental responses" to the outfall (Table 1-2). To answer those questions, the monitoring program focuses on critical constituents in 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).

Table 1-2. Public concerns and possible environmental responses (MWRA 1991)

Public Concern: Is it safe to eat fish and shellfish?

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

Public Concern: Are natural/living resources protected?

- Will nutrient enrichment in the water column contribute to an increase in primary production?
- Will enrichment of organic matter contribute to an increase in benthic respiration and nutrient flux to the water column?
- Will increased water-column and benthic respiration contribute to depressed oxygen levels in the water?
- Will increased water-column and benthic respiration contribute to depressed oxygen levels in the sediment?
- Will nutrient enrichment in the water column contribute to changes in plankton community structure? (Such changes could include stimulation of nuisance or noxious algal blooms and could affect fisheries.)
- Will benthic enrichment contribute to changes in community structure of soft-bottom and hard-bottom macrofauna, possibly also affecting fisheries?
- Will the water column near the diffuser mixing zone have elevated levels of some contaminants?
- Will contaminants affect some size classes or species of plankton and thereby contribute to changes in community structure and/or the marine food web?
- Will finfish and shellfish that live near or migrate by the diffuser be exposed to elevated levels of some contaminants, potentially contributing to adverse health in some populations?
- Will the benthos near the outfall mixing zone and in depositional areas farther away accumulate some contaminants?
- Will benthic macrofauna near the outfall mixing zone be exposed to some contaminants, potentially contributing to changes in community structure?

Public Concern: Is it safe to swim?

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

Public Concern: Are aesthetics being maintained?

- Will changes in water clarity and/or color result from the direct input of effluent particles or other colored constituents, or indirectly through nutrient stimulation of nuisance plankton species?
- Will the loading of floatable debris increase, contributing to visible degradation?

Table 1-3. Summary of the monitoring program

Task	Objective	Sampling Locations And Schedule	Analyses
Effluent			
Effluent sampling	Characterize wastewater discharge from Deer Island Treatment Plant	Monthly	Toxicity
		Weekly	Nutrients
		Daily	Organic material (cBOD)
		Several times monthly	Toxic contaminants
		3x/day	Bacterial indicators, total chlorine residual
		Daily	Solids
Water Column			
Nearfield surveys	Collect water quality data near outfall location	17 surveys/year 21 stations	Temperature Salinity Dissolved oxygen Nutrients Solids Chlorophyll Water clarity Photosynthesis Respiration Plankton Marine mammal observations
Farfield surveys	Collect water quality data throughout Massachusetts and Cape Cod bays	6 surveys/year 26 stations	
Moorings (GoMOOS and USGS)	GoMOOS near Cape Ann and USGS near outfall provide continuous oceanographic data near outfall location	Continuous monitoring GoMOOS at one location USGS at two locations 3 depths	Currents Temperature Salinity Water clarity Chlorophyll
Remote sensing	Provides oceanographic data on a regional scale through satellite imagery	Available daily (cloud-cover permitting)	Surface temperature Chlorophyll
Sea Floor			
Soft-bottom studies	Evaluate sediment quality and benthos in Boston Harbor and Massachusetts Bay	1 survey/year 20 nearfield stations 11 farfield stations	Sediment chemistry Sediment profile imagery Community composition
Hard-bottom studies	Characterize marine benthic communities in rock and cobble areas	1 survey/year 21 stations on 6 transects	Topography Substrate Community composition
Fish and Shellfish			
Winter flounder	Determine contaminant body burden and population health	1 survey/year 5 locations	Tissue contaminant concentrations Physical abnormalities, including liver histopathology
American lobster	Determine contaminant body burden	1 survey/year 3 locations	Tissue contaminant concentrations Physical abnormalities
Blue mussel	Evaluate biological condition and potential contaminant bioaccumulation	1 survey/year 4 locations	Tissue contaminant concentrations

The basic program is augmented by special studies, which are conducted in response to specific permit requirements, scientific questions, and environmental concerns. The monitoring program is designed to compare environmental quality of the Massachusetts Bay system, including Boston Harbor and Cape Cod Bay, before and after the outfall location moved from the harbor to the bay.

Baseline monitoring was initially planned to last for a minimum of three years, as the outfall was originally planned for completion in 1995. Delays in outfall 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 response in Boston Harbor to other facilities improvements (*e.g.*, Leo *et al.* 1995, Pawlowski *et al.* 1996, Rex and Connor 1997, Rex 2000, Rex *et al.* 2002, Taylor 2002, 2003). 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.

Because monitoring had found no unexpected changes to the system after the outfall began operation, extensive changes to the plan were proposed during 2003. A new plan (MWRA 2004), which was accepted by OMSAP and incorporated changes approved by EPA and MADEP, will be implemented in the 2004 monitoring year. Details of that plan are presented in Section 8 of this report.

Contingency Plan

The MWRA contingency plan (MWRA 1997b, 2001, and available at www.mwra.com) describes how, if monitoring results indicate a possible environmental problem, MWRA and the regulatory agencies will respond to determine the cause of the problem and to specify the corrective actions that should be taken if the problem appears to be related to the discharge. The contingency plan identifies the parameters that represent environmentally significant components of the effluent or the ecosystem 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.

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

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

Table 1-4. Contingency plan threshold parameters

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

Every effort is made to incorporate new scientific information and improved understanding resulting from the monitoring program into appropriate thresholds. A process for modifying the contingency plan is set forth in MWRA’s NPDES permit. Revision 1 to the contingency plan was approved during 2001.

Data Management

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

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

Reporting

MWRA's NPDES permit requires regular reports on effluent quality and extensive reporting on the monitoring program. A variety of reports are submitted to OMSAP for review (Table 1-5). Changes to the monitoring program or contingency plan must be reviewed by regulators and published in the *Environmental Monitor*. Data that exceed contingency plan thresholds, and corrective actions, must also be reported. Data that exceed thresholds must be reported within five days after the results become available, and MWRA must make all reasonable efforts to report all data within 90 days of each sampling event.

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

Table 1-5. List of monitoring reports submitted to OMSAP

Report	Description/Objectives
Outfall Monitoring Plan Phase I—Baseline Studies (MWRA 1991) Phase II—Discharge Ambient Monitoring (MWRA 1997a, 2004)	Discusses goals, strategy, and design of baseline and discharge monitoring programs.
Contingency Plan (MWRA 1997b, 2001)	Describes development of threshold parameters and values and MWRA's planned contingency measures.
Program Area Synthesis Reports	Summarize, interpret, and explain annual results for effluent, water column, benthos, and fish and shellfish monitoring areas.
Special Studies Reports	Discuss, analyze, and cross-synthesize data related to specific issues in Massachusetts and Cape Cod bays.
Outfall Monitoring Overviews	Summarize monitoring data and include information relevant to the contingency plan.

Outfall Monitoring Overview

Among the many reports that MWRA completes, this report, the Outfall Monitoring Overview, has been prepared for most baseline-monitoring years and for each year that the permit has been in place (Gayla *et al.*1996, 1997a, 1997b, Werme and Hunt 2000a, 2000b, 2001, 2002, 2003). The report includes a scientific summary for the year of monitoring. Overviews for 1995-1999 included only baseline information. With the outfall operational, subsequent reports have included information relevant to the contingency plan, such as data that exceed thresholds, responses, and corrective activities. 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 2003. It compares all results to contingency plan thresholds. The overview also includes a section on data relevant to the Stellwagen Bank National Marine Sanctuary. This year's report also contains a section on revisions to the monitoring plan.

2. Effluent

Background

Pollution Prevention and Wastewater Treatment

Ensuring that the final treated effluent is as clean as possible 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 the cleanest possible effluent through a vigorous pretreatment program and by maintaining and operating the treatment plant well.

The MWRA Toxic Reduction and Control Program sets and enforces limits on the types and amounts of pollutants that industries can discharge into the sewer system. The program minimizes the contaminants present in the effluent and in the sludge (which is removed during treatment). In addition to regulating industrial discharges, MWRA has implemented programs to reduce mercury from dental facilities and to educate the public about proper disposal of hazardous wastes.

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 compounds, and about 20% of the nitrogen from the influent.

To mitigate accidental discharge of pollutants to the system, MWRA has implemented best management practice plans for the treatment plant, its headworks facilities, the combined sewer overflow facilities, and the sludge pelletizing 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 set limits on these contaminants so as to ensure that these attributes will be protected. Several specific questions in the MWRA ambient monitoring plan respond to public concerns and possible environmental responses by addressing whether the effluent is meeting permit limits (Table 2-1). Other questions require the use of effluent data in conjunction with plume studies (Hunt *et al.* 2002a, 2002b) and water column monitoring (see Section 3, Water Column).

Table 2-1. Monitoring questions related to effluent monitoring

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

The effluent constituents of greatest concern include pathogens, toxic contaminants, organic material, solid material, nutrients, oil and grease, and "floatables," including plastic and other debris, and 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 of marine organisms. Some toxic contaminants can accumulate in marine

life, potentially affecting human health through seafood consumption.

- **Organic material**, a major constituent of sewage, consumes oxygen as it decays. Even under natural conditions, oxygen levels decline in bottom waters during the late summer, so any effluent component that might further decrease oxygen levels is a concern. Too much organic material could also disrupt sea floor communities.
- **Suspended solids**, small particles in the water column, decrease water clarity and consequently affect growth and productivity of algae and other marine plants. Excess suspended solids also detract from people's aesthetic perception of the environment.
- In marine waters, nitrogen is the limiting **nutrient** that controls growth of algae and other aquatic plants. Excess nitrogen can be detrimental, leading to eutrophication and low levels of dissolved oxygen, excess turbidity, and nuisance algal blooms. Nutrients, particularly dissolved forms, are the only components of sewage entering the treatment plant that are not substantially reduced by secondary treatment.
- **Oil and grease** slicks and floating debris known as **floatables** pose aesthetic concerns. Plastic debris can also be harmful to marine life, as plastic bags are sometimes mistaken for food and clog the digestive systems of turtles and marine mammals. Plastic and other debris can also entangle animals and cause them to drown.
- Sewage effluent is disinfected by addition of a form of **chlorine**, sodium hypochlorite, which is the active ingredient in bleach. Unfortunately, while sodium hypochlorite is effective in destroying pathogens, at high enough concentrations, it is also harmful to marine life. 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. Consequently, the outfall permit sets both upper and lower values for pH of the effluent.

Monitoring Design

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

The permit includes numeric limits (Table 2-2) for suspended solids, fecal coliform bacteria, pH, chlorine, PCBs, and carbonaceous biochemical oxygen demand (cBOD). In addition, state water quality standards establish limits for 158 pollutants, and the permit prohibits any discharge that would cause or contribute to exceeding any of those limits. The permit also prohibits discharge of nutrients in amounts that would cause eutrophication. The permit requires MWRA to test the toxicity of the effluent as a whole on sensitive organisms and establishes limits based on the tests. Allowable concentrations of contaminants were based on the predicted dilution at the outfall, which was verified in the field during 2001.

Table 2-2. Reporting requirements of the outfall permit

Parameter	Sample Type	Frequency	Limit
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 chlorine residual	Grab	3/day	631 ug/l daily 456 ug/l monthly
PCB, Aroclors	24-hr composite	1/month	0.045 ng/l
Toxicity LC50	24-hr composite	2/month	50%
Toxicity C-NOEC	24-hr composite	2/month	1.5%
Settleable solids	Grab	1/day	Report only
Chlorides (influent only)	Grab	1/day	
Mercury	24-hr composite	1/month	
Chlordane	24-hr composite	1/month	
4,4' – DDT	24-hr composite	1/month	
Dieldrin	24-hr composite	1/month	
Heptachlor	24-hr composite	1/month	
Ammonia-nitrogen	24-hr composite	1/month	
Total Kjeldahl nitrogen	24-hr composite	1/month	
Total nitrate	24-hr composite	1/month	
Total nitrite	24-hr composite	1/month	
Cyanide, total	Grab	1/month	
Copper, total	24-hr composite	1/month	
Total arsenic	24-hr composite	1/month	
Hexachlorobenzene	24-hr composite	1/month	
Aldrin	24-hr composite	1/month	
Heptachlor epoxide	24-hr composite	1/month	
Total PCBs	24-hr composite	1/month	
Volatile organic compounds	Grab	1/month	

Most parameters are measured in 24-hour composite samples, and some must meet daily, weekly, or monthly limits (Table 2-3). Flow is measured continuously. Nutrient measurements include total Kjeldahl nitrogen, ammonia, nitrate, and nitrite. Organic material is monitored by measuring the cBOD. Monitoring for toxic contaminants includes analyses for heavy metals of concern, chlorinated pesticides, PCBs, volatile organic compounds, PAHs, total residual chlorine, and cyanide. Toxicity is tested using whole effluent samples. Tests for acute toxicity include 48-hour survival of mysid shrimp (*Americamysis bahia*, formerly known as *Mysidopsis bahia*) and inland silverside fish (*Menidia beryllina*). Chronic toxicity is assessed through inland silverside growth-and-survival and sea urchin (*Arbacia punctulata*) one-hour-fertilization tests. Pathogen monitoring consists of enumeration of fecal coliform bacteria. Total suspended solids (TSS) and settleable solids are also measured.

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

Table 2-3. Monitoring plan parameters for effluent

Parameter	Sample Type	Frequency
NUTRIENTS		
Total Kjeldahl nitrogen	Composite	Weekly
Ammonia	Composite	Weekly
Nitrate	Composite	Weekly
Nitrite	Composite	Weekly
Total phosphorus	Composite	Weekly
Total phosphate	Composite	Weekly
Acid base neutrals	Composite	Bimonthly
Volatile organic compounds	Grab	Bimonthly
LOW-DETECTION-LIMIT ANALYSES		
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

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. 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.

Results

Average daily flow of effluent from the Deer Island treatment plant in 2003 was greater than in 1999-2002, due to rain in the spring and fall (Figure 2-1). Approximately 95% of the flow received secondary treatment.

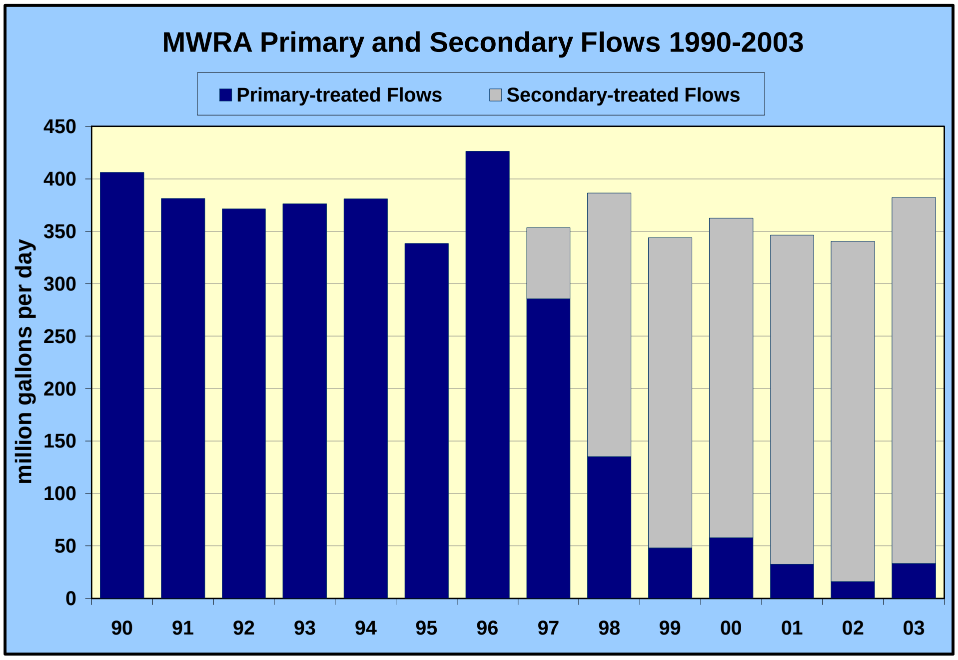


Figure 2-1. Annual effluent flow

Nitrogen loads decreased slightly in 2003 (Figure 2-2, top). For other parameters, the increased flow meant increased total loads. Solids (Figure 2-2, bottom) loads were at approximately the same levels they had been in 1999, slightly higher than in 2001 and 2002.

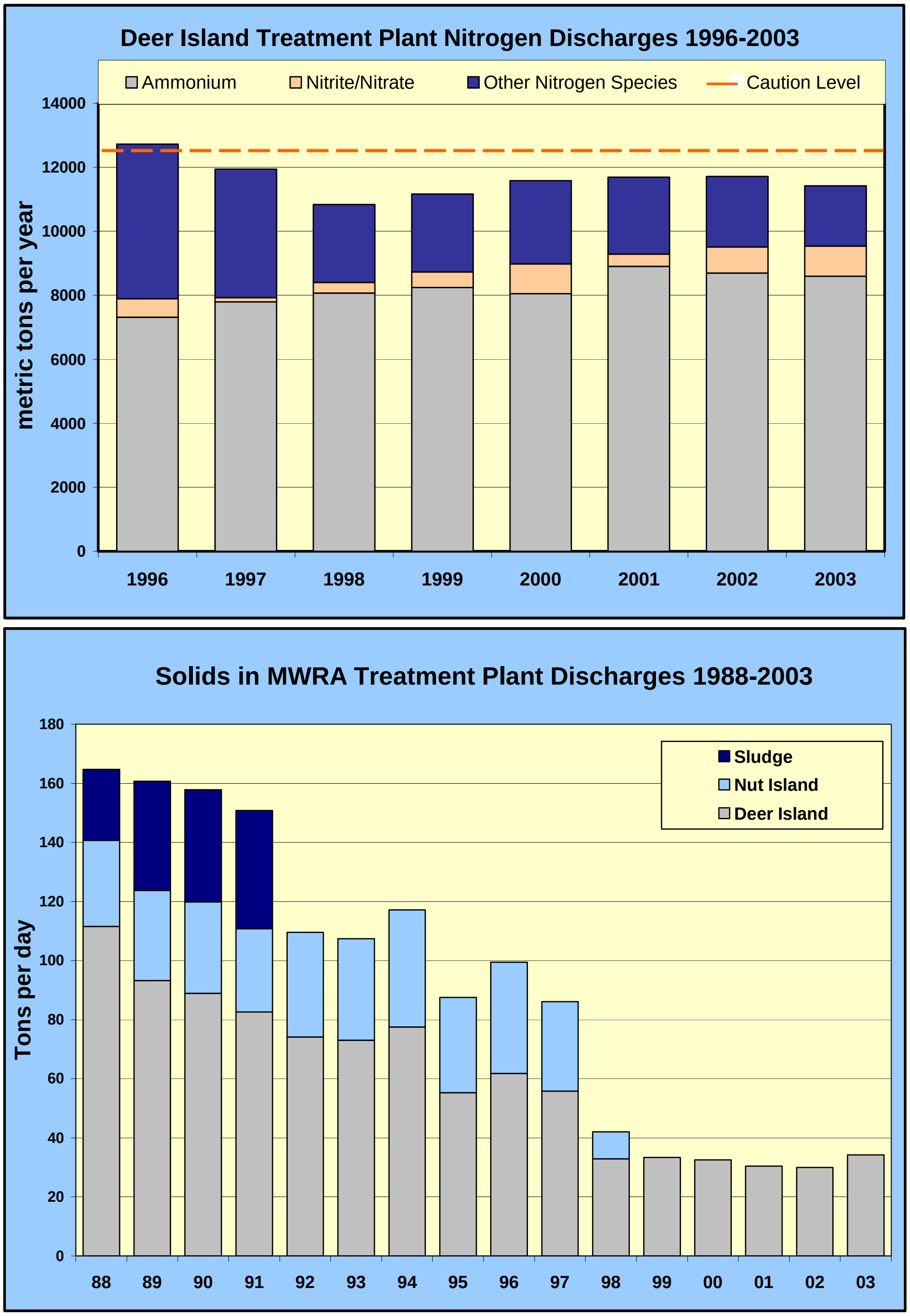


Figure 2-2. Annual nitrogen and solids discharges

Similarly, metals loads were slightly higher in 2003 than in 2001 and 2002, reflecting the increased flow (Figure 2-3, top). Overall, toxic compound concentrations have decreased with increased levels of secondary treatment (for example, mercury in Figure 2-3, bottom).

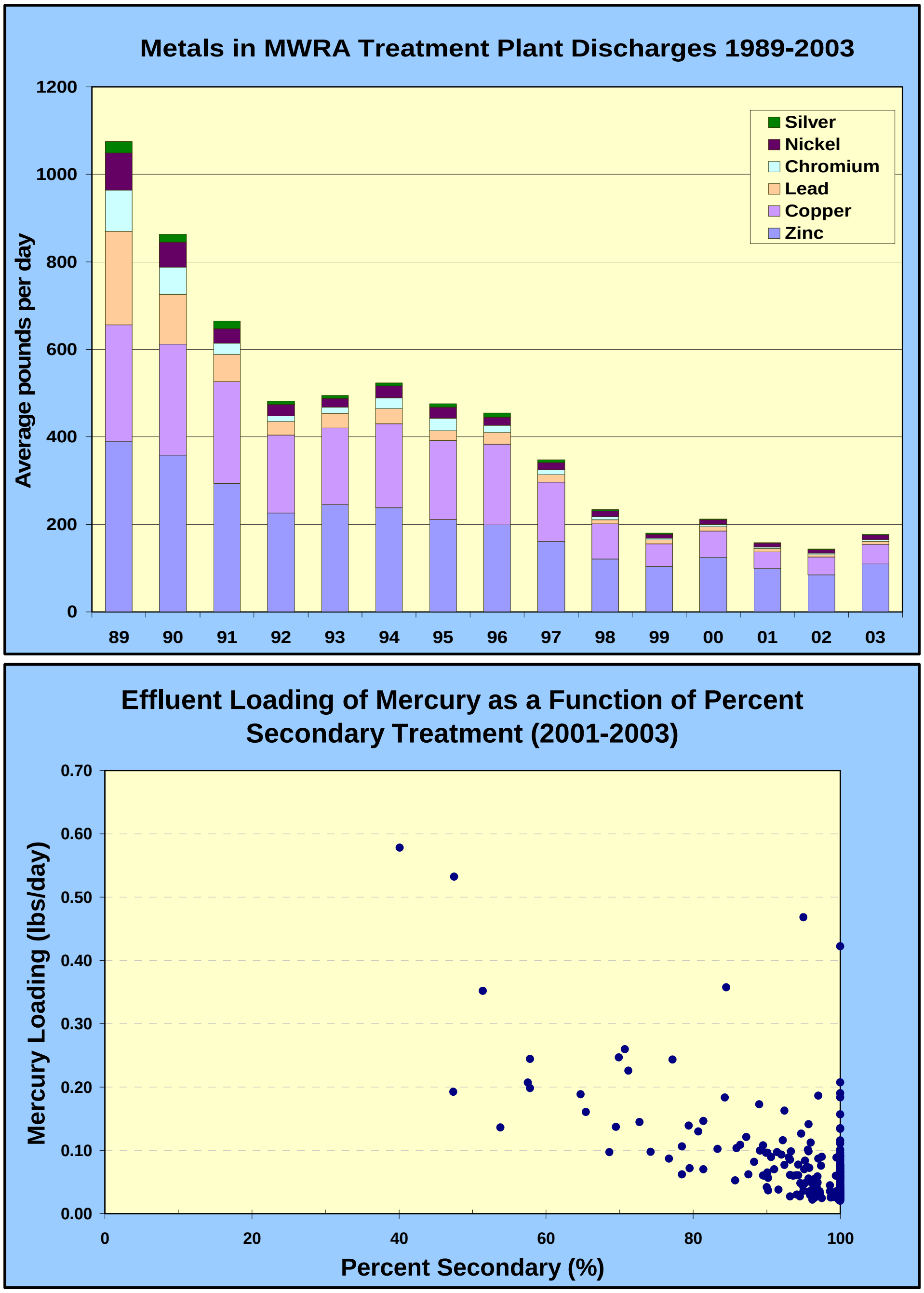


Figure 2-3. Top: Annual metals load; Bottom: mercury loads as a function of amount of secondary treatment.

The total chlorine residual also remained low, as it has since the new outfall began operation and dechlorination of the disinfected effluent began (Figure 2-4).

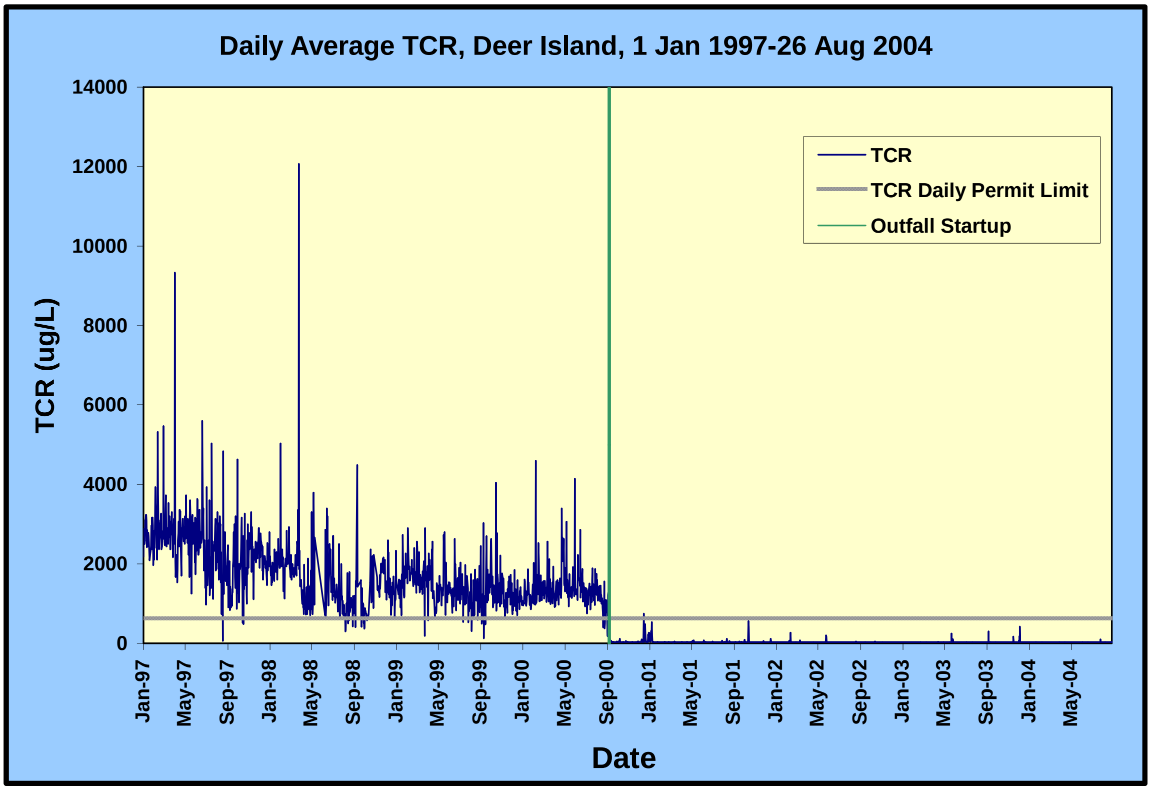


Figure 2-4. Total chlorine residual (TCR), 1997-2004

Contingency Plan Thresholds

The Deer Island Treatment Plant had no permit violations during 2003 (Table 2-5), qualifying it for the Association of Metropolitan Sewerage Agencies Gold Peak Performance Award, an award honoring member agencies that consistently meet all NPDES permit limits during a calendar year.

Table 2-4. Contingency plan threshold values and 2003 results for effluent monitoring

Parameter	Caution Level	Warning Level	2003 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 ug/l daily, 456 ug/l monthly	Not exceeded
Total suspended solids	None	45 mg/l weekly 30 mg/l monthly	Not exceeded
cBOD	None	40 mg/l weekly, 25 mg/l monthly	Not exceeded
Toxicity	None	Acute: effluent LC50<50% for shrimp and fish Chronic: effluent NOEC for fish survival and growth and sea urchin fertilization <1.5% effluent	Not exceeded
PCBs	Aroclor=0.045 ng/l		Not exceeded
Plant performance	5 violations/year	Noncompliance >5% of the time	Not exceeded
Flow	None	Flow >436 for annual average of dry days	Not exceeded
Total nitrogen load	12,500 mtons/year	14,000 mtons/year	Not exceeded
Floatables			Threshold pending
Oil and grease	None	15 mg/l weekly	Not exceeded

3. Water Column

Background

Circulation and Water Properties

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

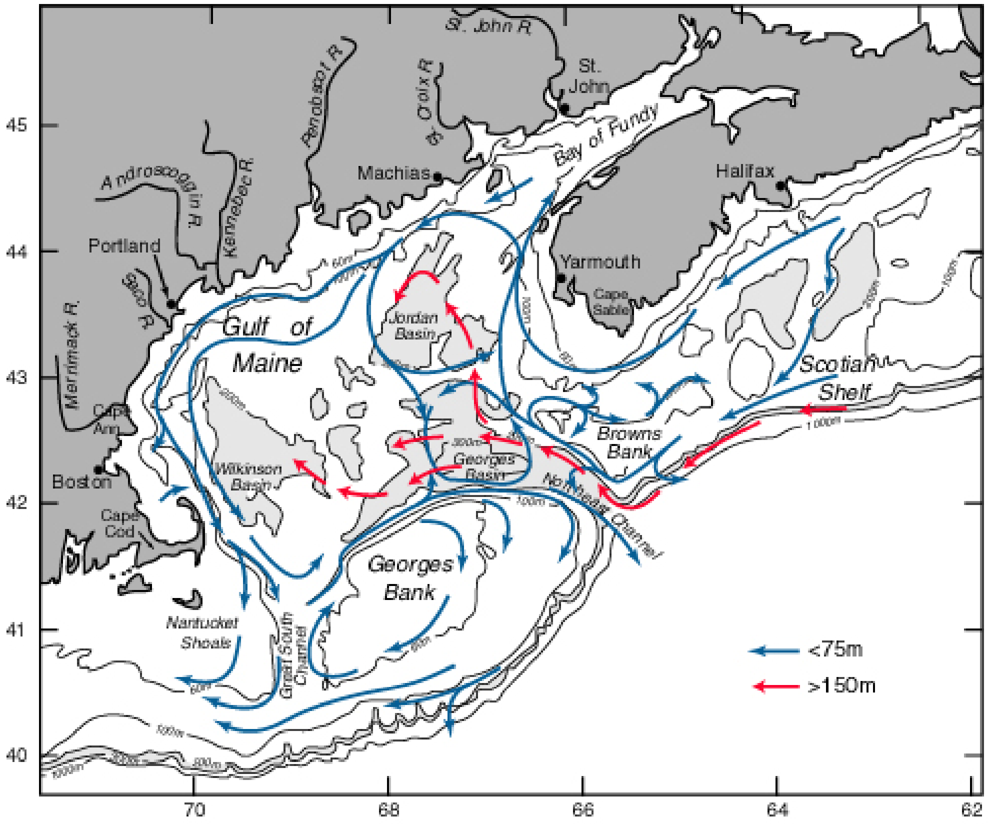


Figure 3-1. General circulation within Massachusetts Bay (from Beardsley et al. 1997)

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

During the summer and fall, the freshwater inflow is less, and so the wind and 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). The flow is very 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. Often, flow can “reverse,” with flow northward along the coast. There are transient gyres in Massachusetts Bay and Cape Cod Bay, which can go 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. In Massachusetts Bay, however, spring blooms do not occur every year. During the years in which there are spring blooms, they begin in the shallowest waters of Cape Cod Bay. Blooms in the deeper Massachusetts Bay waters begin two to three weeks later. Spring phytoplankton blooms are typically followed by an increase in zooplankton abundance. These zooplankton populations are food for many animals, including the endangered right whale.

Later in the spring, the surface waters warm, and the water column stratifies. Inputs of freshwater from rivers contribute to the stratification, with lighter, less saline water remaining at the surface. Stratification effectively separates the surface and bottom waters, preventing replenishment of nutrients to the surface and 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, bottom-dwelling animals respire, and bacteria use up oxygen as they decompose the phytoplankton. 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. Typically, fall blooms end in the early winter, when declining light levels limit photosynthesis. Plankton die and decay, replenishing nutrients in the water column.

In Massachusetts Bay, meteorological and oceanographic conditions greatly influence the timing, magnitude, and spatial extents of the spring and fall blooms.

Environmental Concerns

Water-column monitoring questions focus on the effects of nutrients, organic matter, pathogens, and floatable debris from wastewater on the water quality of Massachusetts Bay (MWRA 1991, Table 3-1). Because organic material and toxic contaminants are effectively removed by secondary treatment, but nutrients are not, nutrient issues cause the greatest concern. The monitoring program looks extensively at possible effects of discharging nutrient-rich effluent into Massachusetts Bay.

One concern is that excess nutrients, particularly nitrogen, could promote algal blooms followed by low levels of dissolved oxygen when the phytoplankton organisms die, sink, and decompose. Another concern is that changes in the relative levels of nutrients could stimulate growth of undesirable algae. Three nuisance or noxious species are of particular concern: the dinoflagellate *Alexandrium fundyense* (the *A. fundyense/tamarense* species group), the diatom *Pseudo-nitzschia multiseries*, and the colonial flagellate *Phaeocystis pouchetii*. *Alexandrium fundyense* can cause paralytic shellfish poisoning, known as PSP or red tide. Its toxin, when sufficiently concentrated, can be fatal to marine mammals, fish, and humans. Some diatoms in the genus *Pseudo-nitzschia* may, at high concentrations (more than 1 million cells per liter), produce sufficient quantities of domoic acid to cause a condition known as amnesic shellfish poisoning. Toxin-forming species occur with and appear identical to non-toxin forming species, when identified under a light microscope. *Phaeocystis pouchetii* is not toxic, but individual cells can aggregate in gelatinous colonies that are thought to be poor food for zooplankton.

Dissolved oxygen concentrations in bottom waters decrease during the stratified period as part of the natural seasonal pattern. Discharged nutrients could feed larger phytoplankton blooms, leading to even lower levels of dissolved oxygen when the cells sink to the bottom and decay. Because of the concern that low 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 periods of low oxygen that are typical in bottom waters correlate with warmer and saltier bottom waters.

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?

Due to source reduction and treatment, toxic contaminants discharged in the MWRA effluent are present at extremely low concentrations. Therefore, most monitoring for the effects of toxic contaminants is focused not on the water column, but on the sediments, which are known to be contaminant sinks, and on fish and shellfish, which could accumulate organic compounds or metals.

Monitoring Design

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

Nearfield surveys provide vertical and horizontal profiles of physical, chemical, and biological characteristics of the water column in the area around the outfall where some effects of the effluent are expected (Figure 3-2). Farfield surveys assess differences across the bays and seasonal changes over a large area (Figure 3-3). Five of the farfield stations mark the boundary of the monitoring area and are in or near the Stellwagen Bank National Marine Sanctuary. Two of these stations form 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. During 2003, 17 surveys of the nearfield and 6 surveys of the farfield were conducted.

Table 3-2. Components of water-column monitoring

Task	Objective	Sampling Locations And Schedule	Analyses
Nearfield surveys	Collect water quality data near outfall location	17 surveys/year 21 stations	Temperature Salinity Dissolved oxygen Nutrients Solids Chlorophyll Water clarity Photosynthesis Respiration Plankton Marine mammal observations
Farfield surveys	Collect water quality data throughout Massachusetts and Cape Cod bays	6 surveys/year 26 stations	
Moorings (GoMOOS and USGS)	GoMOOS near Cape Ann and USGS near outfall provide continuous oceanographic data near outfall location	Continuous monitoring GoMOOS at one location USGS at two locations 3 depths	Currents Temperature Salinity Water clarity Chlorophyll
Remote sensing	Provides oceanographic data on a regional scale through satellite imagery	Available daily (cloud-cover permitting)	Surface temperature Chlorophyll

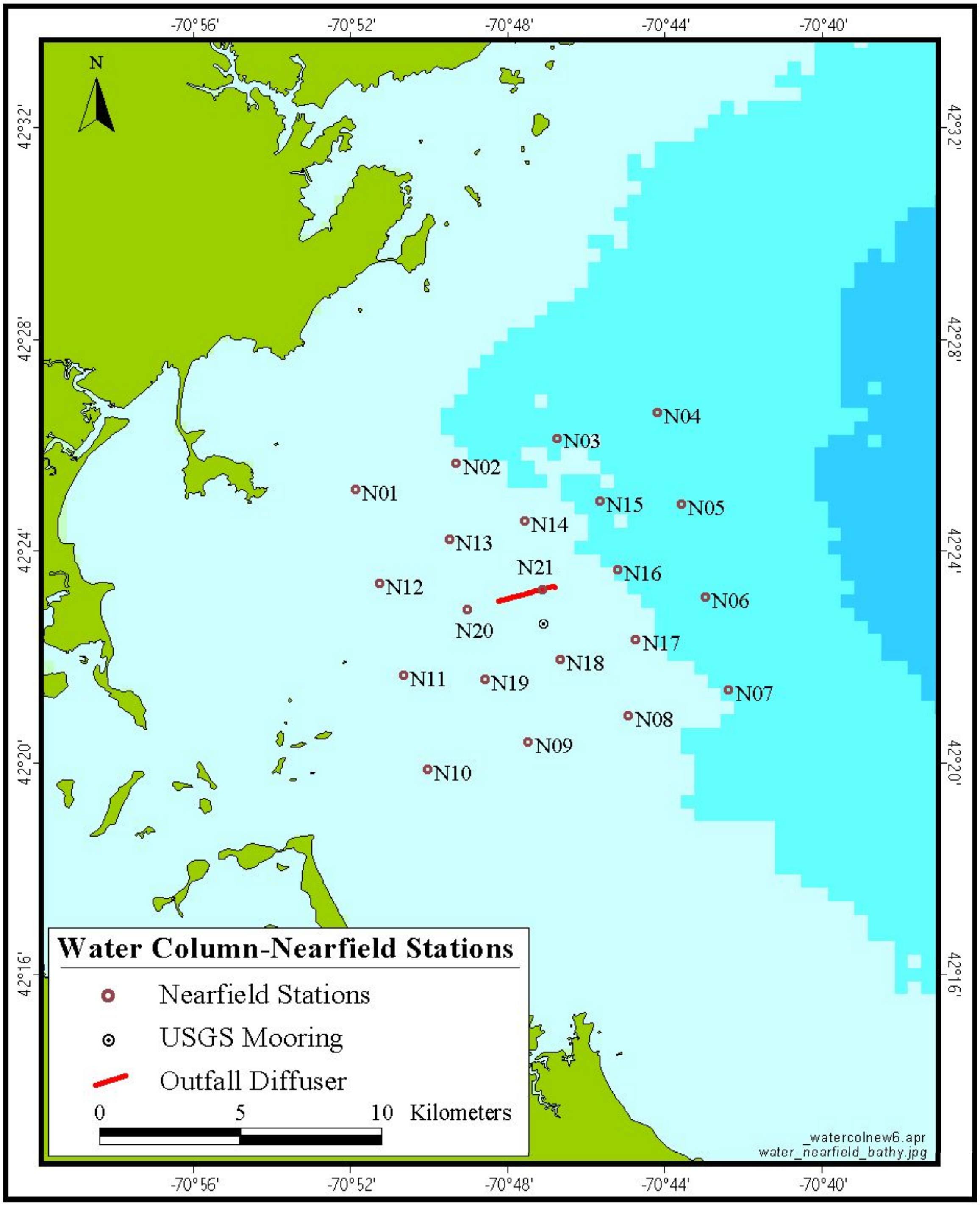


Figure 3-2. Nearfield sampling stations

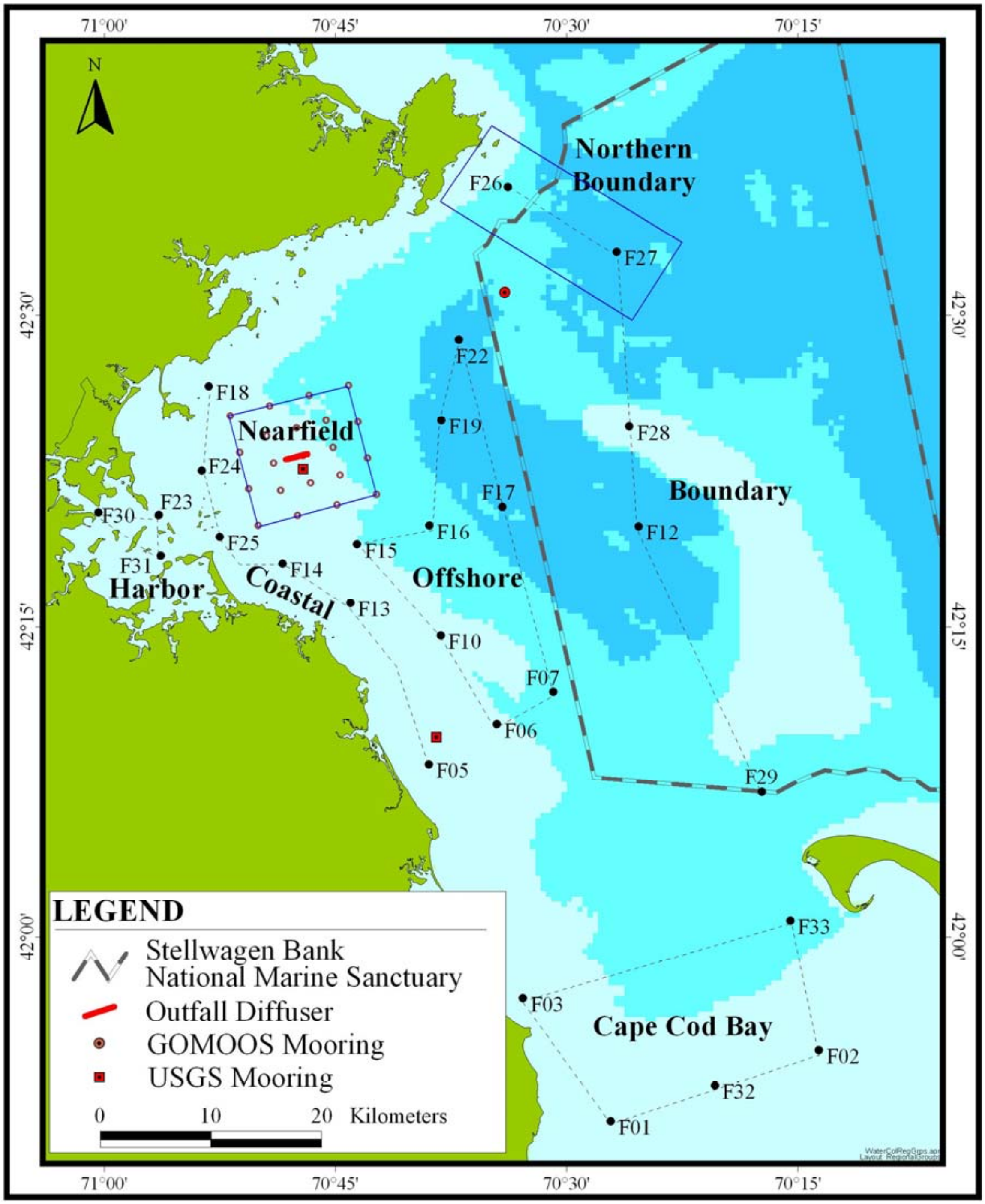


Figure 3-3. Farfield geographic regions and sampling stations

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. Nutrient measurements include the major forms of nitrogen, phosphorus and silica. The measurements focus on the dissolved inorganic forms, which are readily used by phytoplankton. Since 1999, the surveys have also included observations and net tows in the outfall area to assess the presence of floatables.

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

Results

Physical Conditions

Drought, which began in the fall of 2001, continued until April 2003, after which there was a return to more normal freshwater flow conditions (Figure 3-4). (Libby *et al.* 2004a).

Monitoring has shown that the north-south component of the wind stress in the region is important in determining water conditions, as these winds determine the degree of upwelling or downwelling. The year followed a typical pattern of wind stresses, beginning with downwelling, transitioning to upwelling in the summer, and returning to downwelling in the late fall. Stronger summer upwelling resulted in particularly cold bottom waters (Figure 3-5, top).

Surface salinity was lower in 2003 than in 2002, reflecting the end of the drought (Figure 3-5, middle). Bottom salinity decreased more slowly. The pronounced difference in salinity in surface and bottom waters meant greater than usual summer stratification (Figure 3-5, bottom), which persisted through November.

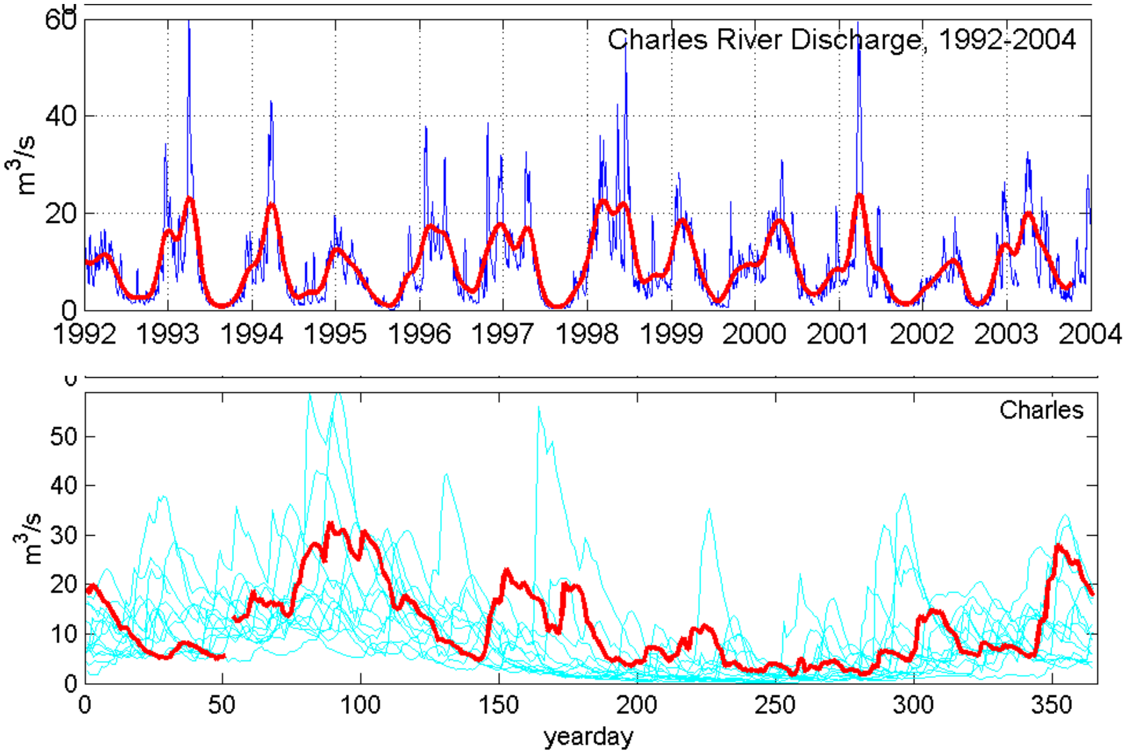


Figure 3-4. Top: Charles River discharge, 1990-early 2004 (data from a gauge at Waltham and 3-month moving average); Bottom: 2003 discharge compared to observations from the past 12 years

Water Quality

As in 2001 and 2002, water quality measurements in 2003 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.* 2004a).

Elevated concentrations of ammonia, the form of nitrogen most readily taken up by phytoplankton, were observed in the nearfield during many surveys, as they had been since the outfall began operation (Figure 3-6, top). These elevated levels had been anticipated, because a large portion of the dissolved inorganic nitrogen in treated effluent is ammonia, and ammonia has proven to be a good short-term tracer of the effluent plume. During the same period, concentrations of ammonia in Boston Harbor have remained low, following a dramatic drop in concentration following effluent diversion to Massachusetts Bay. Averaged over the entire year, the increase in ammonia concentrations in the vicinity of the outfall was small in comparison to the large decrease in ammonia concentrations in the harbor (Figure 3-6, bottom). Ammonia concentrations have also declined at the coastal stations compared to the years immediately preceding the outfall diversion.

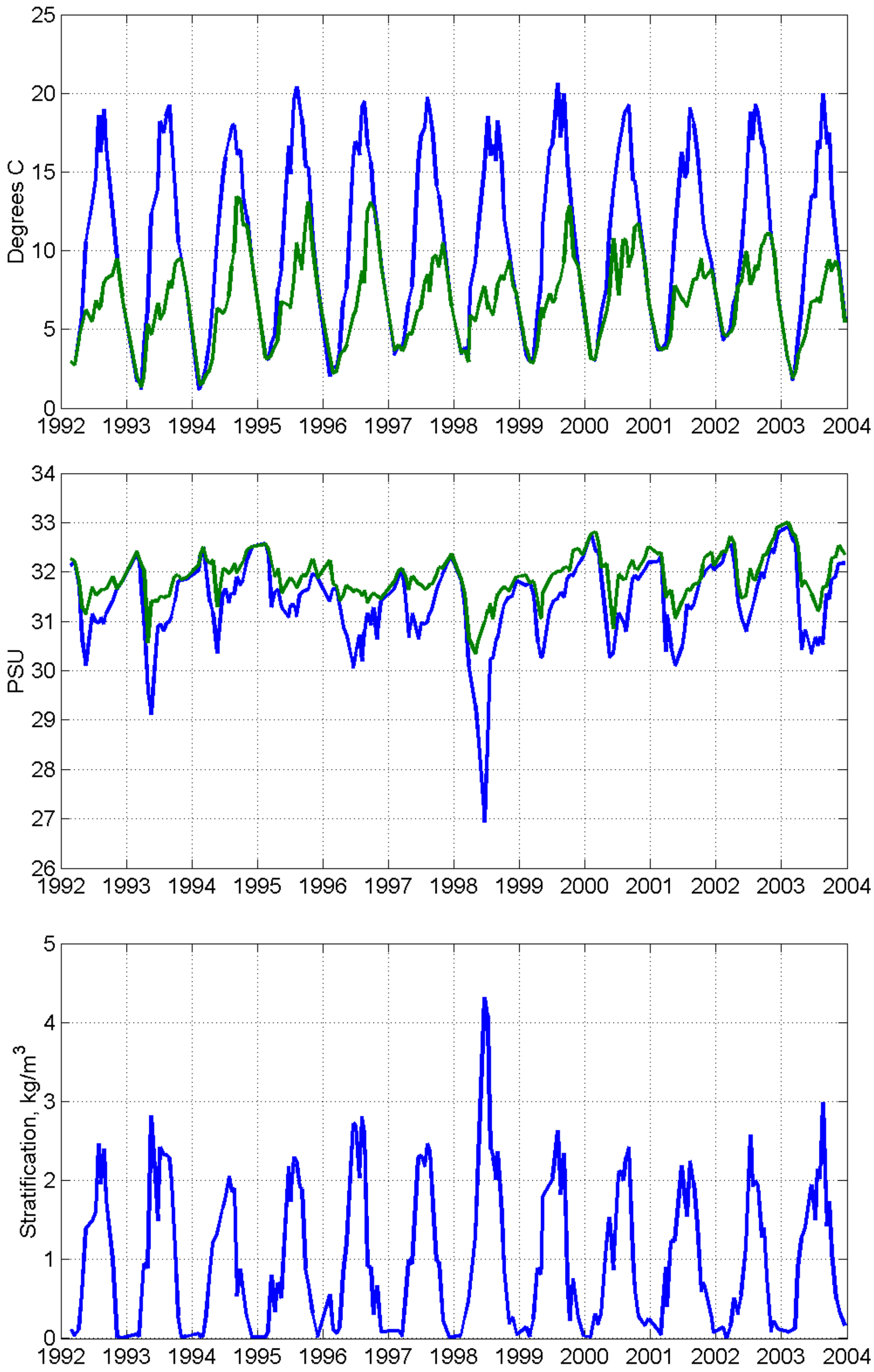


Figure 3-5. Nearfield surface and bottom water temperature, salinity, and stratification (Surface measurements are the upper line for temperature and the lower line for salinity.)

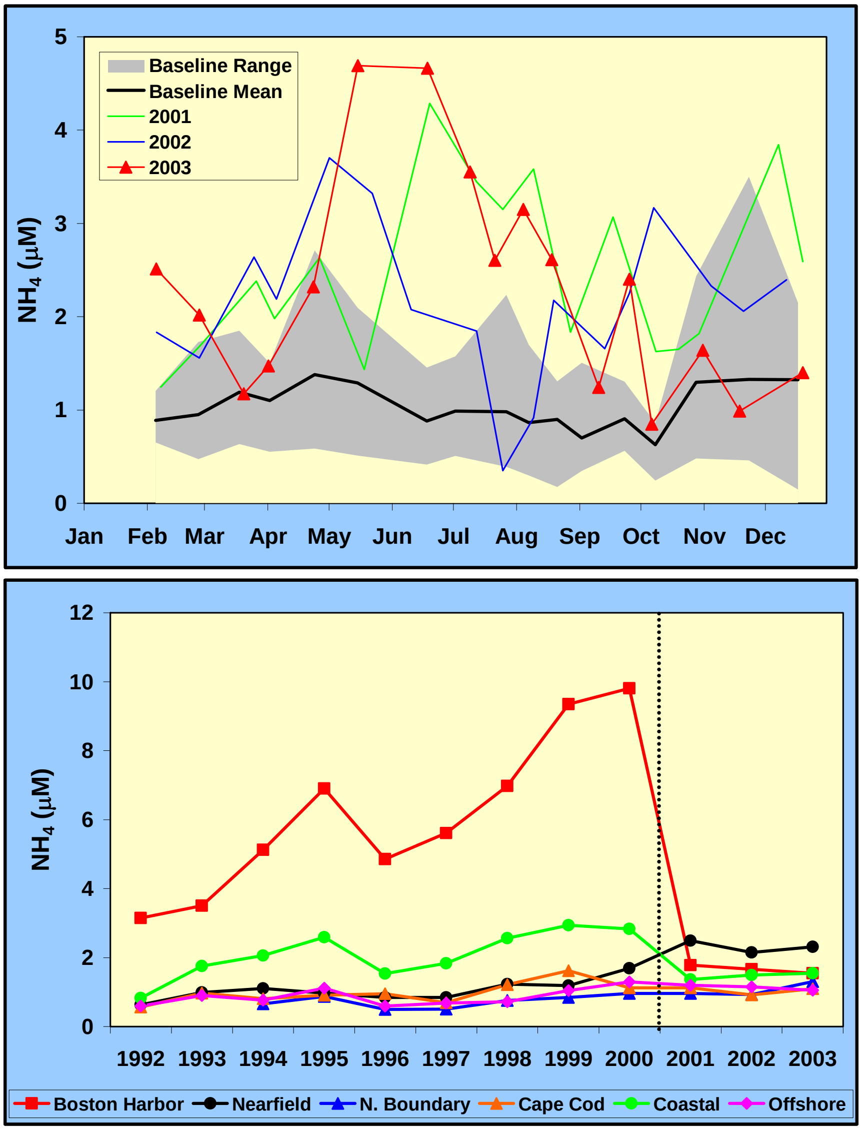


Figure 3-6. Top: 2003 nearfield ammonia concentrations compared to baseline range and mean; Bottom: annual mean ammonia concentrations in Massachusetts Bay regions

Unlike ammonia, for most surveys, concentrations of nitrate, another form of nitrogen readily used by phytoplankton and present in the effluent, fell within the baseline range and showed the same seasonal pattern as seen in baseline monitoring (Figure 3-7, top). Just as during the baseline period, higher nitrate concentrations were observed during the early part of the year. Seasonal stratification led to typical, persistent nutrient depletion in the surface waters, with no evidence of inputs from the outfall (the figures show data averaged over the entire water column). Elevated nitrate levels were observed in the nearfield during the fall, and concentrations of two other nutrients, silicate and phosphate (data not shown), were also present in concentrations above the baseline ranges during these months.

Surprisingly high nutrient concentrations were also observed at farfield stations, suggesting effects of prolonged stratification and perhaps transport from offshore waters. Averaged over the entire year, there were no significant increases in nitrate concentrations (Figure 3-7, bottom). The typical pattern persisted, with highest concentrations at the northern boundary, lowest in Cape Cod Bay, and intermediate levels in the nearfield.

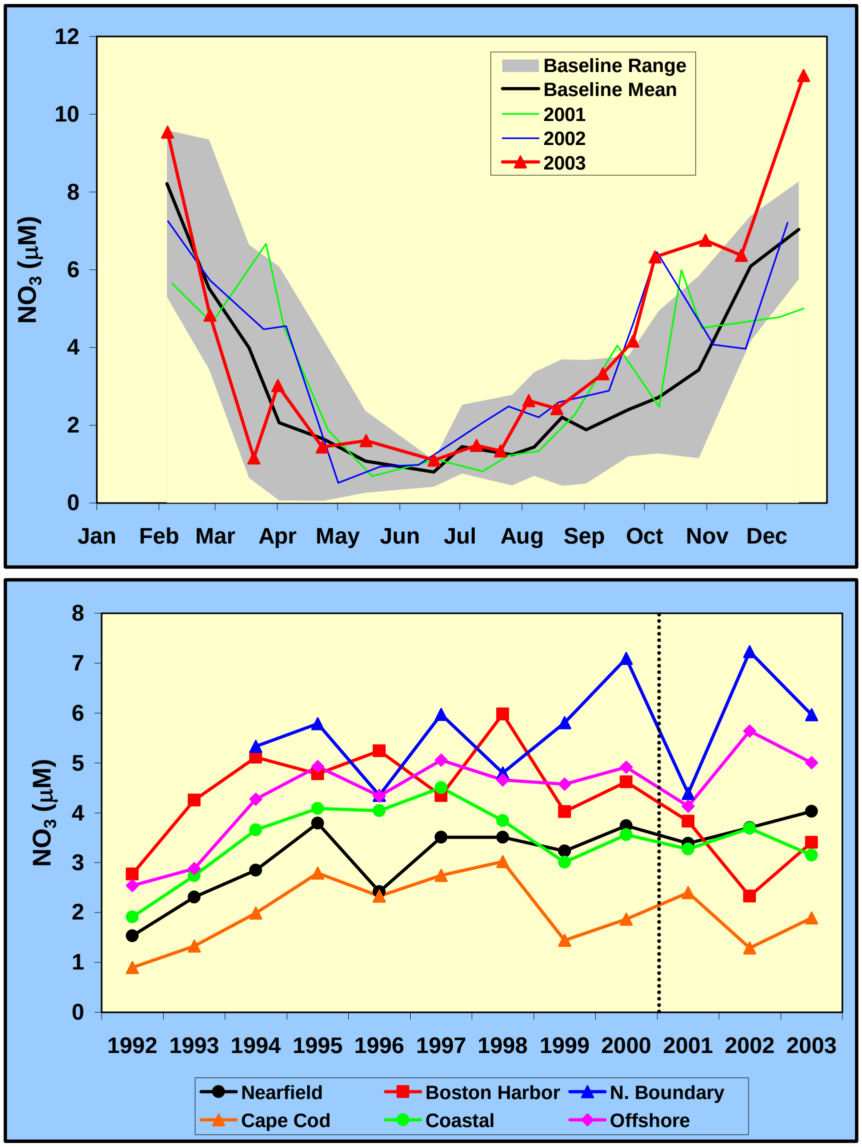


Figure 3-7. Top: 2003 nearfield nitrate concentrations compared to baseline range and mean; Bottom: annual mean nitrate concentrations in Massachusetts Bay regions

Chlorophyll (mg per square meter), a measure of phytoplankton biomass, also continued to show no response to nutrient enrichment of the outfall, even in the nearfield (Figure 3-8). That is, levels of chlorophyll did not increase compared to baseline. The annual and seasonal chlorophyll measurements showed no response to the outfall in the nearfield or any region of the farfield.

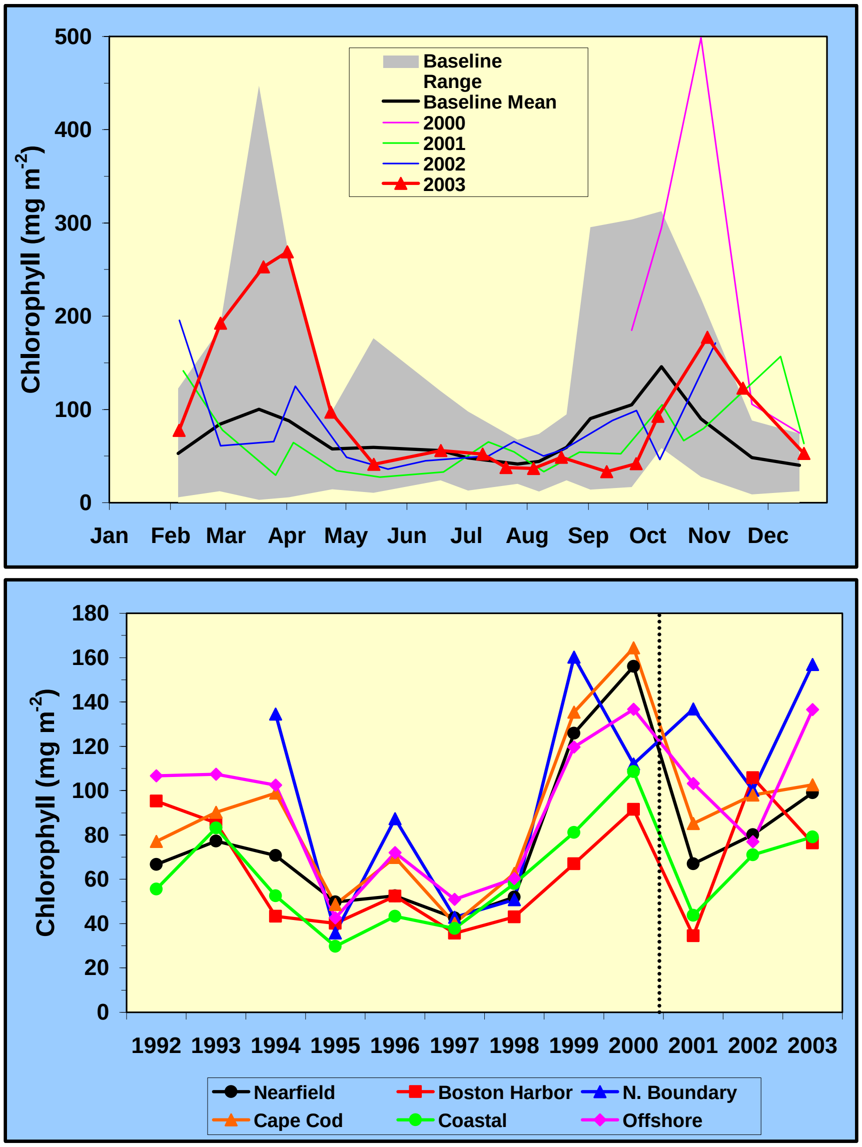


Figure 3-8. Top: 2003 nearfield chlorophyll compared to baseline range and mean; Bottom: annual mean chlorophyll in Massachusetts Bay regions

Measurements of concentrations (Figure 3-9) and percent saturation (not shown) of dissolved oxygen in the bottom waters in 2003 also continued to show no response to nutrient enrichment or addition of organic matter from the outfall. 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. Prolonged stratification in 2003 resulted in continued decline in dissolved oxygen concentrations until mid-November. Nearfield minimum values for 2003 were relatively high considering this prolonged period of stratification.

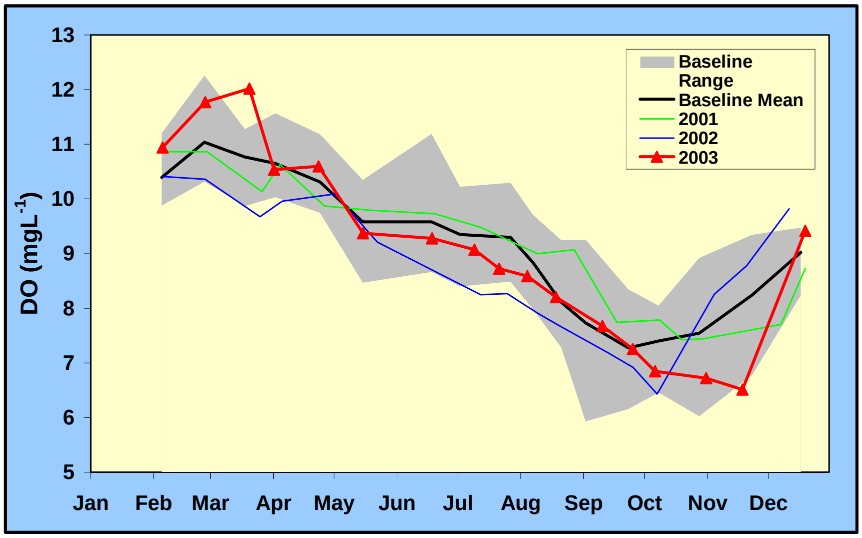


Figure 3-9. 2003 nearfield dissolved oxygen concentrations compared to baseline range and mean

Baseline monitoring identified a relationship between temperature, salinity, and dissolved oxygen in the nearfield. Data from that period were used to develop a statistical model (Geyer *et al.* 2002), which can now be used to predict nearfield dissolved oxygen minima. Using the temperature and salinity measurements for 2003, the model predicted that dissolved oxygen concentrations would be average for 1992-2003 (Figure 3-10). The agreement between the predicted and observed results indicates that the relationship between dissolved oxygen and temperature and salinity has not changed since the outfall began to discharge into Massachusetts Bay.

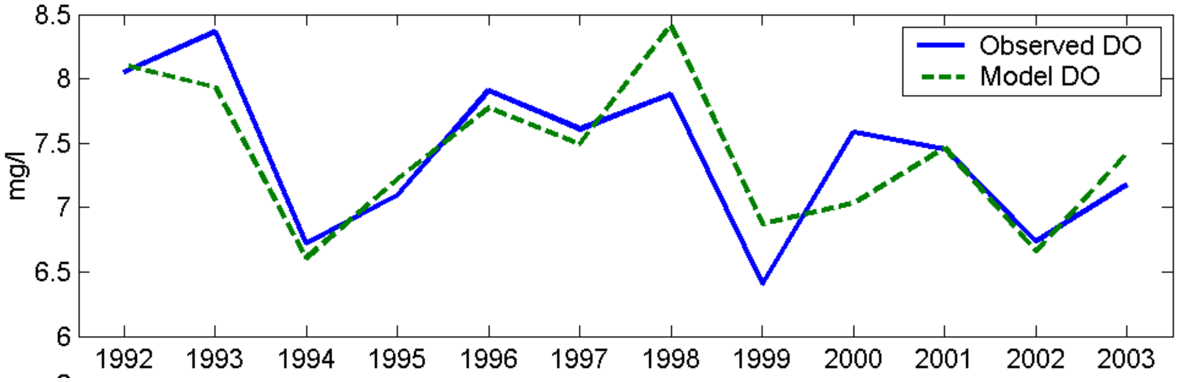


Figure 3-10. Observed and modeled average nearfield near-bottom dissolved oxygen concentrations during September through October

Phytoplankton Communities

Seasonal abundance of phytoplankton in the post-outfall diversion years has remained at or slightly below the baseline mean for most survey dates (Figure 3-11; Libby *et al.* 2004a). Exceptions to this general finding were an April 2003 *Phaeocystis pouchetii* bloom, a late summer 2002 diatom bloom, and later than usual fall blooms in 2001 and 2003. The taxonomic composition of the phytoplankton community has been relatively consistent during the pre- and post-diversion years.

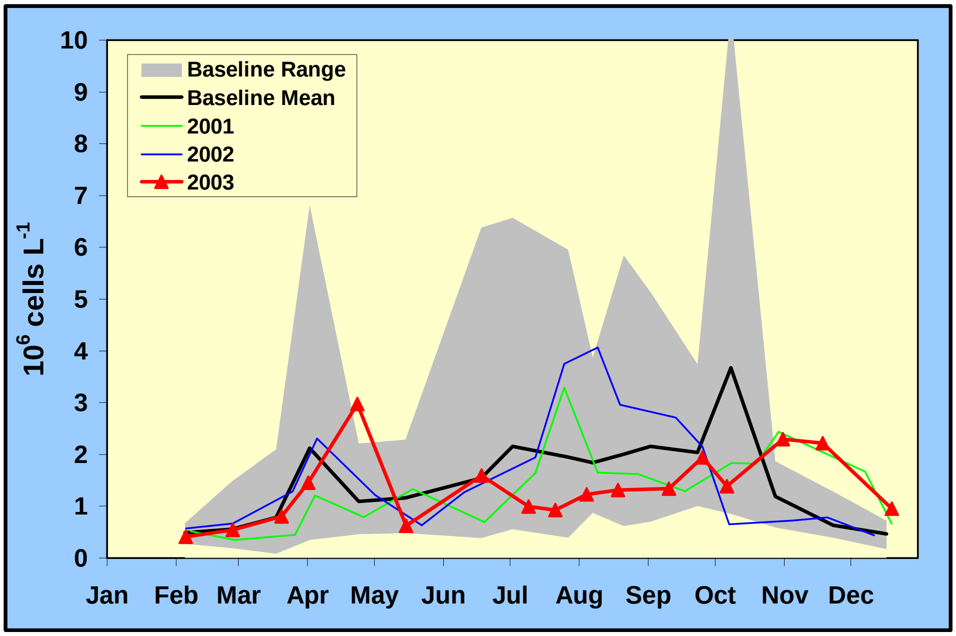


Figure 3-11. Nearfield phytoplankton abundance

The most pronounced change in the phytoplankton community has been the change in the frequency of *Phaeocystis pouchetii* blooms (Figure 3-12, top). During the baseline period, there were spring *Phaeocystis* blooms in 1992, 1994 (only recorded in the farfield), 1997, and 2000. Since the outfall began operation, the blooms have occurred annually. However, this increase in frequency does not appear to be related to the outfall. For example, the 2003 bloom was widespread, occurring at all the Massachusetts Bay stations sampled by MWRA. Satellite images (Figure 2-12, bottom) suggested that the bloom was most intense in the area off Cape Ann, which is upstream from the outfall.

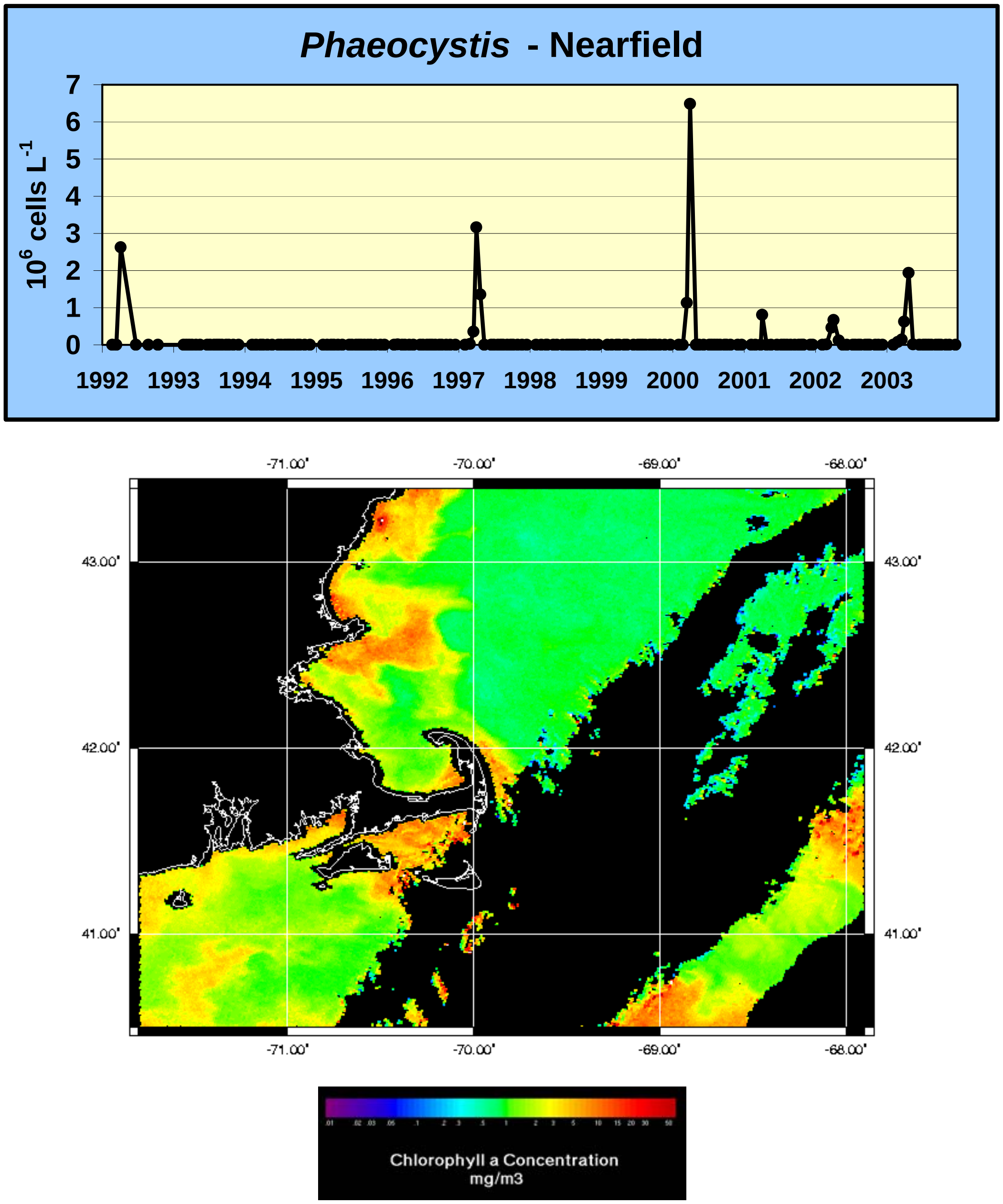


Figure 3-12. Top: abundance of Phaeocystis pouchetii in the nearfield, 1992-2003: Bottom: SeaWiFS chlorophyll a image for March 27, 2003

Other than the *Phaeocystis pouchetii* bloom, there continued to be no detectable increases in nuisance species compared to the baseline. The dinoflagellates *Alexandrium* spp. and diatoms in the genus *Pseudo-nitzschia* were present but in low numbers. *Pseudo-nitzschia pseudodelicatissima*, a potentially toxic diatom that is not currently included in *Pseudo-nitzschia* threshold calculations, was present and at times abundant.

Zooplankton Communities

Patterns of zooplankton abundance in 2003 were similar to many earlier years (Figure 3-13; Libby *et al.* 2004a). As in prior years, abundance was dominated by copepod nauplii and copepodites and adults of the small copepod *Oithona similis.* Ctenophores, which decimated zooplankton populations in 2000 and 2002, were present but did not have a similar impact in 2003.

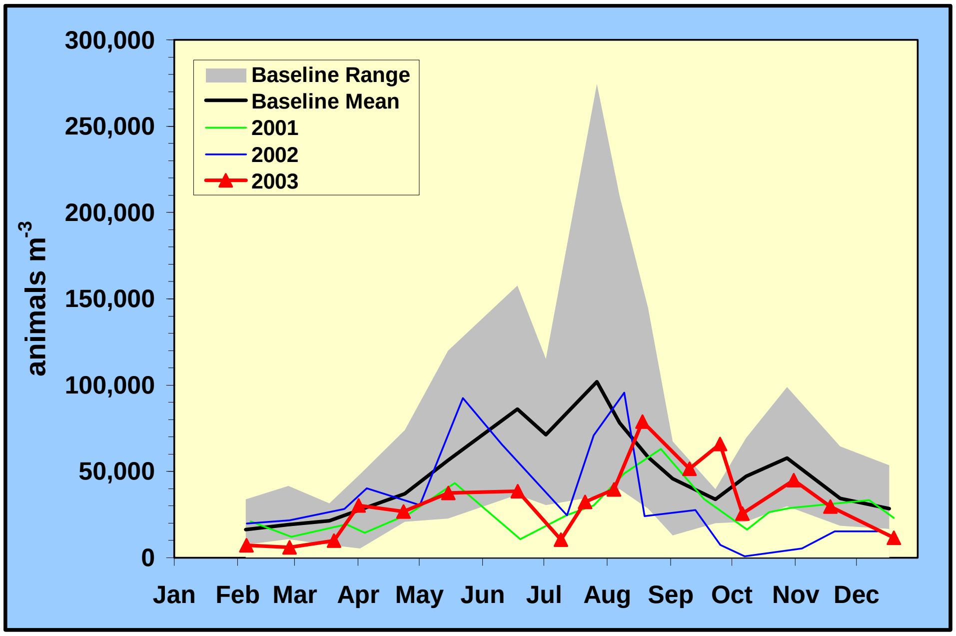


Figure 3-13. Nearfield zooplankton abundance

MWRA's zooplankton monitoring is particularly comprehensive, in that it samples and enumerates small species such as *Oithona similis*. Because Massachusetts and Cape Cod bays are important as seasonal foraging grounds for the endangered northern right whale, which feeds on zooplankton, abundance of larger prey species, such as the more oceanic copepod *Calanus finmarchicus* (copepodites and adults) are also of interest. In the nearfield, abundance of *Calanus finmarchicus* tends to peak in April and May, while the more abundant *Oithona similis* peaks in mid to late summer (Figure 3-14).

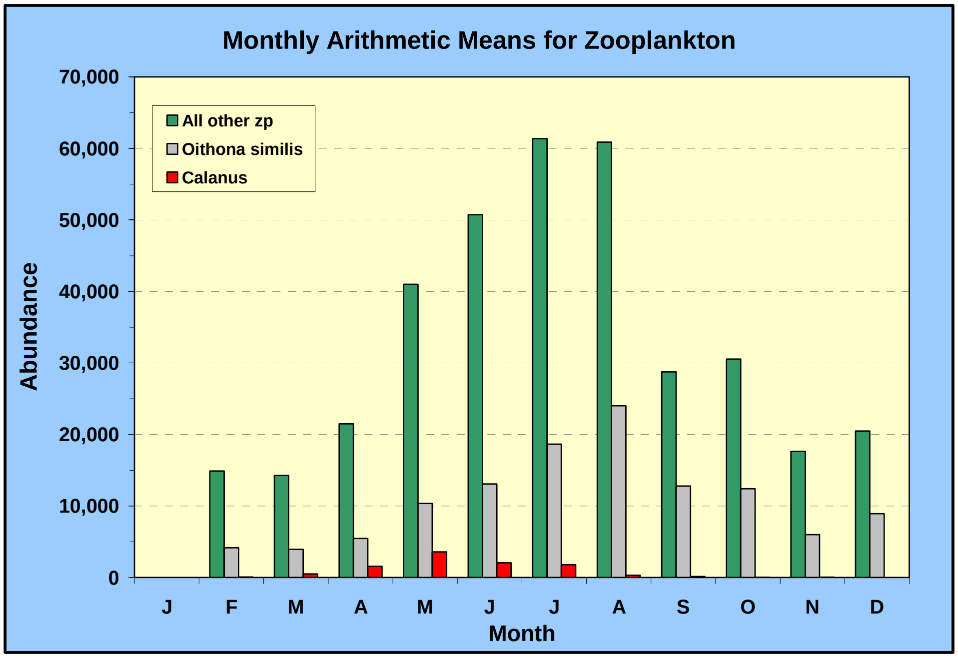


Figure 3-14. Monthly abundance of zooplankton species in Massachusetts Bay, 1992-2003 (individuals per m^3*)*

Recently, scientists working on the MWRA program analyzed *Calanus finmarchicus* abundance data to determine whether there were any indications of effects of the outfall or whether abundance patterns reflected long-term, large-scale climatic variation (Turner *et al.* submitted).

Results of the analyses suggested that large-scale, long-term climate phenomena may have greater influence on zooplankton populations than do local perturbations, such as the outfall discharge. There was a significant negative correlation between annual winter mean abundance of *Calanus finmarchicus* adults and copepodites and the annual boreal North Atlantic Oscillation (NAO) Index, which is a measure of large-scale atmospheric factors that affect climate in eastern North America. Data collected since monitoring began in 1992 show that *Calanus finmarchicus* abundance correlates with higher wind speed (Figure 3-15). Even though the data are highly variable, the relationship is statistically significant at one of MWRA's stations, with wind speed accounting for about 25% of the variation in abundance.

The analyses suggest that zooplankton abundance is affected by long-term, large-scale processes, such as the NAO, and that regional conditions, such as the winter marine climate, have a greater effect on zooplankton abundance than local events.

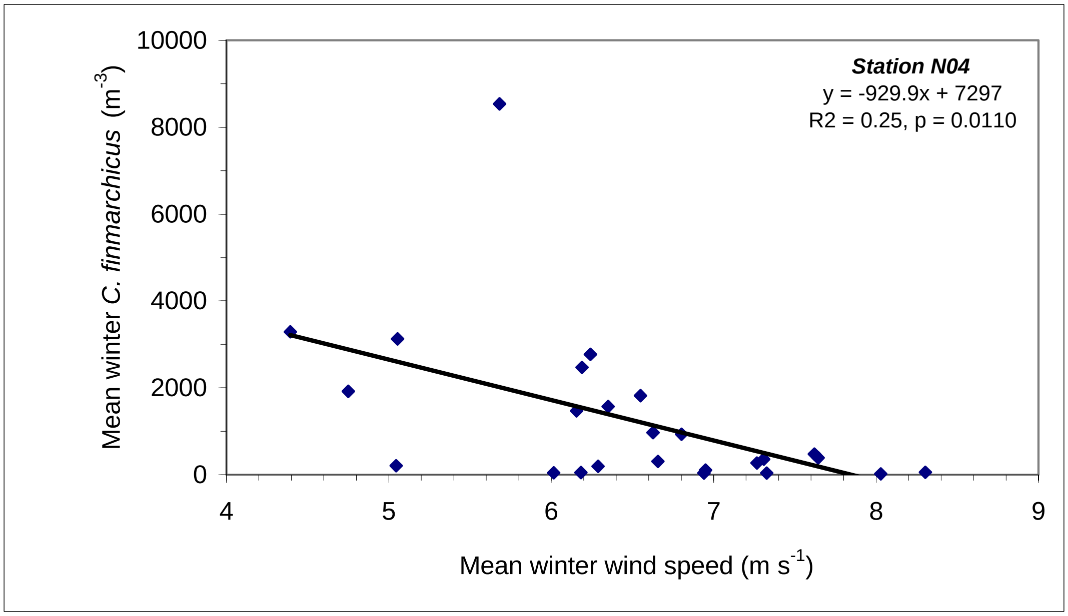


Figure 3-15. Mean monthly winter wind speed vs. monthly winter abundance of Calanus finmarchicus adults and copepodites at one nearfield station

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 was one exceedance of thresholds in 2003—the summer *Phaeocystis* threshold (Table 3-3). This measurement was made at the end of a typical spring *Phaeocystis* bloom, and the exceedance was more likely an artifact of the sampling schedule and the extremely low summer threshold rather than an indication of an effect of the outfall. The number of cells was far below levels that have negative environmental effects. All other monitoring results were within ranges that met the thresholds.

Table 3-3. Contingency plan threshold values for water-column monitoring

Location/ Parameter	Specific Parameter	Baseline	Caution Level	Warning Level	2003 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 = 6.72 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 = 71.8%
Bottom water Stellwagen Basin	Dissolved oxygen concentration	Background 5th percentile 6.2 mg/l	6.5 mg/l for any survey (June-October) unless background conditions lower	Lower than 6.0 mg/l for any survey (June-October) unless background conditions are lower	Lowest survey mean = 7.07 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 = 73.2%
Bottom water nearfield	DO depletion rate (June-October)	0.024 mg/l/d	0.037 mg/l/d	0.049 mg/l/d	0.020 mg/l/d
Chlorophyll nearfield	Annual	71 mg/m^2	107 mg/m^2	143 mg/m^2	99 mg/m^2
	Winter/spring	81 mgml^2	182 mg/m^2	None	178 mg/m^2
	Summer	51 mg/m^2	80 mg/m^2	None	45 mg/m^2
	Autumn	90 mg/m^2	161 mg/m^2	None	87 mg/m^2
Nuisance algae nearfield *Phaeocystis pouchetii*	Winter/spring	470,000 cells/l	2,020,000 cells/l	None	482,000 cells/l
	Summer	72 cells/l	334 cells/l	None	1700 cells/l, caution level exceedance
	Autumn	300 cells/l	2,370 cells/l	None	0 cells/l
Nuisance algae nearfield *Pseudo-nitzschia*	Winter/spring	6,200 cells/l	21,000 cells/l	None	232 cells/l
	Summer	13,000 cells/l	38,000 cells/l	None	60 cells/l
	Autumn	9,700 cells/l	37,900 cells/l	None	8,900 cells/l
Nuisance algae nearfield *Alexandrium fundyense*	Any nearfield sample	Baseline maximum = 163 cells/l	100 cells/l	None	6.6 cells/l maximum
Farfield	PSP toxin extent	Not applicable	New incidence	None	No toxicity or shellfish closures

4. Sea Floor

Background

Bottom Characteristics and Sediment Transport

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

Sediment transport in the region occurs primarily during storms. Typically, waves during storms with winds from the northeast resuspend sediments, which are transported by shallow currents from western Massachusetts Bay toward Cape Cod Bay and by deeper currents to Stellwagen Basin. Cape Cod Bay is partially sheltered from large waves by the arm of Cape Cod, and storm waves are rarely large enough to resuspend sediments in Stellwagen Basin, which is the deepest feature in the region.

Environmental Concerns

Within Boston Harbor, studies of the sediments have documented recovery following the cessation of sludge discharge, improvements to combined sewer overflow (CSO) systems, and improved sewage effluent treatment. Conversely, relocating the outfall raised concerns about potential effects on the offshore sea floor. Concern has focused on three issues: eutrophication and related low levels of dissolved oxygen, accumulation of toxic contaminants in depositional areas, and smothering of animals by particulate matter (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, depressed levels of dissolved oxygen could affect bottom communities. Increasing the amount of particles and organic matter to the bottom could disrupt normal benthic community structure in the vicinity of the discharge. Although source control and treatment plant performance are designed to keep effluent contaminant concentrations too low to affect the sediments, the location of the outfall in an area of considerable sediment transport causes concern about accumulation of toxic contaminants in Cape Cod Bay and Stellwagen Basin. Similarly, concentrations of particulate matter are expected to be low, but there remains some possibility that bottom communities near the outfall could be affected by deposition.

Monitoring Design

Sea floor monitoring includes several components (Table 4-1): measurements of contaminant concentrations and other chemistry parameters in sediments, sediment-profile imaging to provide a rapid assessment of potential effects on 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).

Table 4-2. Components of sea-floor monitoring

Task	Objective	Sampling Locations And Schedule	Analyses
Soft-bottom studies	Evaluate sediment quality and benthos in Boston Harbor and Massachusetts Bay	1 survey/year 20 nearfield stations 11 farfield stations	Sediment chemistry Sediment profile imagery Community composition
Hard-bottom studies	Characterize marine benthic communities in rock and cobble areas	1 survey/year 21 stations on 6 transects	Topography Substrate Community composition

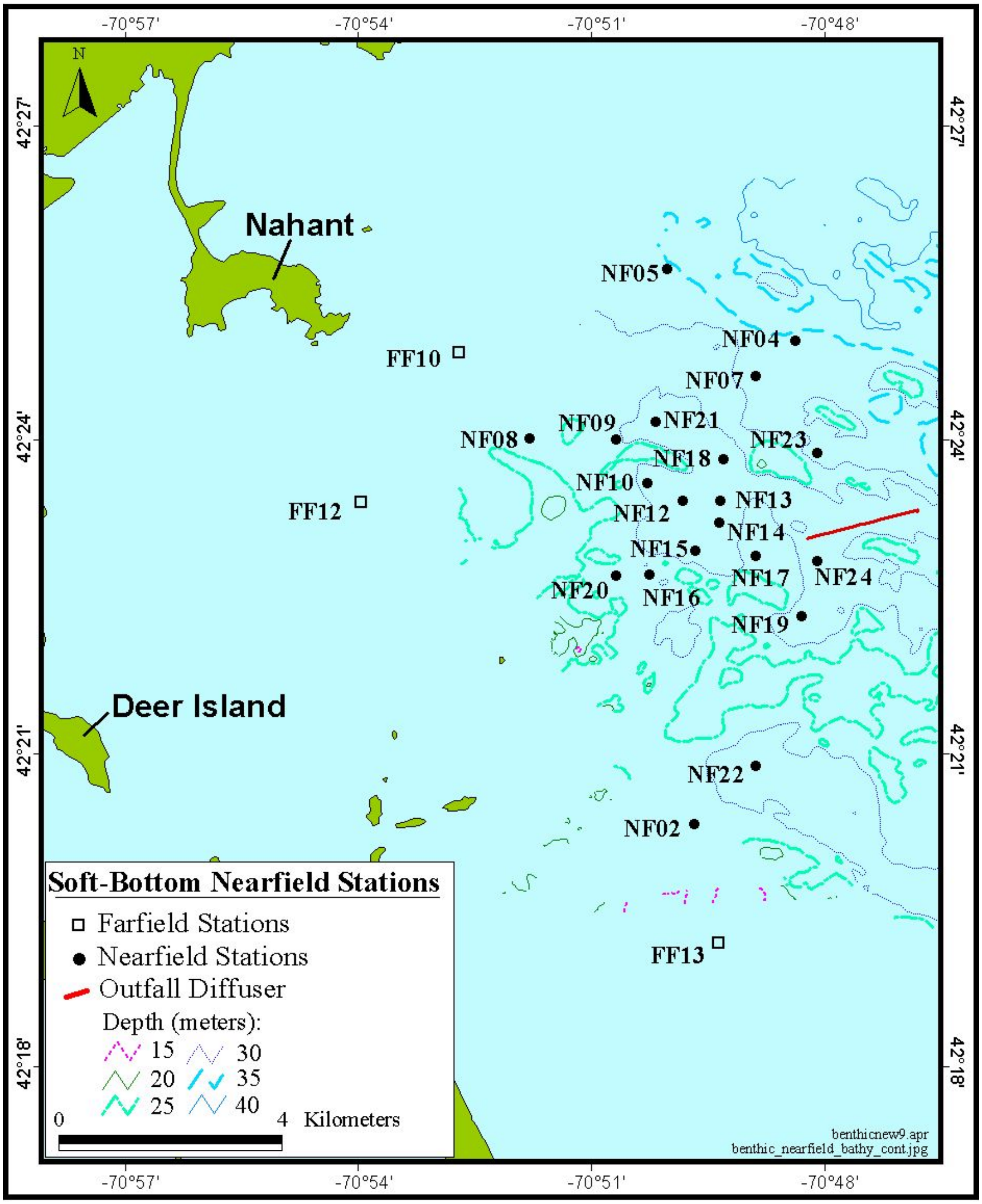


Figure 4-1. Locations of nearfield soft-bottom stations (NF 12 and NF 17 are also sampled by USGS.)

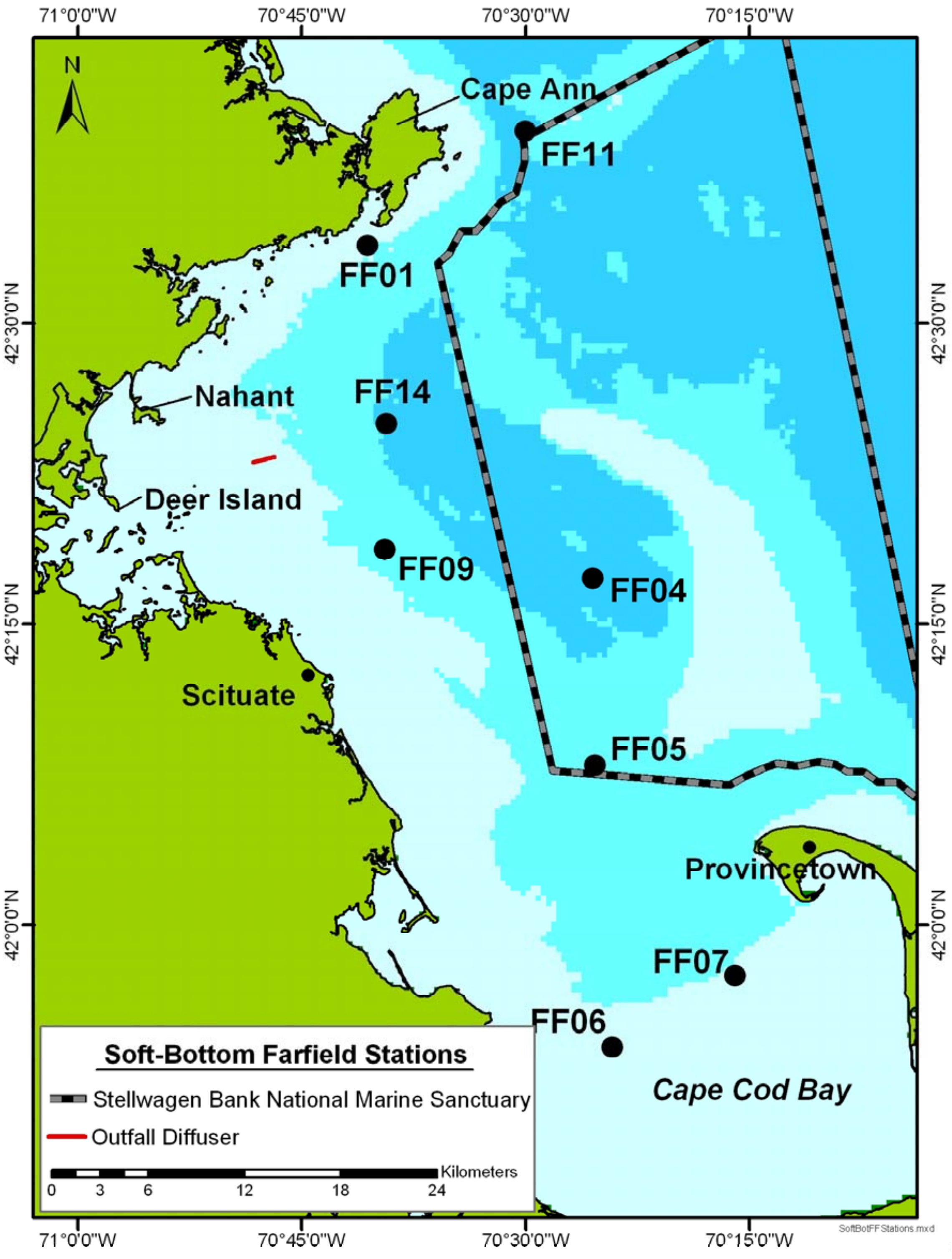


Figure 4-2. Locations of farfield soft-bottom stations

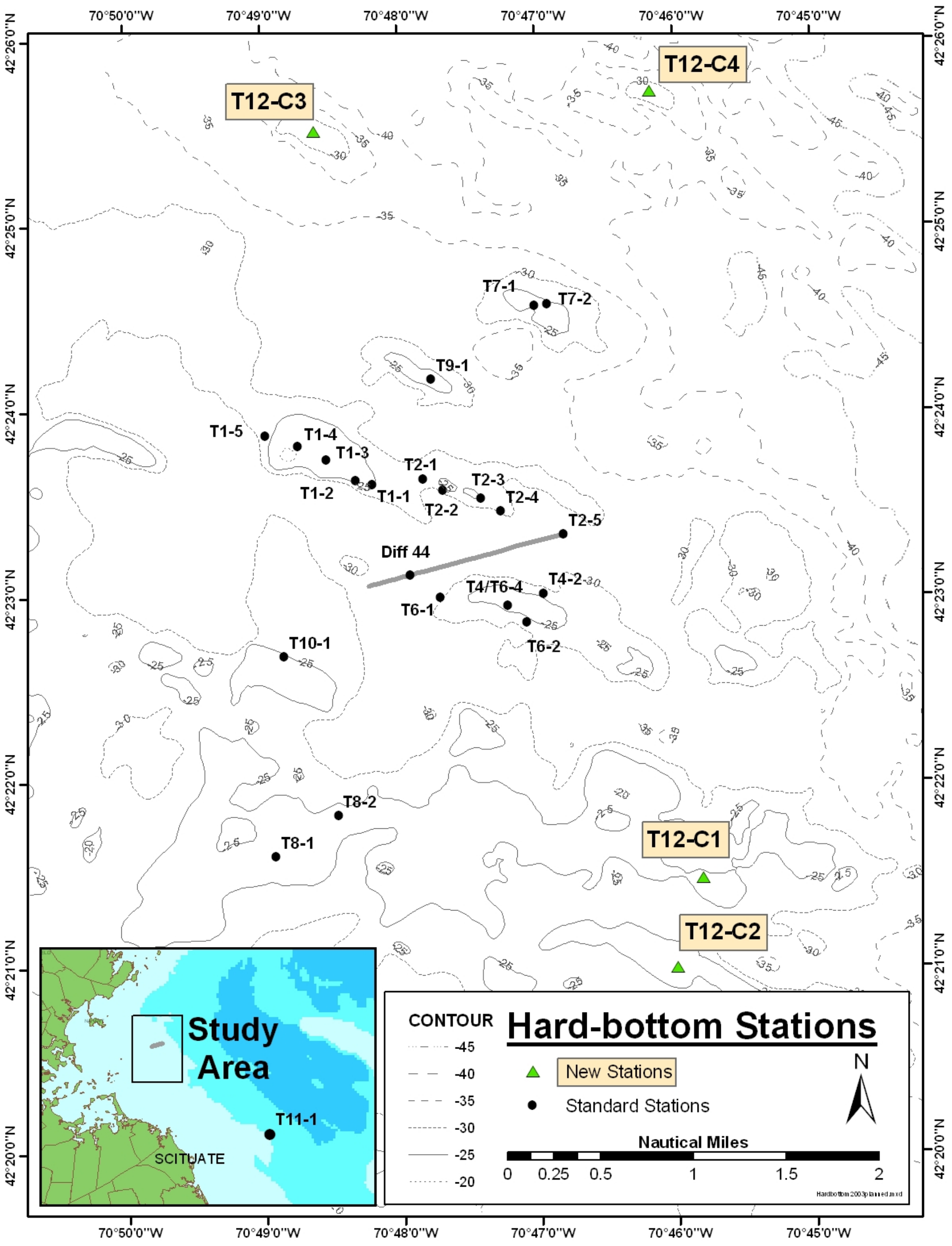


Figure 4-3. Locations of hard-bottom stations

Through 2002, the core of sediment contaminant monitoring consisted of annual, mid-August sampling of sediments at 31 stations throughout Massachusetts and Cape Cod bays. Replicate field samples were taken at all farfield and selected nearfield stations. Single samples were taken at the remaining nearfield stations. Samples were analyzed for PAHs, PCBs, chlorinated pesticides, metals, grain size, total organic carbon (TOC), *Clostridium perfringens* spores, and linear alkyl benzenes. For 2003, EPA and MADEP approved a reduced plan for monitoring toxic contaminants, with analyses completed for only two nearfield stations.

Annual sediment-contaminant monitoring has been complemented by special studies. One study, a collaborative effort between MWRA and USGS, has investigated sediment transport and contaminant levels in Boston Harbor, Massachusetts Bay, and Cape Cod Bay. USGS has periodically sampled four stations within Boston Harbor since 1977 and has taken sediment cores three times a year from two stations, one sandy and one muddy, near the Massachusetts Bay outfall since 1989 (USGS 1997b; Figure 4-1). Since 1992, these stations have also been occupied by MWRA. USGS also uses a mooring in the nearfield to collect hydrographic data and samples of suspended matter in sediment traps. Suspended matter samples are analyzed for metals, grain size, TOC, and effluent tracers.

Sediment-profile image monitoring is conducted in August of each year at 23 nearfield stations to give area-wide assessments of sediment quality and benthic community status. The sediment-profile images provide more rapid assessments of benthic habitat conditions than is possible from traditional faunal analyses. A system called “Quick Look,” which uses digital video cameras along with film, provides an even faster assessment. A real-time narration of the videotape describes the substrate and estimates depth to which oxygen penetrates, known as the oxidation-reduction (redox) potential discontinuity (RPD). Later, complete analyses of films provide information on prism penetration, surface relief, apparent color RPD depth, sediment grain size, sediment layering, fauna and structures, and successional stage of the soft-bottom animal communities.

Monitoring the benthic infauna also consists of annual surveys conducted in August. Sampling of 23 nearfield stations provides spatial coverage and local detail about the fauna in depositional areas located within eight kilometers of the diffuser. Farfield sampling of eight additional stations in Massachusetts and Cape Cod bays contributes regional data on soft-bottom habitats. 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 lab. 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 23 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 there is a layer of fine material on the hard surface), and biota (taxa identified to species or species groups and counted).

Some station changes in the hard-bottom program were made for 2003. Two stations were discontinued, one because it was relatively devoid of life and one because it was redundant with another station. Two additional stations were established, one about two miles southeast of the outfall and one about ten miles off the coast from Scituate, Massachusetts, well south of the outfall. The sampling plan as of 2003 therefore included one active diffuser head, one inactive diffuser head, 13 sites near the outfall (nine to the north and four to the south), three nearfield reference sites to the north of the outfall, four nearfield reference sites south of the outfall, and one farfield reference site, the station off Scituate.

Results

Sediment 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 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.

For 2003, data from the two stations sampled for toxic contaminants were within the baseline range for almost all samples. Bulk sediments and sewage-tracer data also fell within the baseline range. For example, 2003 concentrations of the sewage tracer *Clostridium perfringens* spores were generally below the baseline mean (Figure 4-4).

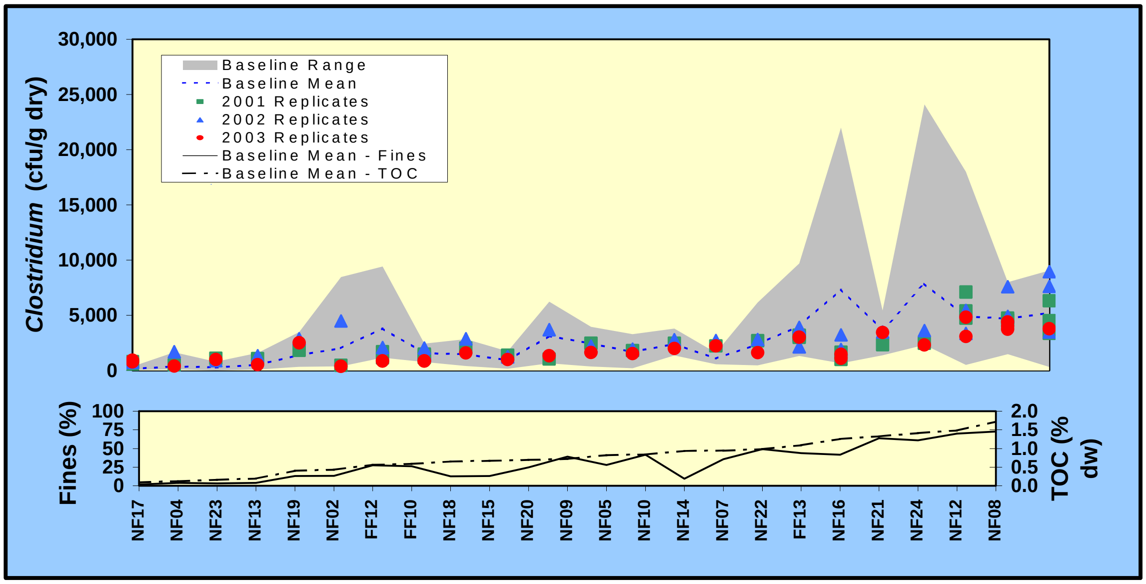


Figure 4-4. Clostridium perfringens spores and percent fine sediments at nearfield stations

A detailed analysis of post-outfall operation *Clostridium perfringens* spore concentrations, sediment grain size, and total organic carbon compared with data from just the two years preceding outfall start-up rather than the entire baseline period did suggest that an effluent signal could be detected at stations near the outfall. This finding was expected.

Sediment-Profile Imaging

Sediment-profile imaging measurements in 2003 showed no effects from the outfall. The mean apparent color RPD depth was statistically the same as the baseline mean (Figure 4-5). No relationship between RPD depth and outfall operation has been detected, even at Station NF24, a muddy station close to the outfall, where negative effects might be most expected.

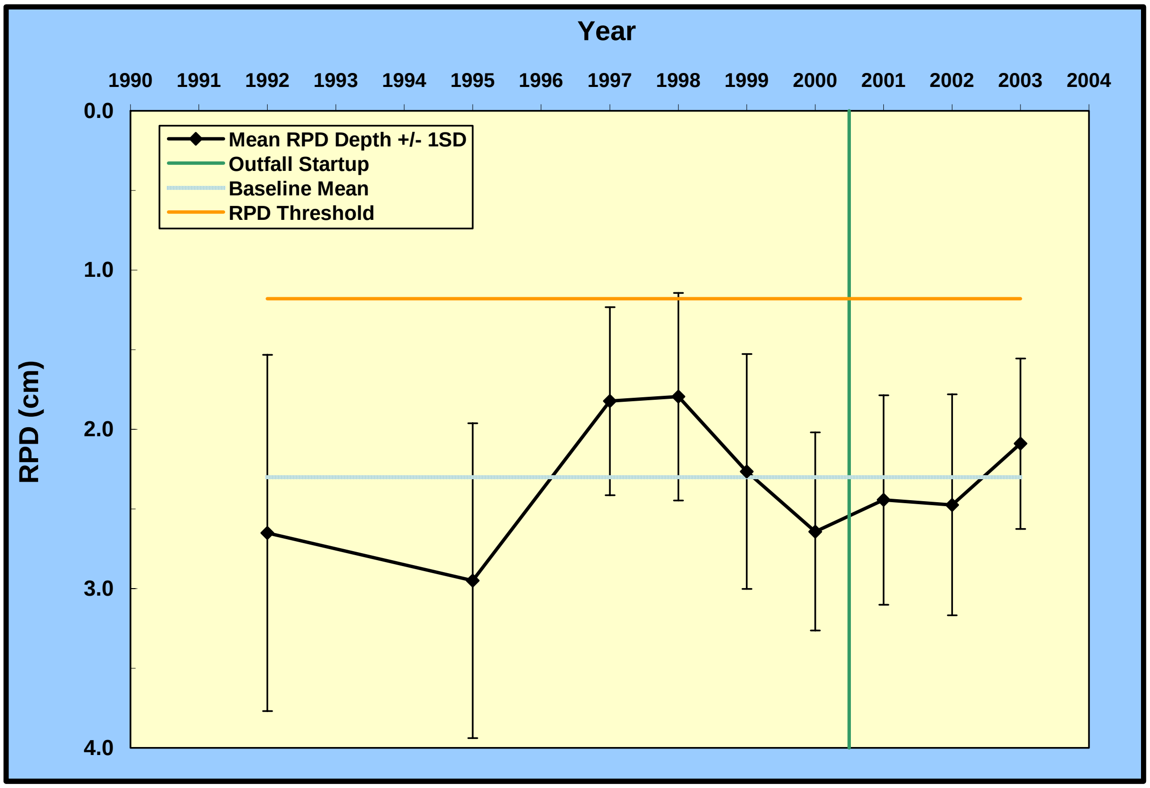


Figure 4-5. Apparent color RPD for all data from nearfield stations

Soft-bottom Communities

The soft-bottom communities have also shown no response to the outfall. During the baseline period, multivariate analyses indicated that sediment grain size was the dominant factor in structuring the benthic communities (Maciolek *et al.* 2004). In the nearfield, stations with fine sediments are dominated by polychaete worms, such as *Prionospio steenstrupi*, *Spio limicola*, *Mediomastus californiensis*, and *Aricidea catherinae*. Sandier stations are 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 differ 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*, predominate at most stations. *Prionospio steenstrupi,* which is dominant at many nearfield stations, is also common at some of the farfield stations. Another polychaete, *Cossura longicirrata*, dominates 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 three years of post-discharge monitoring have detected some statistical differences in community parameters, such as increased numbers of some species and increased 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 (Maciolek *et al.* 2004).

The mean density of animals was highest in 2002 and only slightly lower in 2003 (Figure 4-6). The average number of species increased slightly in 2003 (from 74 to 76 species). One diversity measure, log-series *alpha*, continued an upward trend, while other community parameters, Shannon diversity and Pielou’s evenness were essentially the same in 2003 as in 2002.

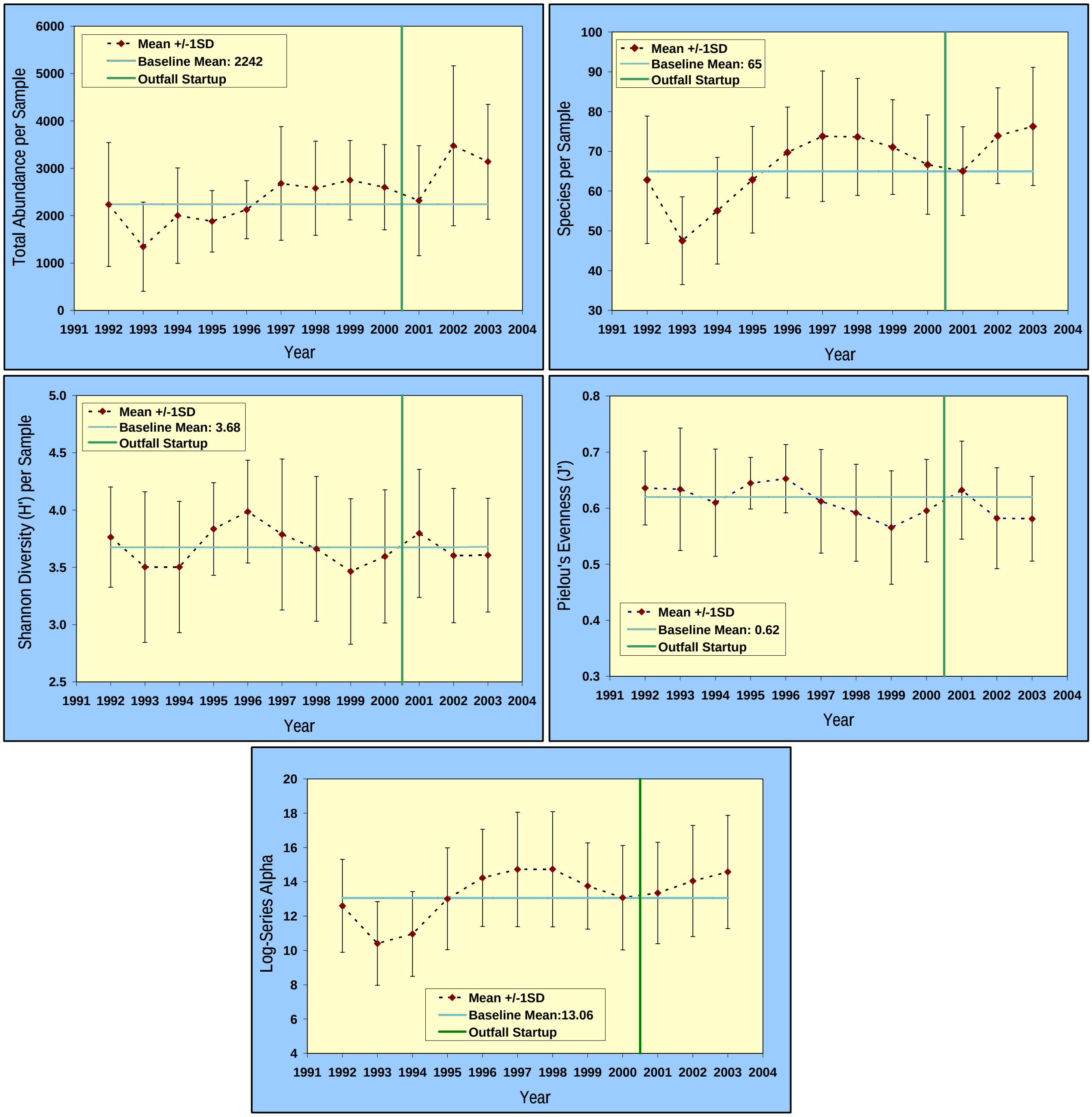


Figure 4-6. Community parameters in the nearfield, 1992-2003: abundance per sample, number species per sample, Shannon diversity, Pielou's evenness, log-series alpha

Hard-bottom Communities

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

Any changes since the outfall began operation have been modest, and it is difficult to attribute them to outfall operation. Sediment drape has increased at three of the nine stations directly to the north of the outfall and at two of the three stations considered northern nearfield reference stations. There have been decreases in coralline algae cover at the same stations. The declines were less pronounced in 2003 than in 2001 and 2002, but coralline algae cover did decline at the third northern nearfield reference site in 2003. Declines in upright algae were also detected at northern stations.

Several trends have been observed that appear to be regional. Abundance of the green sea urchin *Strongylocentrotus droebachiensis* appears to follow a cyclical pattern, declining during 1996-2000, increasing in 2001 and 2002, and declining in 2003. Crabs in the genus *Cancer* and the lobster *Homarus americanus* appear to have increased over time. The cod *Gadus morhua* has also increased in numbers since the mid 1990s, with a decrease in 2003.

One unusual phenomenon in 2003 was the dense aggregations of barnacles *Balanus* spp. observed throughout the study area. Massive settlements of barnacles were found at seven sites north and south of the diffuser and off Scituate. Less dramatic, but still heavy, settlements were found at four additional sites, both near the outfall and at great distance. Barnacles were frequently so crowded that they formed tall, twisted colonies, and overcrowding had led to mass mortality at many sites, including Diffuser #44. These large settlements followed a peak in barnacle larvae detected in 2002 water column monitoring (Figure 4-7).

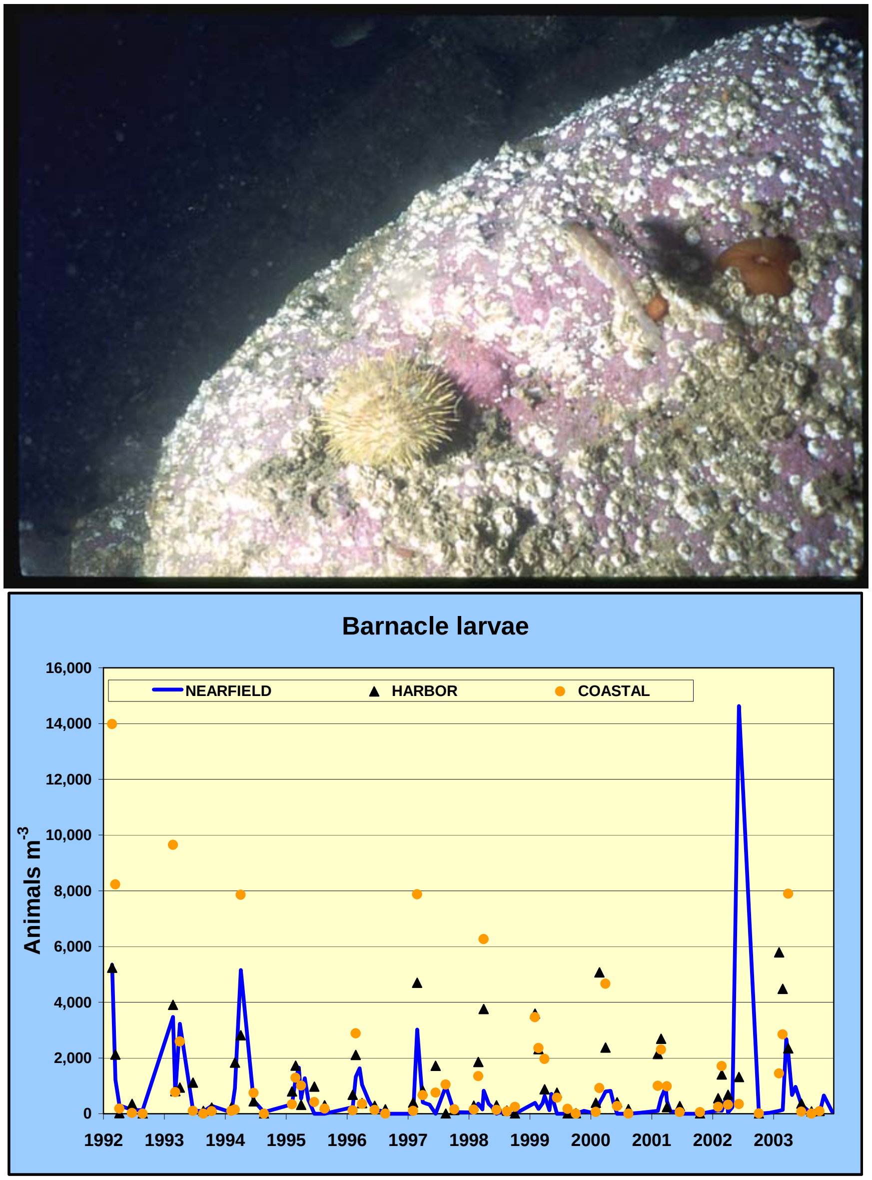


Figure 4-7. Top: dense barnacle settlement photographed in 2003; Bottom: abundance of barnacle larvae in the water column, 1992-2003

Contingency Plan Thresholds

No contingency plan threshold parameters for sea-floor monitoring were exceeded in 2003. Those parameters include contaminant concentrations, RPD depth, and benthic diversity and species composition in soft-bottom communities (Table 4-3).

Table 4-3. No contingency plan baseline and threshold values for sea-floor monitoring were exceeded in 2003.

Location	Parameter	Caution Level	Warning Level	2003 Results
Sediments, nearfield	RPD depth	1.18 cm	None	2.14 cm
Benthic diversity, nearfield	Species per sample	<47.74 or >79.95	None	76.5
	Fisher's log-series alpha	<10.05 or >15.63	None	14.63
	Shannon diversity	<3.30 or >4.02	None	3.61
	Pielou's evenness	<0.56 or >0.67	None	0.58
Species composition, nearfield	Percent opportunists	10%	25%	0.53%

5. Fish and Shellfish

Background

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

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

Is it safe to eat fish and shellfish?

Will toxic chemicals accumulate in the edible tissues of fish and shellfish, and thereby contribute to human health problems?

- Has the level of contaminants in the tissues of fish and shellfish around the outfall changed since discharge began?
- Do the levels of contaminants in the edible tissue of fish and shellfish around the outfall represent a risk to human health?
- Are the contaminant levels in fish and shellfish different between outfall, Boston Harbor, and a reference site?

Are natural/living resources protected?

Will fish and shellfish that live near or migrate by the diffuser be exposed to elevated levels of some contaminants, potentially contributing to adverse health in some populations?

- Has the level of contaminants in the tissues of fish and shellfish around the outfall changed since discharge began?
- Are the contaminant levels in fish and shellfish different between the outfall, Boston Harbor, and a reference site?
- Are the contaminant levels in fish and shellfish different between outfall, Boston Harbor, and a reference site?
- Has the incidence of disease and/or abnormalities in fish or shellfish changed?

Because many toxic contaminants adhere to particles, animals that live on the bottom, in contact with sediments, and animals that eat bottom-dwelling organisms are most likely to be affected. Exposure to contaminated sediments could result in fin erosion, black gill disease, or other, subtler, abnormalities in flounder, lobster, or other bottom-dwelling animals. Shellfish that feed by filtering suspended matter from large volumes of water are also potential bioaccumulators of toxic contaminants. Consumption of filter-feeding animals by predators could result in transferring contaminants up the food chain and ultimately to humans.

Monitoring Design

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

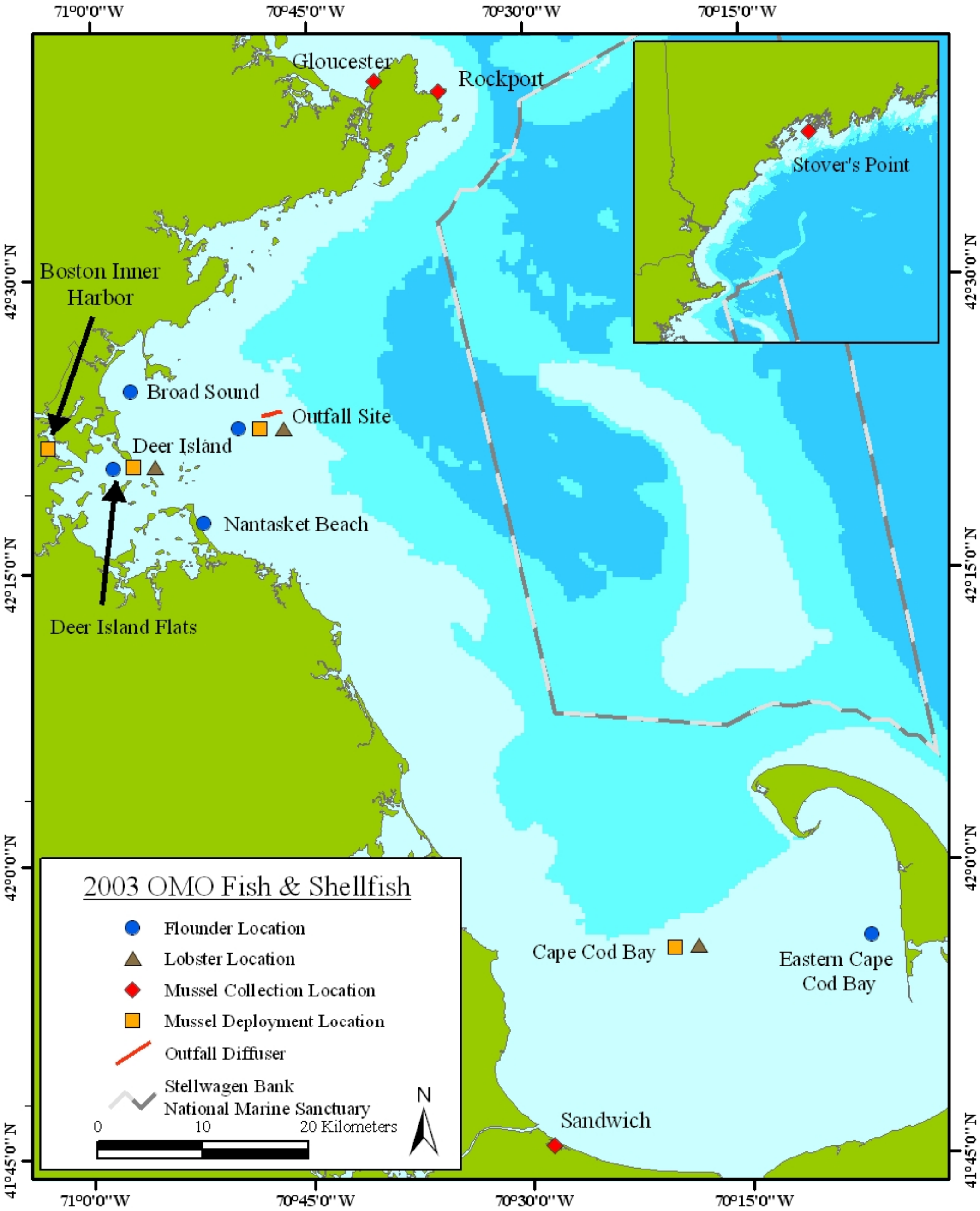


Figure 5-1. Sampling areas for fish and shellfish monitoring

Winter Flounder

Like all flatfish, winter flounder live on and eat food from the bottom, often lying partially buried in the sediments. Consequently, flounder can be exposed to contaminants directly, through contact with the sediments, or indirectly, by ingesting contaminated prey. Flounder are collected from five locations—Deer Island Flats, Broad Sound, off Nantasket Beach, the outfall site, and eastern Cape Cod Bay. Livers are examined to quantify three types of vacuolation (centrotubular, tubular, and focal, representing increasing severity), microphage aggregation, biliary duct proliferation, and neoplasia or tumors. Neoplasia and vacuolation have been associated with chronic exposure to contaminants.

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

Lobster

Lobsters live on a variety of surfaces within the region, including mud, sand, gravel, and rock outcrops. Commercial lobstermen collect lobsters for the monitoring program. Lobsters are taken from Deer Island Flats, the area near the outfall, and eastern Cape Cod Bay to determine specimen health and tissue contaminant burden. Chemical analyses are performed on composite samples. Meat (from the tail and claw) and hepatopancreas are analyzed for lipids, PCBs, pesticides, and mercury. Hepatopancreas samples are also analyzed for PAHs, lead, silver, cadmium, chromium, copper, nickel, and zinc.

Blue Mussel

Like other filter feeders, blue mussels process large volumes of water and can concentrate toxic metals and organic compounds in their tissues. Mussels can be readily maintained in fixed cages, so they are convenient monitoring tools. Mussels are collected from clean reference sites (which have included Rockport, Gloucester, and Sandwich, Massachusetts, and Stover's Point, Maine). They are placed in cages and deployed in replicate arrays. In 2003, deployment sites included Boston Inner Harbor, Deer Island Light, the outfall site, the "B" Buoy located just to the south of the outfall site, and Cape Cod Bay.

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.

Results

Winter Flounder

Fifty sexually mature (at least three years old) winter flounder were taken from each of the five sampling sites in April and May 2003 (Lefkovitz *et al.* 2004). Each of the fish was examined for physical characteristics. All fish were used for histological and age analyses. Fifteen fish from each of three sites were designated for chemical analyses.

Tumors were absent and incidence of fin erosion was low in fish collected in 2003. However, external ulcers were noted on many fish, particularly on fish from Boston Harbor and western Massachusetts Bay. Ulcers had not been specifically included as part of the physical assessment provided for in the monitoring plan. Consequently, their presence prompted a special study (described in Section 6, Special Studies).

As in previous years, the mild centrotubular hydropic vacuolation (CHV) was the most common form of vacuolation noted in histological analyses. Incidence of CHV was low at all sites (Figure 5-2) and below the baseline mean at the outfall site.

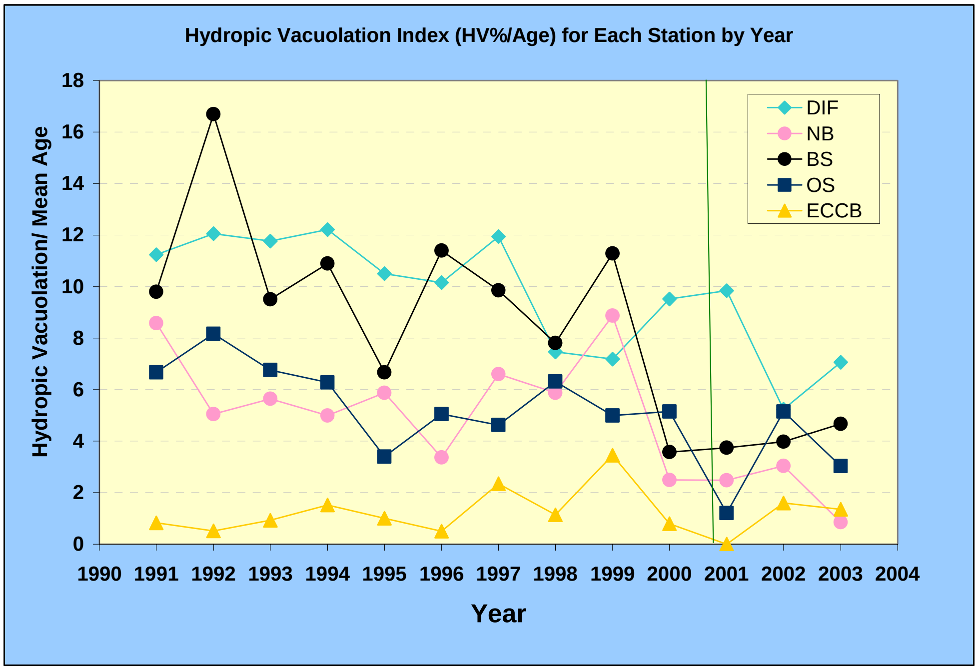


Figure 5-2. Prevalence of centrotubular hydropic vacuolation (CHV) normalized for age (DIF = Deer Island Flats, OS = Outfall Site, ECCB = Eastern Cape Cod Bay, NB = Nantasket Beach, and BS = Broad Sound)

Levels of organic contaminants in flounder fillets and livers from fish caught at the outfall site in 2003 were within the historical baseline range. In fillets, average levels of organic contaminants (such as PCBs; Figure 5-3, top) were not significantly different for the three post-discharge years when compared to the final three years of baseline monitoring, during which secondary treatment had been implemented. In flounder livers (Figure 5-3, bottom), mean PCB concentrations were statistically greater in the post-discharge years compared to the three years immediately before outfall start-up (2,419 ng/l compared to 1,222 ng/l). However, the 2003 levels of PCBs in flounder livers were within the range for the entire baseline.

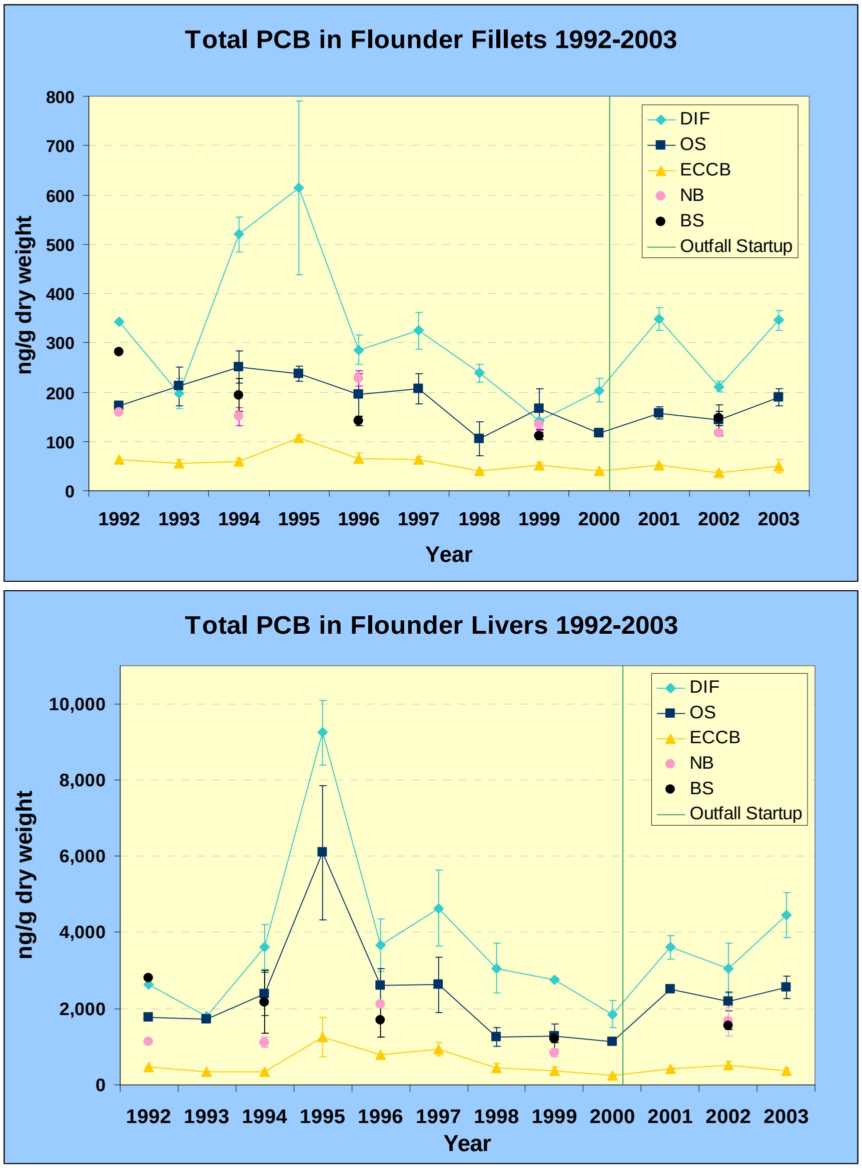


Figure 5-3. PCB concentrations in flounder fillets and livers. (DIF = Deer Island Flats, OS = Outfall Site, ECCB = Eastern Cape Cod Bay, NB = Nantasket Beach, BS = Broad Sound)

Concentrations of most metals in 2003 fell within the historical range. For mercury, the 2003 mean level in flounder fillet (Figure 5-4) and livers (not shown) from the outfall site was relatively high compared to 2001 and 2002; however, mean mercury levels from the three post-outfall-relocation years (considered together) were not significantly different from the 1998-2000 years. MWRA is further monitoring mercury levels in flounder to evaluate whether the high value from 2003 represents a trend or whether it is a result of variation in sampling and measurement.

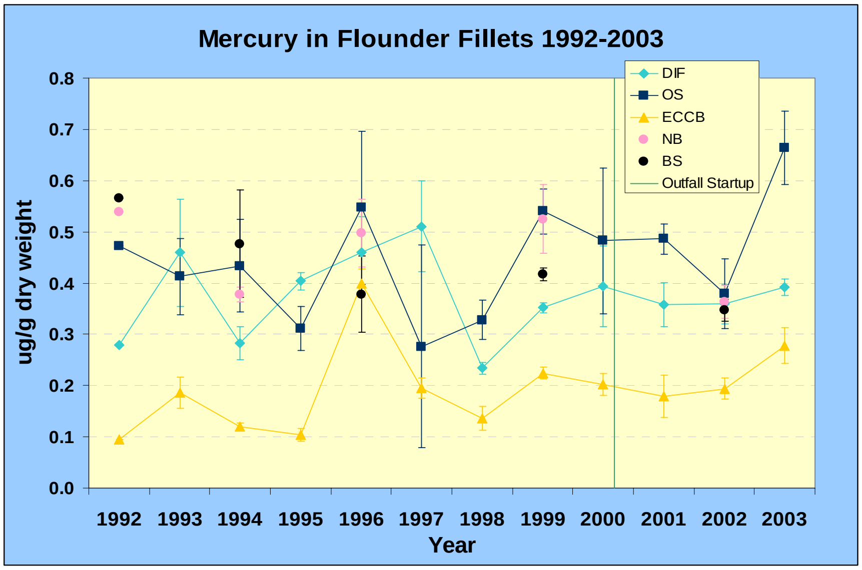


Figure 5-4. Mercury in flounder fillets, 1992-2003 (DIF = Deer Island Flats, OS = Outfall Site, ECCB = Eastern Cape Cod Bay, NB = Nantasket Beach, BS = Broad Sound)

Lobster

Fifteen lobsters from each of three areas—Deer Island Flats, the outfall site, and eastern Cape Cod Bay—were purchased from commercial lobstermen observed to be fishing in the areas (Lefkovitz *et al.* 2004). The lobsters were approximately the same size at all sites. Only males were collected at eastern Cape Cod Bay, mostly males were taken at Deer Island Flats, and the sex ratio was about even in lobsters from the outfall site. No gross abnormalities were noted.

For most compounds, contaminant concentrations in lobster meat and hepatopancreas were low, and no effects of relocating the outfall were detected. PCB concentrations showed a different pattern, with an anomalously high mean concentration in meat and hepatopancreas from animals collected at the outfall site (Figure 5-5).

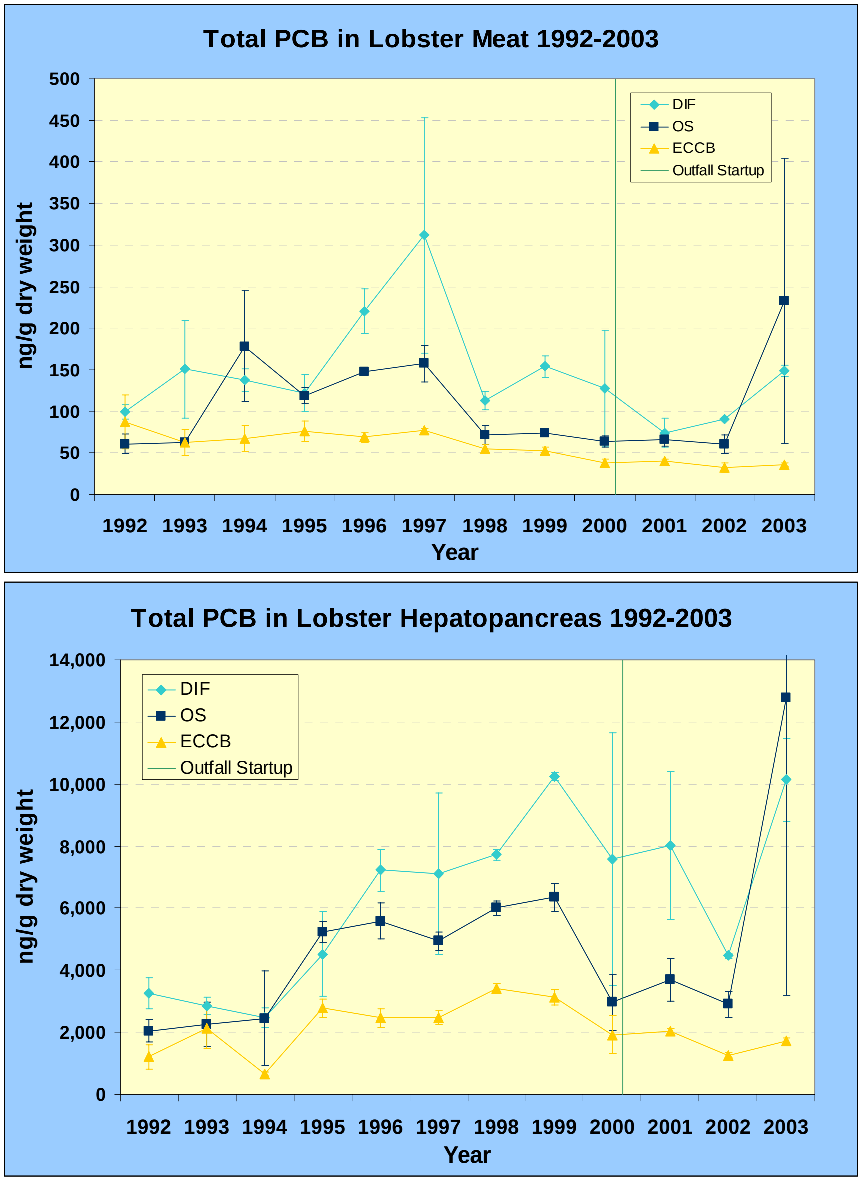


Figure 5-5. PCB concentrations in lobster meat and hepatopancreas (DIF = Deer Island Flats, OS = Outfall Site, ECCB = Eastern Cape Cod Bay)

These findings prompted additional analyses, which showed that the high values could be attributed to one individual lobster in one of the composite samples. Confirmatory analyses using gas chromatography/mass spectrometry (GC/MS) indicated that the pattern of PCB congeners in the highly contaminated animal was different from the pattern in less contaminated lobsters (Figure 5-6). The pattern also varied from that seen in lobsters from New Bedford Harbor, an area that is highly contaminated with PCBs. The reason for the anomaly is not known.

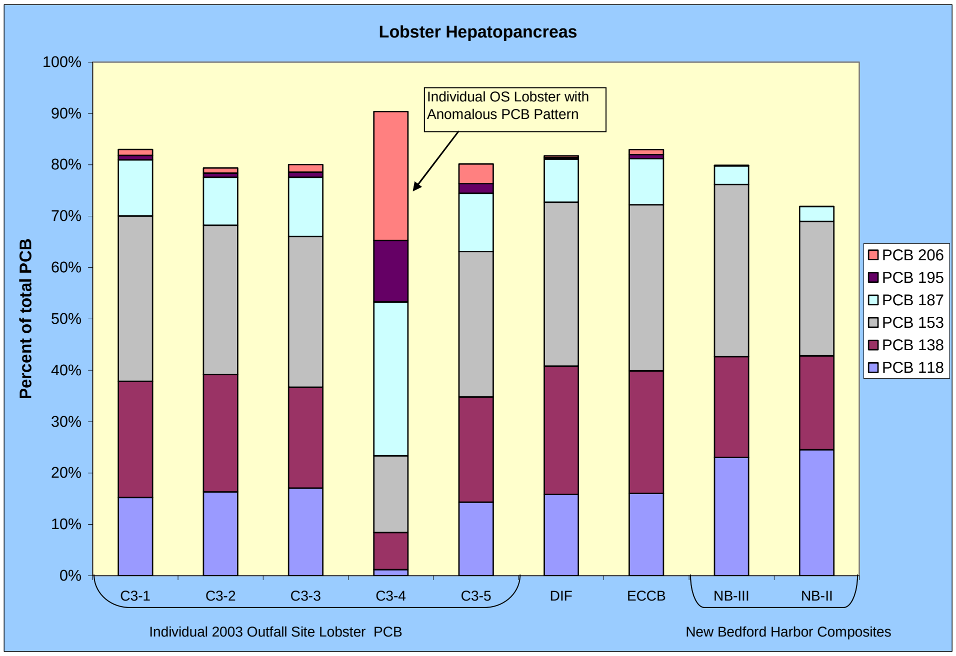


Figure 5-6. Distribution of selected PCB congeners in lobster hepatopancreas samples from Massachusetts Bay and New Bedford Harbor

Blue Mussel

Mussel arrays were recovered after 40 and 60 days (Lefkovitz *et al.* 2004). Survival was high, ranging from 92 to 99%.

Historically, the Boston Inner Harbor and Deer Island sites have shown the highest concentrations of contaminants, and the Cape Cod Bay and outfall sites were the lowest. Overall, the inner harbor site still showed the greatest degree of bioaccumulation (Figure 5-7).

It has been possible to detect some changes in mussels deployed at the outfall site (Table 5-2), both because the mussels are placed within the mixing zone where they are continually exposed to effluent and because the laboratory measurements used by the program are sensitive and precise. There have been significant increases in chlordane and PAHs in mussels deployed at the outfall site and small but statistically significant increases in mercury, copper, lead, and DDTs. For most constituents, the increases are only apparent when post-discharge data are compared to data from the three years prior to outfall start-up, 1998-2000, when secondary treatment had been implemented but discharge was still to the harbor.

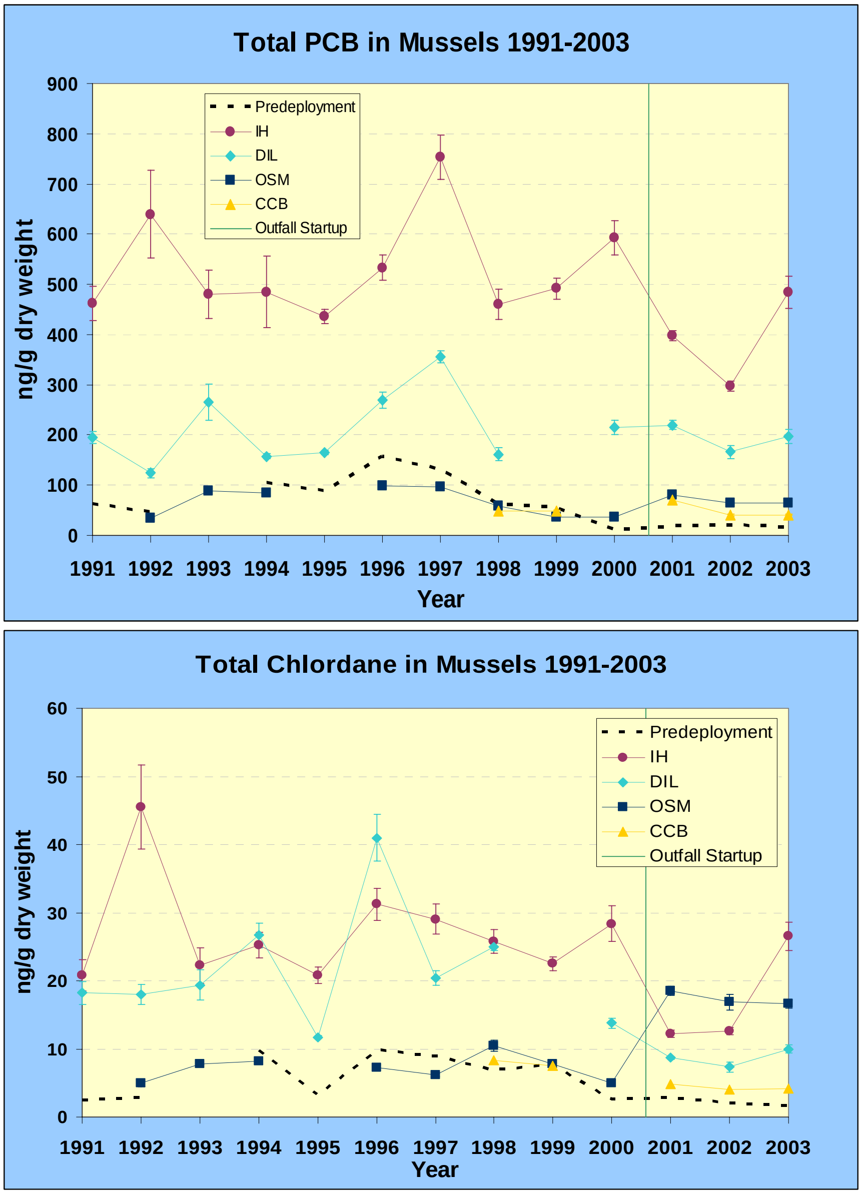


Figure 5-7. Selected contaminant concentrations in mussels. (IH = Inner Harbor, DIL = Deer Island Light, OSM = Outfall Site, CCB = Cape Cod Bay)

Table 5-2. Comparison of contaminant concentrations at the outfall site during the three years prior to and the three years since outfall operation. (Student two-sample T-test, with increases significant at <0.05; NA=not analyzed; ND=not detected. The comparison of three years before and after discharge was chosen to examine solely the period in which secondary treatment had been implemented.)

Parameter	**Flounder**		**Lobster**		**Mussel**
	Fillet	**Liver**	**Meat**	**Hepatopancreas**	
Cadmium	NA	No change	NA	No change	NA
Chromium	NA	No change	NA	No change	NA
Copper	NA	No change	NA	No change	NA
Lead	NA	No change	NA	No change	Increased
Mercury	No change	No change	No change	No change	Increased
Nickel	NA	No change	NA	No change	NA
Silver	NA	No change	NA	No change	NA
Zinc	NA	No change	NA	No change	NA
Total DDTs	No change	No change	No change	Decreased	Increased
Total PCBs	No change	Increased	No change	No change	Increased
Total PAHs	NA	No change	NA	No change	Increased
Total chlordanes	No change	No change	Decreased	Decreased	Increased
Dieldrin	No change	No change	No change	Decreased	Increased
LMW PAHs	NA	NA	NA	NA	No change
HMW PAHs	NA	NA	NA	NA	Increased

Contingency Plan Thresholds

Threshold parameters for fish and shellfish include levels of toxic contaminants in flounder, lobster, and mussels and liver disease in flounder (Table 5-3). Some thresholds are based on U.S. Food and Drug Administration (FDA) limits for maximum concentrations of specific contaminants in edible portions of food. Others are based on the baseline monitoring.

During 2003, as in 2001 and 2002, the caution threshold for PAHs was exceeded in mussels. The earlier exceedances were reviewed (Hunt *et al.* 2002c, OMSAP 2003c) and have been found to be a result of the placement of the mussels within the plume rather than an unexpected effect of the discharge.

Table 5-3. Contingency plan baseline, threshold, and 2003 values for fish and shellfish monitoring

Parameter Type/ Location	Parameter	Baseline	Caution Level	Warning Level	2003 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	0.105 ppm
Flounder tissue, lipid normalized, nearfield	Chlordane	242 ppb	484 ppb	None	143 ppb
	Dieldrin	63.7 ppb	127 ppb	None	29.2 ppb
	DDT	775.9 ppb	1552 ppb	None	583 ppb
Flounder nearfield	Liver disease (CHV)	24.4%	44.9%	None	16%
Lobster tissue nearfield	PCB	0.015 ppm	1 ppm wet weight	1.6 ppm wet weight	0.029 ppm
	Mercury	0.148 ppm	0.5 ppm wet weight	0.8 ppm wet weight	0.112 ppm
Lobster tissue, lipid normalized, nearfield	Chlordane	75 ppb	150 ppb	None	77.9 ppb
	Dieldrin	161 ppb	322 ppb	None	27.8 ppb
	DDT	341.3 ppb	683 ppb	None	129 ppb
Mussel tissue nearfield	PCB	0.011 ppm	1 ppm wet weight	1.6 ppm wet weight	0.0085 ppm
	Lead	0.415 ppm	2 ppm wet weight	3 ppm wet weight	0.226 ppm
	Mercury	0.019 ppm	0.5 ppm wet weight	0.8 ppm wet weight	0.017 ppm
Mussel tissue, lipid normalized, nearfield	Chlordane	102.3 ppb	205 ppb	None	191 ppb
	Dieldrin	25 ppb	50 ppb	None	21.6 ppb
	DDT	241.7 ppb	483 ppb	None	179 ppb
	PAH	1080 ppb	2160 ppb	None	3690 ppb, caution level exceedance

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 2003, special studies included a visual inspection of the outfall, an analysis of water chemistry data from Boston Harbor and Massachusetts Bay, continued study of nutrient flux at the sediment-water interface, marine mammal observations, assessment of PCB analyses used in fish and shellfish monitoring, and a review of available information on flounder ulcers.

Outfall Inspection

MWRA conducted a visual inspection of the outfall during June 2003. The inspection used the same equipment as is used in hard-bottom surveys to record the condition of each outfall riser and diffuser cap on videotape. The survey found no damage that might affect proper functioning of the outfall. All diffuser caps had the same vigorous epifaunal growth as has been documented during hard-bottom surveys of diffusers #2 and #44, (such as in Figure 6-1). The growth did not obstruct any of the diffuser ports that are open and discharging.

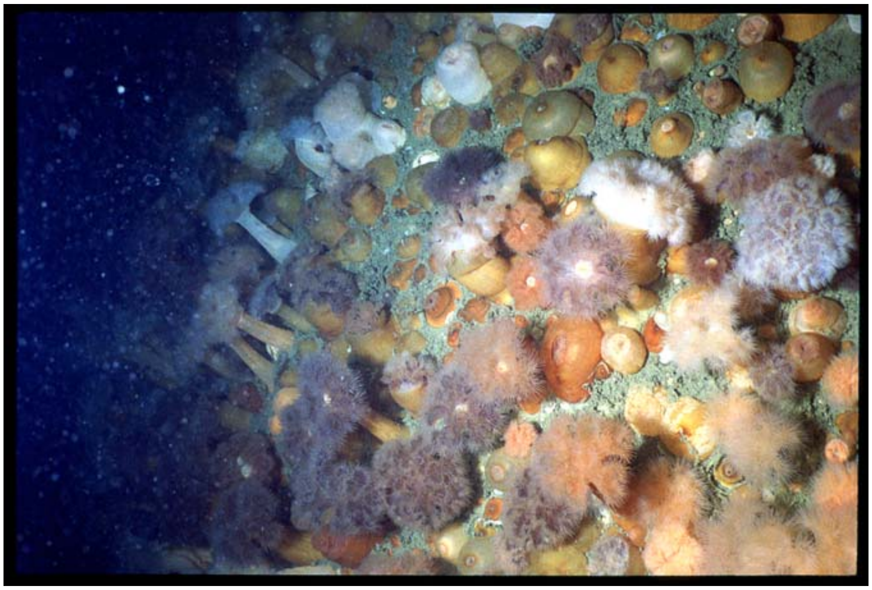


Figure 6-1. Outfall diffuser #2 (photograph taken during 2003 hard-bottom survey)

Water Chemistry in Boston Harbor and Massachusetts Bay

MWRA recently completed an analysis of water chemistry data from Boston Harbor and Massachusetts Bay to determine the effects of ceasing effluent discharge in the harbor and transferring it to the bay (Taylor 2004). The analysis used data from the outfall monitoring program and additional information from a separate harbor monitoring program. It compared baseline water quality data with information from the first 24 months following relocation of the outfall.

In Boston Harbor, there were significant improvements in many water quality parameters during the first 24 months following diversion of the effluent. Nutrient measurements, including total nitrogen, dissolved inorganic nitrogen, total phosphorus, dissolved inorganic phosphorus, the molar ratio of total nitrogen to total phosphorus, and the molar ratio of dissolved inorganic nitrogen to phosphorus all declined during the period. Phytoplankton biomass, measured as chlorophyll *a*, and particulate organic carbon also declined during the period. These measurements are all indicative of healthier, less eutrophic conditions.

During the same period, at the nearfield stations close to the Massachusetts Bay outfall, there were significant increases in some of the water quality parameters. Significant increases in total nitrogen, dissolved organic nitrogen, total phosphorus, the molar ratio of dissolved inorganic nitrogen to phosphorus, and particulate organic carbon were detected. Increases in these parameters were not significant when considered over the whole of Massachusetts Bay.

For Massachusetts Bay as a whole, significant changes were detected for three parameters: an increase in the molar ratio of dissolved inorganic nitrogen to silicate, a decrease in total organic carbon, and an increase in salinity. These changes are thought to be responses to regional conditions rather than to the outfall.

For example, Figure 6-2 shows dissolved inorganic nitrogen (top) and chlorophyll (bottom) along a transect of stations extending from the New England Aquarium in Boston’s inner harbor to the outfall and then southeast to a station located off the tip of Race Point at the edge of Cape Cod Bay. For both parameters, there were significant decreases in the harbor following the transfer of the outfall, and for nitrogen, there was a concurrent increase in concentrations at the outfall site. No significant changes were detected beyond the nearfield stations. Although dissolved inorganic nitrogen increased in the nearfield, there was no relative increase in chlorophyll in the nearfield. There was a dramatic drop in chlorophyll in the harbor.

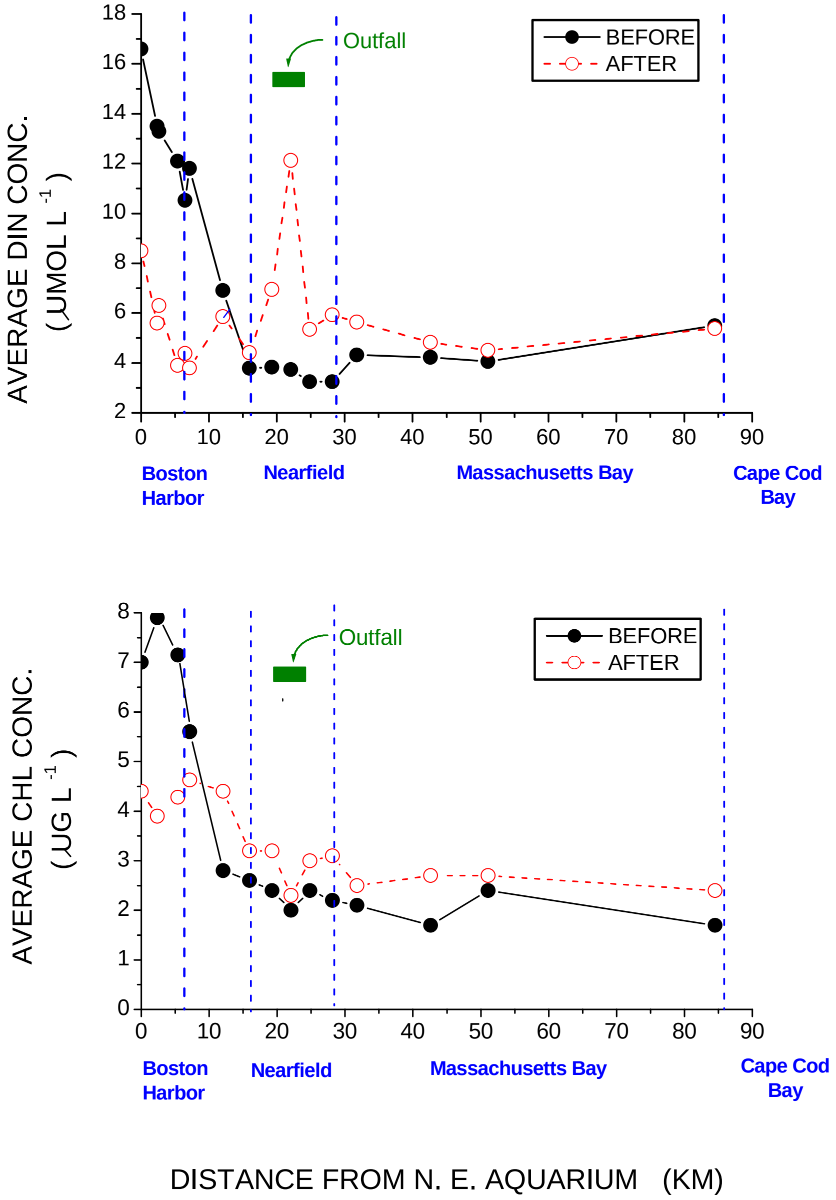


Figure 6-2. Dissolved inorganic nitrogen and chlorophyll concentrations before and after outfall transfer from Boston Harbor to Massachusetts Bay (from Taylor 2004)

Nutrient Flux

One concern about the outfall was that diversion of effluent from Boston Harbor to Massachusetts Bay might increase loads of organic matter to the nearfield, enhancing benthic respiration and nutrient fluxes between the sediments and the water column. 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 rates of denitrification, sediment oxygen demand, and the flux of nutrients in the vicinity of the outfall and to assess the importance of these processes on nutrient and oxygen levels (Table 6-1).

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?

MWRA has been monitoring the sediment-water interface since 1992. In 2003, studies were continued at four sites in the harbor, three sites in the nearfield, and one site in Stellwagen Basin (Tucker *et al.* 2004). Since the outfall came on line, MWRA has detected no changes that could be attributed to the organic matter enrichment at the nearfield or in Stellwagen Basin. Rates of benthic respiration and nutrient fluxes have been well within the baseline ranges. Chlorophyll levels in the sediments also remained within the baseline range. Small increases in organic matter content of surface sediments in the nearfield, which had been detected in 2001 and 2002, did not continue in 2003.

While little or no change has been detected in Massachusetts Bay, positive changes have been evident in Boston Harbor. Decreases in total organic carbon have been measured at some stations. Sediment chlorophyll concentrations decreased at two harbor stations in 2002. At three stations, sediment oxygen demand and nutrient fluxes were lower than at any previous time during the monitoring period, and large variability among harbor stations had essentially vanished.

Marine Mammal Observations

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

Since 1995, MWRA has included endangered species observers on monitoring surveys. In 2003, observers were included on 26 water quality surveys (Short *et al.* 2004). 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 2003 surveys, 16 individual whales, 6 harbor porpoise, and more than 100 Atlantic white-sided dolphins were directly observed by the trained observers and other members of the monitoring team. Thirteen large baleen whales were sighted, more than twice as many as in 2002, but fewer than in 1998-2001. Studies by the Whale Center of New England confirmed an increase in humpback whales in the region compared to 2002, primarily over the southeast portion of Stellwagen Bank.

PCB Analyses

Over the years of fish and shellfish monitoring, chemists noted that concentrations of one PCB congener, PCB 180, were high relative to other congeners. This finding was particularly noticed in samples with higher overall concentrations of organic compounds, such as flounder livers and lobster hepatopancreas. A special study (Lefkovitz *et al.* 2001) found that the analytical method used by the program, gas chromatography/electron capture detection (GC/ECD), could be responsible for the high concentrations. Using the standard GC/ECD method, a common environmental compound, bis-2-ethylhexyl phthalate, often coelutes with PCB 180.

During 2003, MWRA reviewed monitoring program data to determine the effects of including or not including PCB 180 data in calculating total PCB concentrations. The review found that overall, the effects on the data were not great. Figure 6-3, for example, shows little change to average total PCB levels over the course of the monitoring program. However, the difference in some individual samples was high—as high as a 42% change in total PCBs. As a result of the study, MWRA will exclude PCB 180 from evaluations in its annual fish and shellfish monitoring reports. The congener will continue to be used in calculations of total PCBs for threshold testing.

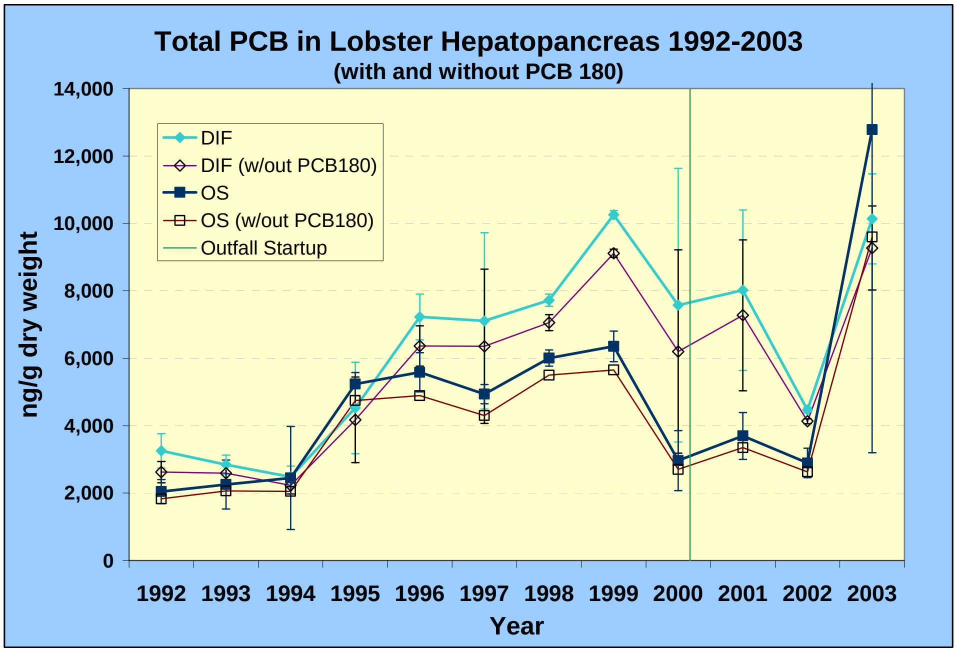


Figure 6-3. Total PCBs in lobster hepatopancreas at Deer Island Flats (DIF) and the outfall site (OS) with and without PCB 180

Flounder Ulcers

During the 2003 sampling, scientists noted external ulcers on the blind (bottom) side of a number of flounder (Figure 6-4). This unusual finding prompted a review of additional information from other investigators, including the Massachusetts Division of Marine Fisheries (MDMF), EPA Narragansett Laboratory, and NMFS (Moore 2003, Lefkovitz *et al.* 2004). The review found that the highest prevalence of ulcers was found Boston Harbor and western Massachusetts Bay (Figure 6-5), and indicated that the ulcers had not been frequently observed prior to 2001. MWRA requested additional testing of the fish, including microbiological and histological observations of the ulcers. These tests failed to detect an etiology of the lesions, although there appeared to be an infectious process involved.

As a result, studies were planned to expand the regular April 2004 flounder survey to increase the number of stations and to study the microbiology of the lesions.

Figure 6-4. Blind-side flounder ulcers

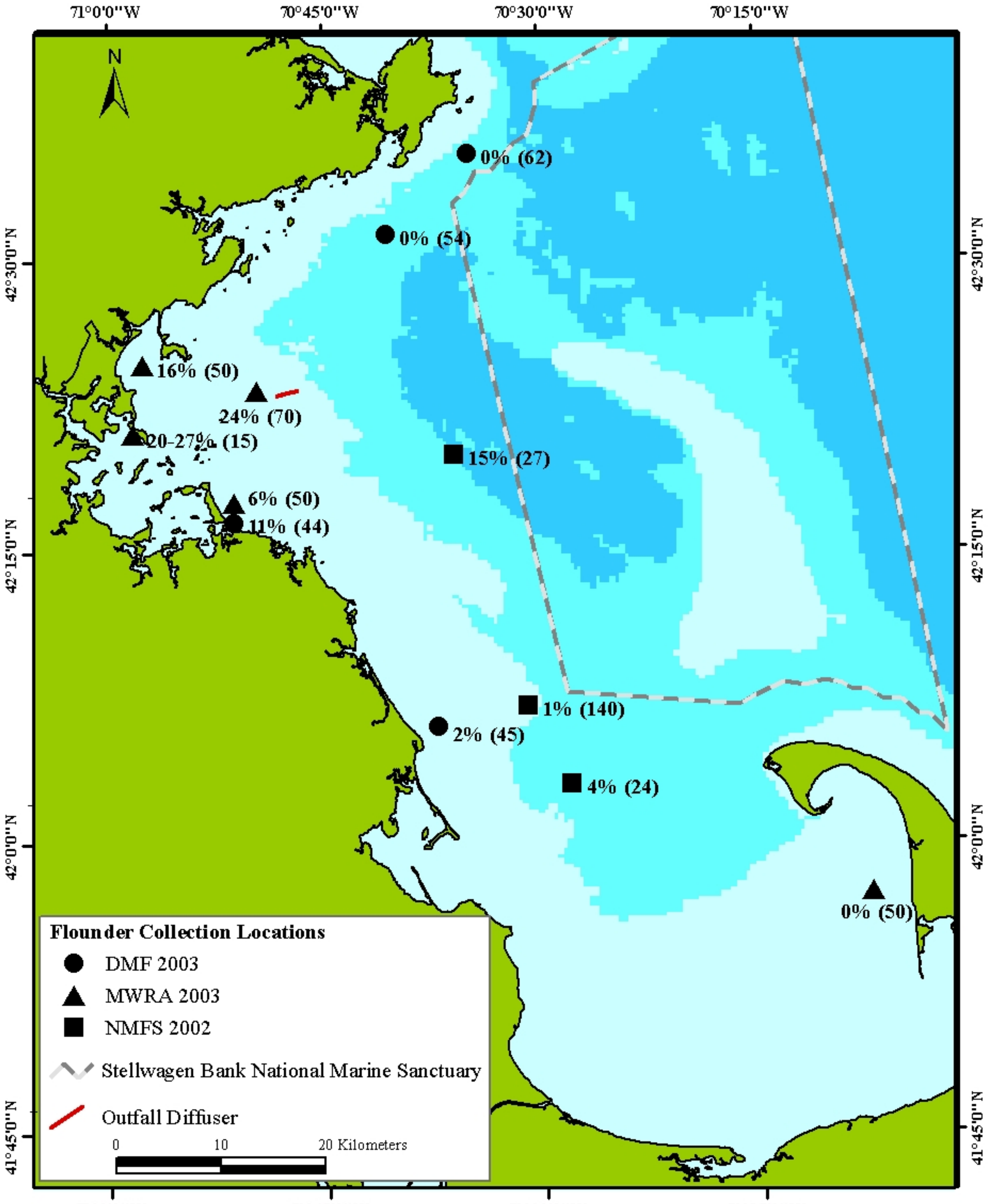


Figure 6-5. Prevalence of ulcers in winter flounder noted in 2002 and 2003 (Numbers indicate the percentage of fish with ulcers at each location. Numbers in parentheses indicate number of fish examined.)

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 of Massachusetts Bay and the rest of the Gulf of Maine. Its boundaries lie approximately 25 miles east of Boston, three miles north of Provincetown, and three miles south of Gloucester. Stellwagen Basin, which is partially within the sanctuary, is the deepest part of Massachusetts Bay and a long-term sink for fine-grained sediments. Stellwagen Bank, a sand-and-gravel plateau, lies to the east of Stellwagen Basin and has water depths of about 65 feet. Tidal mixing of nutrients throughout the relatively shallow water column creates a rich habitat for marine life on Stellwagen Bank.

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

Monitoring Design

MWRA’s regular water-column and sea-floor monitoring efforts include stations within and near the sanctuary. Five water-column stations, including four within the sanctuary and one just outside its northern border, are considered “boundary” stations, that is, 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.

Since 2001, the sanctuary managers, in conjunction with MWRA’s contractor Battelle, have conducted a supplemental monitoring program, which added four stations to the August and October MWRA surveys (Figure 7-1). These sites were selected to provide a more comprehensive evaluation of water quality across the sanctuary and to increase the understanding of the potential effects of the relocated outfall. The program and results for 2003 are presented described in Libby *et al.* 2004b.

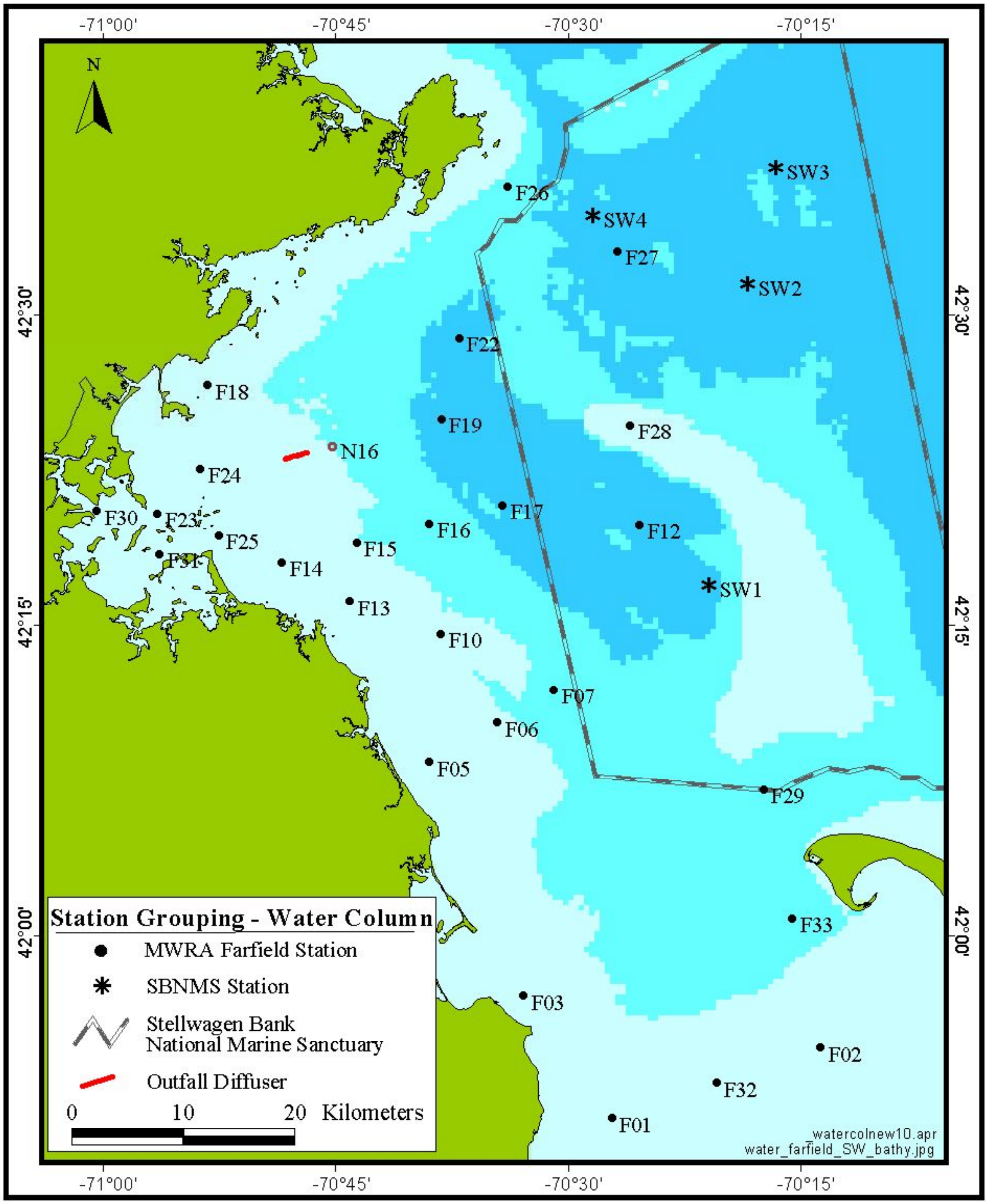


Figure 7-1. Water column stations, including the additional Stellwagen Bank National Marine Sanctuary (SBNMS) stations sampled in August and October 2001-2003

Two MWRA sea-floor stations are within the sanctuary, one at the southern boundary and one within Stellwagen Basin (see Figure 4-2). A third sea-floor station is just north of the sanctuary boundary and a fourth station 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 circulation pattern that transports diluted effluent south and southeastward in Massachusetts Bay. These stations are sampled annually in August.

Results

Water Column

Overall, water quality within the sanctuary was excellent during 2003. There was no indication of any effect of the MWRA outfall (Libby *et al.* 2004a, 2004b).

Mean concentrations of dissolved oxygen in bottom waters of Stellwagen Basin during regular MWRA monitoring were within the low end of the baseline range. The survey minimum concentration measured in Stellwagen Basin in 2003 was 7.07 mg/l, well above the 6.2 mg/l contingency plan background measurement (Figure 7-2). The survey minimum percent saturation was 73.2%, above the 66.3% contingency plan background.

In 2003, as in 2002, the water column remained stratified until the late fall, and dissolved oxygen concentrations continued to decline after the October survey. Data from the GoMOOS “A” mooring, located in the northwest corner of the sanctuary, indicated that the minimum concentration, 6.2 mg/l, was reached on November 10 (Figure 7-3). Dissolved oxygen probably reached concentrations lower than 6 mg/l within Stellwagen Basin.

Elevated concentrations of ammonia were measured at offshore and boundary stations in October. However, the elevated ammonia concentrations were not likely to be associated with the outfall. Currents at the time were not transporting water masses from the outfall to offshore, and phosphate concentrations did not follow the same pattern of elevated concentrations.

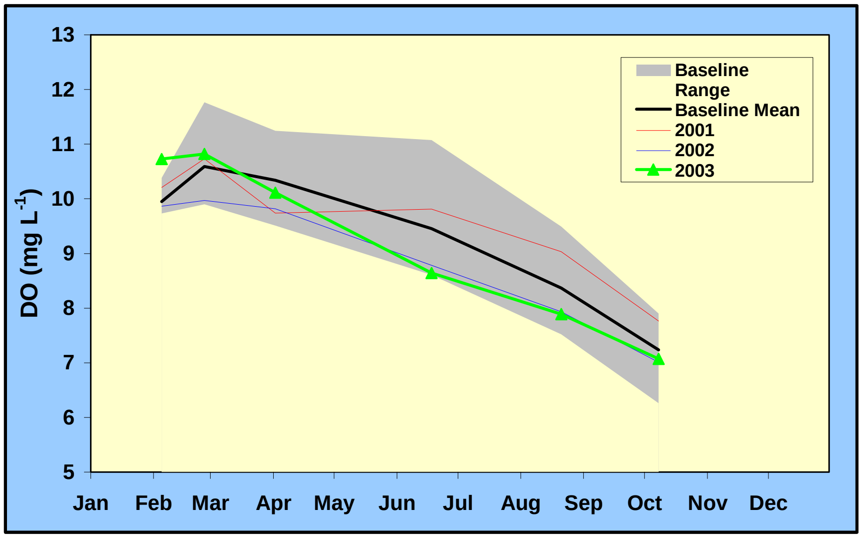


Figure 7-2. Post-discharge survey mean dissolved oxygen concentrations in Stellwagen Basin compared to baseline mean and range

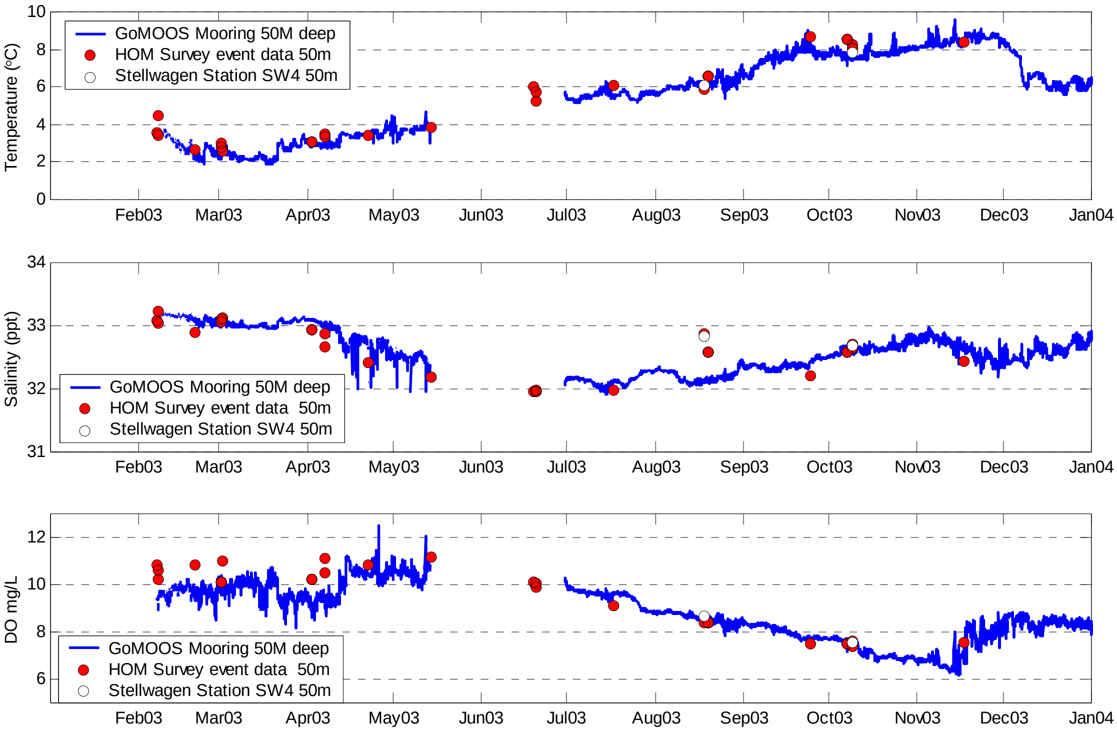


Figure 7-3. Near-bottom salinity, temperature, and dissolved oxygen data from the GoMOOS "A" mooring, and MWRA and Stellwagen Bank monitoring stations

Annual mean nutrient concentrations in the sanctuary have not changed substantially since the outfall began operation (Figure 7-4). While ammonia concentrations have risen in the nearfield, there has been no comparable annual increase in Stellwagen Bank or Cape Cod Bay despite the elevated levels observed in October 2003. Nitrate concentrations have remained the same in all regions, with concentrations within the sanctuary higher than but not significantly different from levels at other monitoring stations, as they have been in other years.

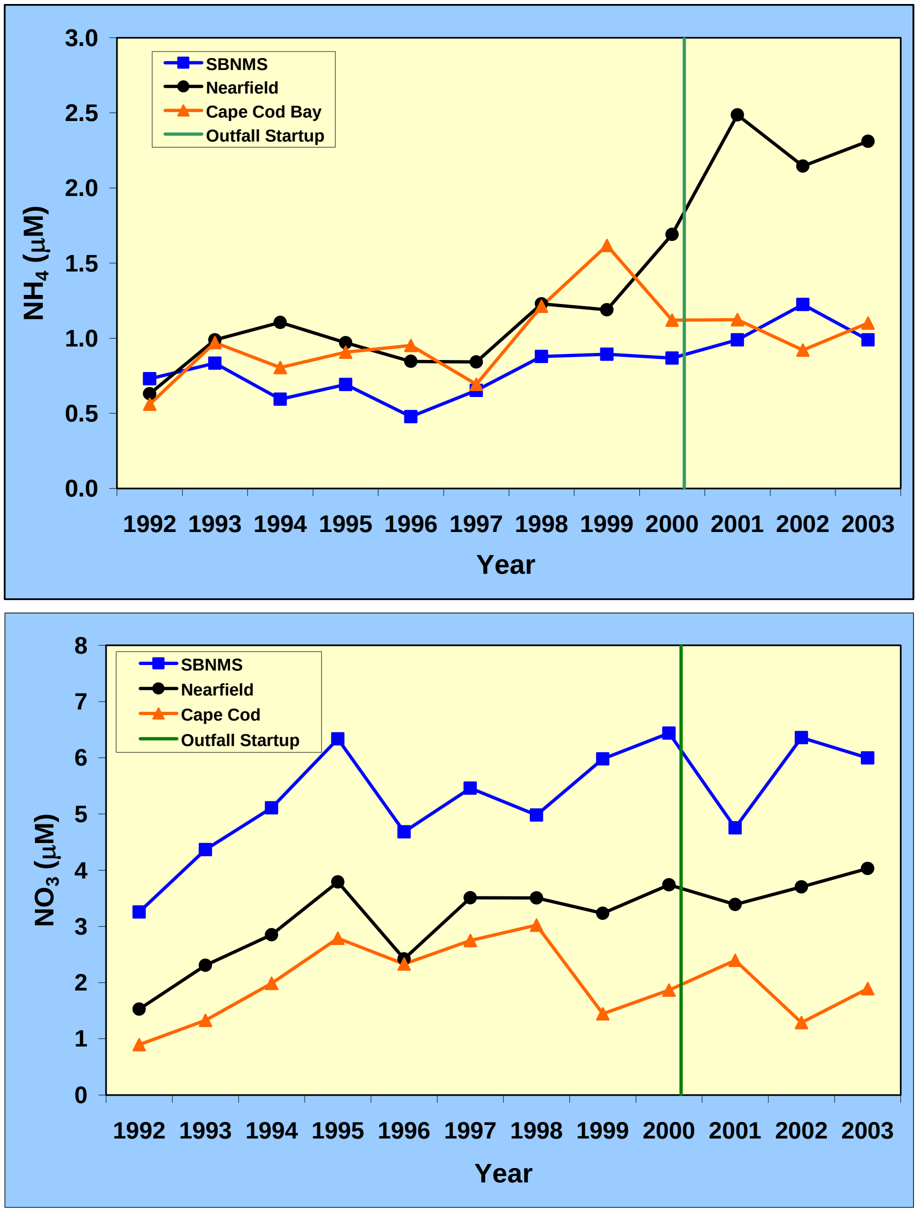


Figure 7-4. Annual mean ammonia and nitrate in the Stellwagen Bank National Marine Sanctuary and other regions of Massachusetts and Cape Cod bays

Similarly, mean annual chlorophyll has not changed in response to the outfall discharge (Figure 7-5). Annual chlorophyll levels were similar throughout the region.

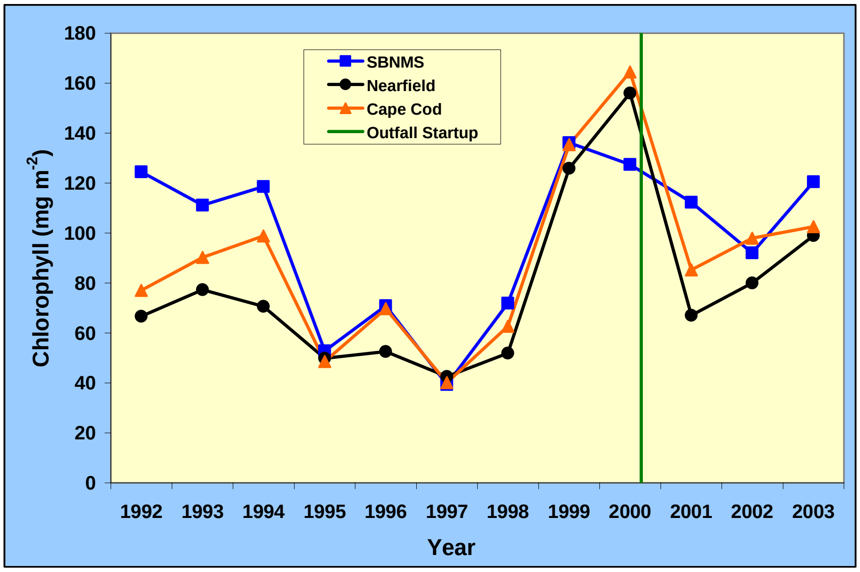


Figure 7-5. Annual mean chlorophyll in Stellwagen Bank National Marine Sanctuary and other regions

There were no confirmed blooms of harmful or nuisance phytoplankton species during August-October 2003 (Libby *et al.* 2004a). However, in October, the potentially toxic species *Pseudo-nitzchia pungens* was present throughout Massachusetts Bay and in the sanctuary. *Pseudo-nitzchia delicatissama* was also present and in higher numbers. Presence of these species appeared to be part of a widespread bloom, and they may have contributed to a marine mammal die-off observed in the Gulf of Maine and Georges Bank. Presence of these species was not, however, attributed to the outfall.

The MWRA monitoring program also documented a spring *Phaeocystis pouchetii* bloom throughout Massachusetts and Cape Cod bays. The bloom was most pronounced in northern Massachusetts Bay, including stations located within the sanctuary. The 2003 bloom began in February and lasted until May, beginning earlier and lasting longer than previous blooms, which have typically occurred during April. MWRA data suggest that the spring *Phaeocystis pouchetii* bloom is becoming a more regular event in the bays (see Section 3, Water Column).

Sea Floor

No changes in concentrations of sewage tracers or sewage-related contaminants were observed in the sediments from stations within the sanctuary, and there were no changes in community parameters in 2003 (Maciolek *et al.* 2004). Concentrations of *Clostridium perfringens* spores remained at or below levels measured in the early 1990s.

All four deep-water stations, both in and outside the sanctuary, continued to support a distinct infaunal community with recognizable differences from communities in the nearfield or Cape Cod Bay. Benthic community parameters at individual stations showed no pattern of change following start-up of the outfall in 2000 (Figure 7-6). Overall, the numbers of individual organisms and species per sample have increased, paralleling results from throughout Massachusetts Bay. No consistent pattern has been found to relate to outfall operation.

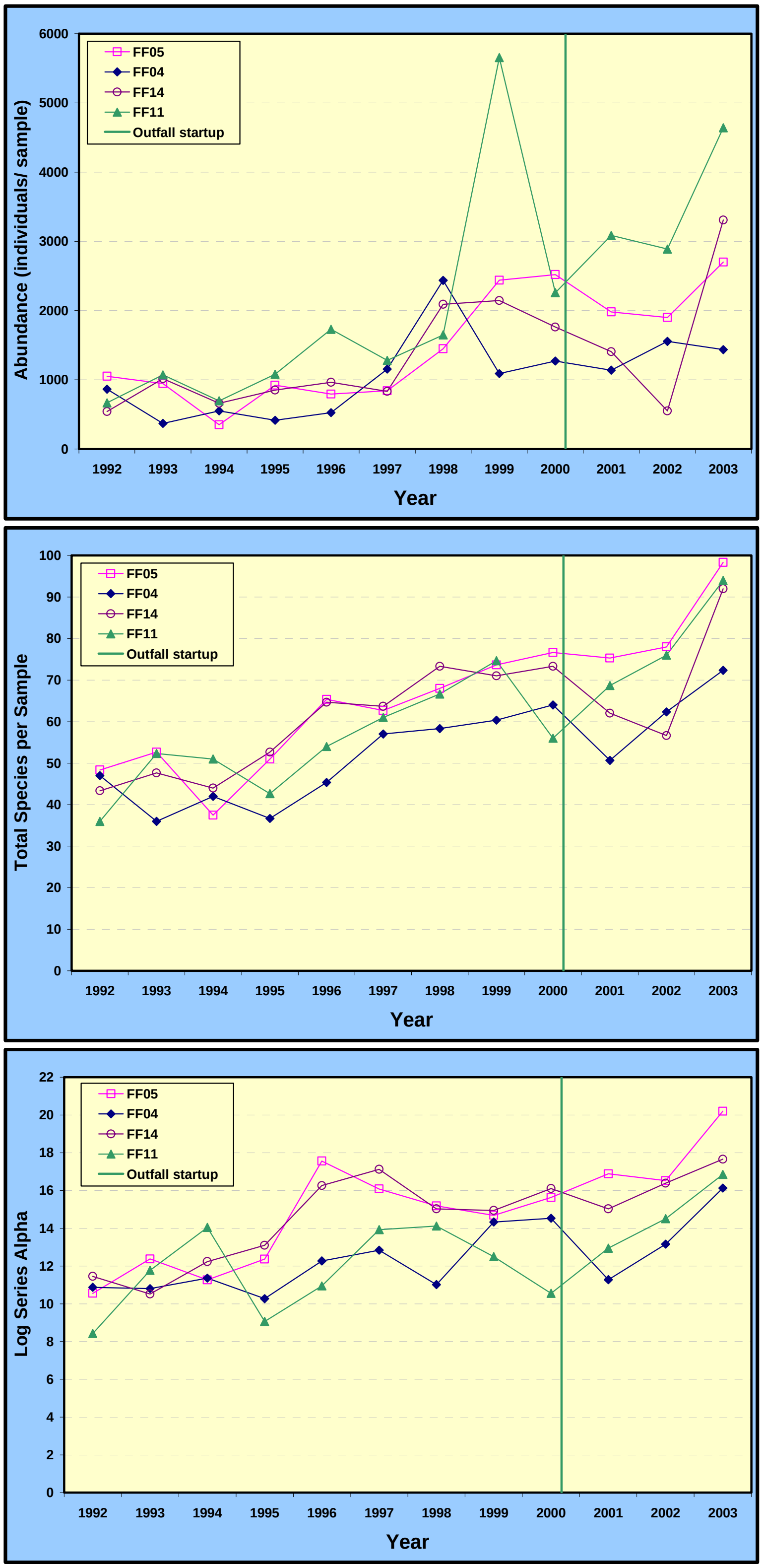


Figure 7-6. Benthic community parameters at stations within the boundary region, 1992-2003

8. Monitoring Plan Revision

Much of 2003 was devoted to revising the 1997 monitoring plan. Regular revisions to the plan were anticipated by the original plan (MWRA 1997a and available at www.mwra.com) and by the NPDES permit for the outfall. Two factors suggested that a comprehensive review was appropriate:

- **The effluent being discharged into Massachusetts Bay is cleaner than had been anticipated.** The original plan had presumed that the outfall would begin operation before secondary treatment was implemented. In fact, within about six months of outfall start-up, all three batteries of secondary treatment were in operation. The original plan also assumed that concentrations of toxic contaminants in secondary effluent would be higher than those that actually occur.
- **Only minimal environmental effects have been detected.** After more than nine years of baseline and two years of post-discharge monitoring to compare with baseline conditions, only minimal and expected effects had been detected.

Therefore, it was time to refocus the program away from localized and short-term effects to the potential for long-term effects.

This first revision was developed through a series of OMSAP workshops held during the spring and summer (MWRA 2003a, b, c; OMSAP 2003a, b, c). A draft revised plan was submitted to EPA and MADEP and posted in the *Environmental Monitor* in November 2003. A final version, incorporating changes made by EPA and MADEP, was published in March 2004 (MWRA 2004 and available at www.mwra.com).

The revised plan continues to be directed towards answering monitoring questions and is organized by the same environmental measurement areas: effluent, water column, sea floor, and fish and shellfish. The plan also continues to include special studies, which focus on emerging issues, may use novel or non-standard methods, and are designed to be completed in a definite timeframe.

Effluent

The effluent monitoring program continues to focus on NPDES permit limits and other parameters for which there are contingency plan thresholds (Table 8-1).

Table 8-1. Effluent monitoring parameters

Parameter	Sample Type	Frequency	Limit
Permit-required monitoring			
Flow	Flow meter	Continuous	Report only
Flow dry day	Flow meter	Continuous	436 MGD annual average
cBOD	24-hr composite	1/day	40 mg/l weekly 25 mg/l monthly
TSS	24-hr composite	1/day	45 mg/l weekly 30 mg/l monthly
pH	Grab	1/day	Not <6 or >9
Fecal coliform bacteria	Grab	3/day	14,000 col/100ml
Total residual chlorine	Grab	3/day	631 µg/l daily 456 µg/l monthly
PCB, Aroclors	24-hr composite	1/month	0.045 ng/l
Toxicity LC50	24-hr composite	2/month	50%
Toxicity C-NOEC	24-hr composite	2/month	1.5%
Settleable solids	Grab	1/day	Report only
Chlorides (influent only)	Grab	1/day	
Mercury	24-hr composite	1/month	
Chlordane	24-hr composite	1/month	
4,4' – DDT	24-hr composite	1/month	
Dieldrin	24-hr composite	1/month	
Heptachlor	24-hr composite	1/month	
Ammonia-nitrogen	24-hr composite	1/month	
Total Kjeldahl nitrogen	24-hr composite	1/month	
Total nitrate	24-hr composite	1/month	
Total nitrite	24-hr composite	1/month	
Cyanide, total	Grab	1/month	
Copper, total	24-hr composite	1/month	
Total arsenic	24-hr composite	1/month	
Hexachlorobenzene	24-hr composite	1/month	
Aldrin	24-hr composite	1/month	
Heptachlor epoxide	24-hr composite	1/month	
Total PCBs	24-hr composite	1/month	
Volatile organic compounds	Grab	1/month	
Contingency plan-required monitoring			
Oil and grease, as petroleum hydrocarbons	Grab	Weekly	Warning threshold/ 15 mg/l
Floatables	Continuous	Under development	
Plant performance	Ongoing		5 violations/year

The plan also provides for several special effluent monitoring studies:

- Detailed characterization of toxic contaminants.
- Nutrients.
- Pathogens.
- Sewage tracers.

Water Column

Most of the monitoring questions relating to possible water-column effects of the outfall have been answered: there are minimal, if any, acute effects on the environment (OMSAP 2002). Continued monitoring is necessary to evaluate possible long-term or unexpected effects.

A review of the monitoring used a statistical model approach to describe the trends, seasonal cycles, and redundancy in the data. It focused on chlorophyll and bottom water dissolved oxygen and showed that both datasets have substantial spatial and temporal redundancy. That is, for those parameters, the data were similar for adjacent stations or adjacent surveys (approximately three weeks apart). This finding helped to justify a reduction in the number of sampling stations and surveys.

The statistical modeling effort had two additional interesting results:

(1) The apparent seasonal cycle in chlorophyll was not statistically significant. As a result, although the statistical model of bottom water dissolved oxygen had a sinusoidal curve (Figure 8-1, bottom), the model for chlorophyll did not (Figure 8-1, top). This is due to the substantial variability in phytoplankton blooms between years which had been noted during baseline monitoring, but the extent of difference from oceanographers' expectations for "typical" cycles was not fully appreciated until the long-term dataset was subjected to the rigorous statistical analysis described above.

(2) There was a significant jump in chlorophyll in year 2000 (Figure 8-1, top). The modeling approach included a test for a step change in the data on September 2000, the date of outfall diversion. Although the jump may appear to be evidence of an outfall effect, further analysis indicated that the change to higher chlorophyll levels began in late 1998.

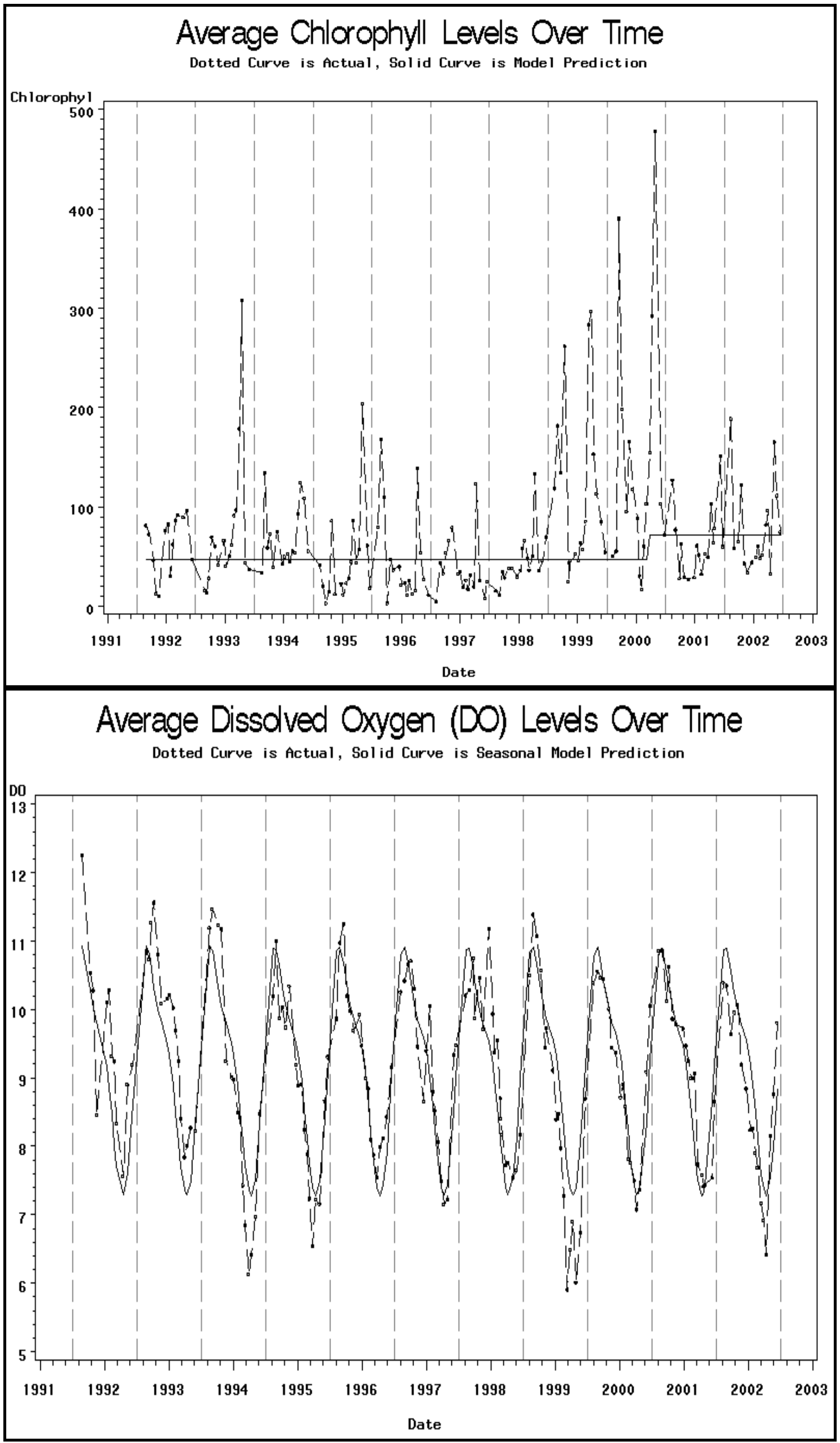
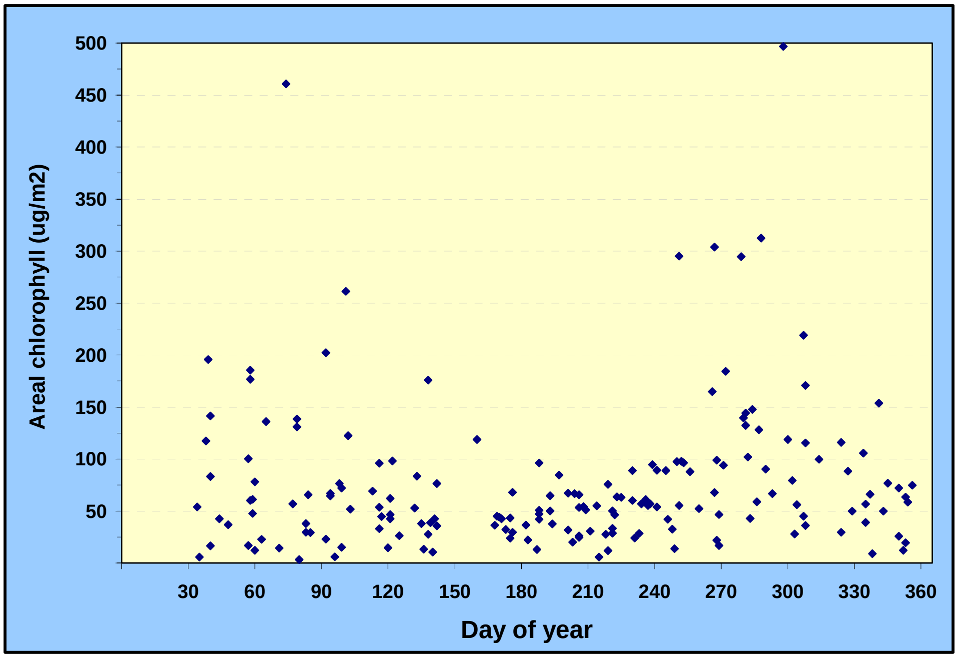


Figure 8-1. Top: Actual and modeled chlorophyll (mg/m^2); Bottom: actual and modeled dissolved oxygen concentrations (mg/l)



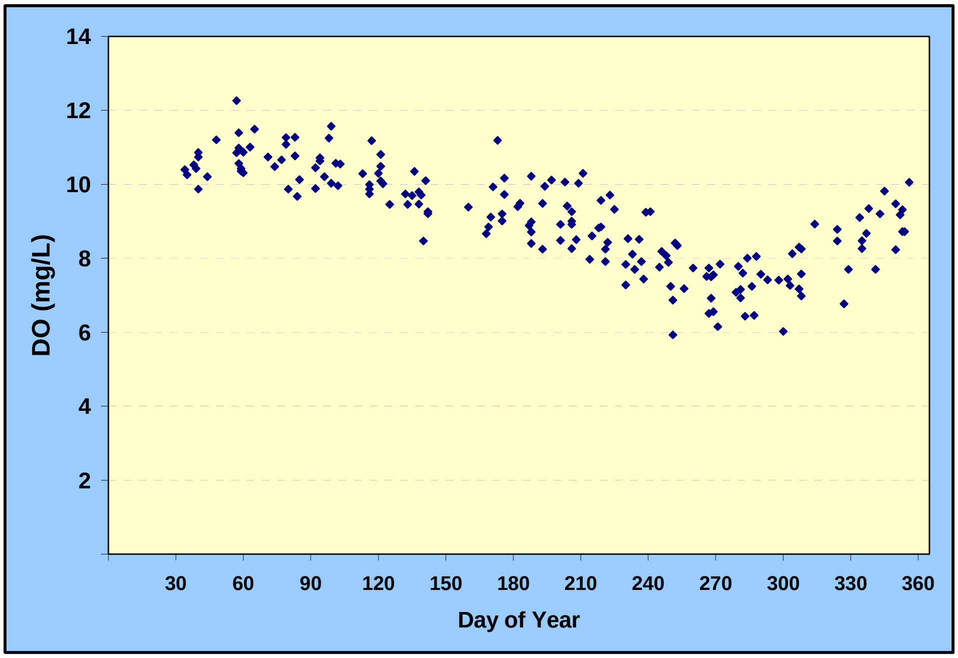


Figure 8-2. Top: Survey average chlorophyll plotted by day of year; Bottom: survey average dissolved oxygen plotted by day of year

The monitoring plan lists several key features that MWRA will continue to characterize through regular monitoring and special studies:

- The winter/spring bloom, including peaks in chlorophyll, production, and phytoplankton biomass in the nearfield.
- Early spring blooms of the nuisance species *Phaeocystis pouchetii* and resulting effect on zooplankton.
- Spatial extent of chlorophyll blooms.
- Late spring occurrence of paralytic shellfish poisoning.
- Stratification, dissolved oxygen, and nutrient levels at the beginning of the summer.
- Summertime levels of chlorophyll and nutrients in the nearfield.
- Rate of decline of dissolved oxygen concentrations over the summer and the fall dissolved oxygen minimum.
- Summer upwelling or mixing events.
- Fall bloom peaks of chlorophyll, carbon, phytoplankton, and production in the nearfield.
- Phytoplankton and zooplankton community structure throughout the growing season.
- Exchange between the Gulf of Maine and Massachusetts Bay.

Beginning in 2004, water-column monitoring will be carried out during twelve surveys of seven nearfield stations and six surveys of 25 farfield stations. Parameters included are listed in Tables 8-2 and 8-3.

Table 8-2. Nearfield water column monitoring

Parameter	Measurement details
Temperature Salinity Dissolved oxygen Chlorophyll fluorescence Transmissometry Irradiance Depth of sensors	In-situ sensor measurements 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

Table 8-3. Farfield water column monitoring

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

Special studies will augment the regular monitoring program:

- Additional nutrient analyses to support modeling efforts.
- Additional plankton sampling and analysis to put local blooms into a regional context.
- A study of zooplankton in Cape Cod Bay.
- Additional nutrients and plankton monitoring to examine short-term variability.
- Ongoing study of water circulation and particle fate.
- Continuous measurement of biological parameters.
- Remote sensing.
- Modeling.
- Floatables sampling.
- Marine mammal observations.

Sea Floor

Contaminant concentrations in sediments and sediment traps near the outfall have not shown rapid increases in sewage tracers since the outfall began operation (MWRA 2003a, Bothner *et al.* 2002). Neither have there been major changes in the soft-bottom infauna or the hard-bottom communities. Accordingly, the benthic monitoring program will continue to study soft-bottom chemistry and benthic communities, but will shift in focus to assessment of long-term effects.

The core of the monitoring program will be study of 23 nearfield and eight farfield soft-bottom stations. Two nearfield stations will be sampled annually, while the remaining stations were randomly split into two groups, which will be sampled on alternate years. Species composition and abundance will be measured for all stations sampled. Chemical constituents, including PAHs, PCBs, pesticides, and metals, and other sediment characteristics or tracers, such as TOC, sediment grain size, and *Clostridium perfringens* spore counts, will be measured annually at two stations once every three years at other stations. Sediment-profile images for measurement of RPD depth and other physical and biological parameters will be made each year at all 23 nearfield stations. Extensive sediment contaminant measurements will be made every three years.

The regular monitoring program will be augmented by special studies:

- Hard-bottom benthos in the nearfield.
- Benthic nutrient flux.
- Sediment transport.

Fish and Shellfish

During the first two years after the outfall began operation, there were no indications that contaminant concentrations increased in the representative resource species monitored by the program, winter flounder and lobster. There were measured increases in chlordanes and PAHs in blue mussels placed within the outfall mixing zone, but the elevated concentrations do not suggest an environmental risk (Hunt *et al.* 2002c, OMSAP 2003d). Ulcers observed on the blind side of flounder from Deer Island and western Massachusetts Bay are being studied.

Chemical and histological monitoring of winter flounder and chemical studies of lobsters and mussels will continue but at a reduced effort and frequency, aimed at detecting long-term rather than acute effects.

Flounder and lobster will be sampled from Deer Island Flats, the outfall site, and eastern Cape Cod Bay. Flounder will also be taken near Nantasket Beach. Flounder and lobster will be examined for external lesions. Histology analyses for flounder will be made every year; chemical analyses will be completed every third year. Mussels will be deployed every three years at three locations: outside the mixing zone at the outfall, in Inner Boston Harbor, and at Deer Island Light. Chemical analyses are listed in Table 8-4.

Table 8-4. Fish and shellfish analyses

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

Special studies will augment the regular monitoring:

- Enhanced mussel bioaccumulation.
- Flounder blind side lesions.

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List of Acronyms

BOD	Biochemical oxygen demand
BS	Broad Sound
cBOD	Carbonaceous biochemical oxygen demand
CCB	Cape Cod Bay
CHV	Centrotubular hydropic vacuolation
C-NOEC	Chronic test, no observable effect concentration
CSO	Combined sewer overflow
DDT	Dichlorodiphenyltrichloroethane
DIF	Deer Island Flats
DIL	Deer Island Light
DMF	Massachusetts Division of Marine Fisheries
DO	Dissolved oxygen
ECCB	Eastern Cape Cod Bay
EPA	U.S. Environmental Protection Agency
FDA	U.S. Food and Drug Administration
GC/MS	Gas chromatography/mass spectrometry
GC/ECD	Gas chromatography/electron capture detection
GoMOOS	Gulf of Maine Ocean Observation System
HMW	High molecular weight
IAAC	Inter-agency Advisory Committee
IH	Inner Harbor
LC50	50% mortality concentration
LMW	Low molecular weight
MADEP	Massachusetts Department of Environmental Protection
MDMF	Massachusetts Division of Marine Fisheries
MGD	Million gallons per day
MWRA	Massachusetts Water Resources Authority
NA	Not analyzed
NAO	North Atlantic Oscillation
NB	Nantasket Beach
ND	Not detected
NMFS	National Marine Fisheries Service
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
OSM	Outfall site
PAH	Polycyclic aromatic hydrocarbon
PC	Particulate carbon
PCB	Polychlorinated biphenyl
ppb	Parts per billion
ppm	Parts per million
PIAC	Public Interest Advisory Committee
RPD	Redox potential discontinuity

PSP	Paralytic shellfish poisoning
SBNMS	Stellwagen Bank National Marine Sanctuary
SEIS	Supplemental Environmental Impact Statement
TCR	Total chlorine residual
TOC	Total organic carbon
TSS	Total suspended solids
USGS	U.S. Geological Survey

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