2002 outfall monitoring overview

Massachusetts Water Resources Authority

Environmental Quality Department
Report ENQUAD 2003-12

Citation:
Werme C, Hunt CD. 2003. 2002 Outfall monitoring overview. Boston: Massachusetts Water Resources Authority. Report ENQUAD 2003-12. 80p.

2002
Outfall Monitoring Overview

submitted to

Massachusetts Water Resources Authority
Environmental Quality Department
100 First Avenue
Charlestown Navy Yard
Boston, MA 02129

prepared by

Christine Werme
Berkeley, CA 94708

and

Carlton D. Hunt
Battelle
397 Washington Street
Duxbury, MA 02332

November 15, 2003

Table of Contents

List of Figures

List of Tables

Summary

During 2002, the second full year of discharge from the Massachusetts Bay outfall, the Deer Island treatment plant operated as designed, with no detectable negative effects on the health of Massachusetts and Cape Cod bays. Total loads of many parameters measured within the effluent, including solids and metals, are low. The treatment plant earned the Association of Metropolitan Sewerage Agencies Silver Award for facilities that had five or fewer permit violations during the year.

After nine years of baseline monitoring and two years of post-discharge monitoring, MWRA has been able to answer many of the questions that were posed when the program began (Table 1). Overall, conditions within the bays have not changed from baseline conditions.

There were, however, five contingency plan exceedances during the year (Table 2).

As required by the permit, field tests conducted in 2001 confirmed that the outfall's minimum dilution is equal to the minimum dilution that had been predicted when it was designed. This confirmation was achieved by comparing field results to model predictions. The "minimum" dilution (1:70) described in the permit is that dilution predicted by the model for a selected set of combined worst-case conditions. Since those conditions would rarely exist in the field, the actual field results were compared to model predictions made under corresponding conditions. The field measurements made under stratified conditions in July found an initial dilution of about 1:100, and the model gave similar results. EPA and MADEP approved the certification of the outfall in October 2002.

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 are likely.

During 2002, MWRA initiated an overall review of the monitoring program and began plans to focus it on the potential for long-term chronic effects. The review evaluated the nearly ten years of baseline monitoring, which provided abundant data to use in evaluating possible effects of the outfall, and two years of post-discharge monitoring, which have documented minimal short-term effects of the relocated discharge.

Table 1. Summary of monitoring questions and status as of the end of 2002

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?	Ongoing monitoring.
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 to for pathogens to reach background concentrations before reaching shellfish beds, confirmed by plume studies conducted in 2001.
Are pathogens transported to beaches at levels that might affect swimmer health?	Dilution is sufficient for pathogens to reach background concentrations before reaching beaches, confirmed by plume studies conducted in 2001.
Has the clarity and/or color of the water around the outfall changed?	No observed changes.
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.
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 changed be correlated with effluent or ambient water nutrient concentrations, or can farfield changes be correlated with nearfield changes?	Conditions have not changed from background.

Monitoring Question	Status
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 change has been detected.
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?	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 in *Clostridium perfringens* spores, the most sensitive sewage tracers.
Has the concentration of contaminants in sediments changed?	No general increase in contaminants in nearby sediments. Effluent signal can be detected in silver, a sensitive sewage tracer, in sediment traps and in *Clostridium perfringens* spores in sediments with 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 in 2001 and 2002; not yet known whether these changes are related to the outfall.
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 will result 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.

Monitoring Question	Status
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?	No short-term changes.

*Table 2. Summary of contingency plan thresholds and exceedances as of 2002. (NA = not applicable, ✓ = no exceedance, **C** = caution level exceedance, **W** = warning level exceedance)*

Location/ Parameter Type	Parameter	2000	2001	2002
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
	Oil and grease	✓	✓	✓
Water Column				
Nearfield bottom water	Dissolved oxygen concentration	C	✓	✓
	Dissolved oxygen saturation	C	✓	✓
Stellwagen Basin bottom water	Dissolved oxygen concentration	✓	✓	✓
	Dissolved oxygen saturation	✓	✓	✓
Nearfield bottom water	Dissolved oxygen depletion rate (June-October)	NA	✓	✓
Nearfield chlorophyll	Annual	NA	✓	✓
	Winter/spring	NA	✓	✓
	Summer	NA	✓	✓
	Autumn	C	✓	✓
Nearfield nuisance algae *Phaeocystis pouchetii*	Winter/spring	NA	✓	✓
	Summer	NA	✓	C
	Autumn	✓	✓	✓
Nearfield nuisance algae *Pseudonitzchia*	Winter/spring	NA	✓	✓
	Summer	NA	✓	✓
	Autumn	✓	✓	✓
Nearfield nuisance	Any sample	✓	✓	✓

Location/ Parameter Type	Parameter	2000	2001	2002
algae *Alexandrium fundyense*				
Farfield shellfish	PSP toxin extent	✓	✓	✓
Plume	Initial dilution	NA	✓	Completed
Sea Floor				
Nearfield sediment contaminants	Acenaphthene	NA	✓	✓
	Acenaphylene	NA	✓	✓
	Anthracene	NA	✓	✓
	Benz(a)pyrene	NA	✓	✓
	Benzo(a)pyrene	NA	✓	✓
	Cadmium	NA	✓	✓
	Chromium	NA	✓	✓
	Chrysene	NA	✓	✓
	Copper	NA	✓	✓
	Dibenzo(a,h)anthracene	NA	✓	✓
	Fluoranthene	NA	✓	✓
	Fluorene	NA	✓	✓
	Lead	NA	✓	✓
	Mercury	NA	✓	✓
	Naphthalene	NA	✓	✓
	Nickel	NA	✓	✓
	p,p'-DDE	NA	✓	✓
	Phenanthrene	NA	✓	✓
	Pyrene	NA	✓	✓
	Silver	NA	✓	✓
	Total DDTs	NA	✓	✓
	Total HMW PAH	NA	✓	✓
	Total LMW PAH	NA	✓	✓
	Total PAH	NA	✓	✓
	Total PCBs	NA	✓	✓
	Zinc	NA	✓	✓
Nearfield sediment	RPD depth	NA	✓	✓
Nearfield benthic diversity	Species per sample	NA	✓	✓
	Fisher's log-series alpha	NA	✓	✓
	Shannon diversity	NA	✓	✓
	Pielou's evenness	NA	✓	✓
Nearfield species composition	Percent opportunists	NA	✓	✓
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	✓	✓

Location/ Parameter Type	Parameter	2000	2001	2002
	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

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 to affect sensitive resources, and it was feasible to construct an outfall tunnel to the location.

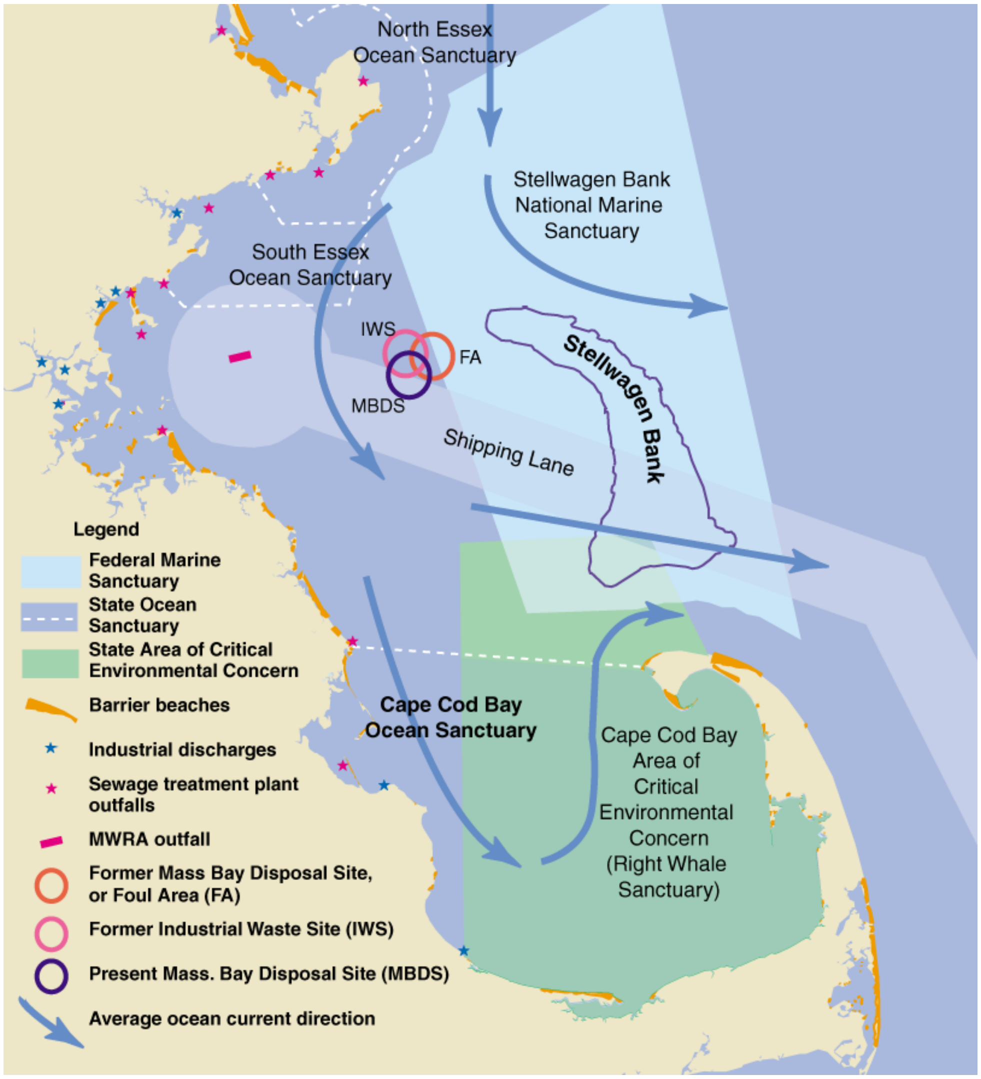

Figure 1-1. Map of Massachusetts and Cape Cod bays

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 new 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 an ongoing pollution prevention program that 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. MWRA must implement a contingency plan (MWRA 1997b, 2001), which identifies relevant environmental quality parameters and thresholds, which, if exceeded, would require a response.

EPA and MADEP have established an independent panel of scientists to review monitoring data and provide advice on key scientific issues related to the permit. This panel, 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 its 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 2002
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)</td></tr>
<tr><td>IAAC as of December 2002</td><td>PIAC as of December 2002</td></tr>
<tr><td>MA Coastal Zone Management
Christian Krahforst
Jan Smith (alternate)
MA Department of Environmental Protection
Russell Isaac
Steven Lipman (alternate)
MA Division of Marine Fisheries
Jack Schwartz
James Fair (alternate)
National Marine Fisheries Service
David Dow (alternate)
Stellwagen Bank National Marine Sanctuary
Ben Haskell
US Army Corps of Engineers
Thomas Fredette
US Environmental Protection Agency
Matthew Liebman
David Tomey (alternate)
US Geological Survey
Michael Bothner</td><td>Patty Foley (chair, representative of Save the Harbor/Save the Bay)
Association for the Preservation of Cape Cod
Maggie Geist
Bays Legal Fund
Wayne Bergeron
The Boston Harbor Association
Vivian Li
Joan LeBlanc (alternate)
Cape Cod Commission
John Lipman
Steve Tucker (alternate)
Center for Coastal Studies
Peter Borrelli
Conservation Law Foundation
Anthony Chatwin
New England Aquarium
Marianne Farrington
Massachusetts Audubon Society
Robert Buchsbaum
MWRA Advisory Board
Joseph Favaloro
Safer Waters in Massachusetts
Salvatore Genovese
Polly Bradley (alternate)
Save the Harbor/Save the Bay
Bruce Berman (alternate)
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 developed and refined were developed 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 that are conducted in response to specific permit requirements, scientific questions, and environmental concerns. The monitoring program is designed to compare environmental quality of the Massachusetts Bay system, including Boston Harbor and Cape Cod Bay, before and after the outfall location moved from the harbor to the bay.

Baseline monitoring was initially planned to last for a minimum of three years, as the outfall was originally planned for completion in 1995. Delays in outfall construction 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 (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.

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 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)	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, is prepared for each year of the monitoring program (Gayla *et al.*1996, 1997a, 1997b, Werme and Hunt 2000a, 2000b, 2001, 2002). The report includes a scientific summary of each year of monitoring. Overviews for 1995-1999 included only baseline information. With the outfall operational, subsequent reports include information relevant to the contingency plan, such as data that exceed thresholds, responses, and corrective activities. When data suggest that monitoring activities, parameters, or thresholds should be changed, the report summarizes those recommendations.

This year's outfall monitoring overview presents monitoring program results for effluent and field data for 2002. 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 presents plans for revisions to the monitoring plan. At the end of 2002, MWRA had completed nearly ten years of baseline monitoring and two years of post-discharge monitoring, which have documented minimal short-term effects of the relocated discharge. Therefore, MWRA has begun to review the program and refocus it on the potential for long-term chronic effects.

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 18-22% 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 the environment, public health, and aesthetics would 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 Quality).

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," that is, plastic and other debris. The MWRA permit also sets limits for chlorine and pH.

Pathogens, including bacteria, viruses, and protozoa, are found in human and animal waste and can cause disease. Human exposure to water-borne pathogens can occur through consumption of contaminated shellfish or through ingestion or physical contact while swimming.

Toxic contaminants include heavy metals, such as copper and lead, polychlorinated biphenyls (PCBs), pesticides, polycyclic aromatic hydrocarbons (PAHs), and petroleum hydrocarbons. Toxic contaminants can lower survival and reproduction 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 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

The main purpose of effluent monitoring is to measure the concentrations and variability of constituents of the effluent. Effluent monitoring is designed to assess compliance with NPDES permit limits, which are based on state and federal water quality standards and criteria, ambient conditions, and the 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
LABs	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 nonstandard, 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, but does not explicitly describe how MWRA must carry out this evaluation. To date, MWRA has collected data on anthropogenic viruses, viral indicators, and *Enterococcus* bacteria in the influent and effluent.

The monitoring plan further calls for an evaluation of effluent tracers. On an ongoing basis, MWRA evaluates proposals to study potential effluent tracers. Currently, MWRA is co-sponsoring with SeaGrant, a University of Massachusetts and Tufts University study of endocrine disruptors in influent, effluent, Boston Harbor, and the vicinity of the outfall site. MWRA has also measured sulfur and nitrogen isotope patterns in effluent to help determine whether nitrogen isotopes may be useful tracers. MWRA has also provided samples to other investigators using this tool to trace the effluent signature in the bay.

Results

Average daily flow of effluent from the Deer Island treatment plant in 2002 was slightly less than 2000 and 2001, reflecting a continuing drought (Figure 2-1). Approximately 98% of the flow received secondary treatment, the greatest percentage ever.

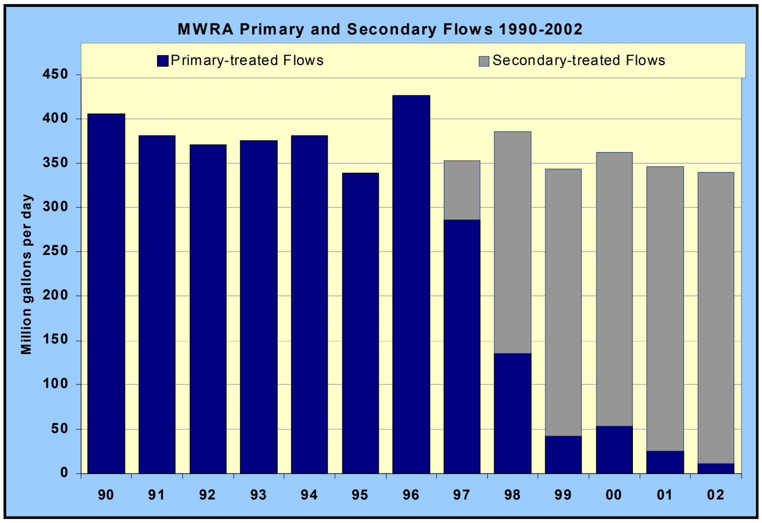

Figure 2-1. Annual effluent flow

For many parameters, total loads decreased or remained at approximately the 2001 level (Figure 2-2). Nitrogen loads, while decreasing with the implementation of secondary treatment, have increased since 1998, but have remained below threshold values. About 80% of the total nitrogen is dissolved inorganic nitrogen, mostly ammonia.

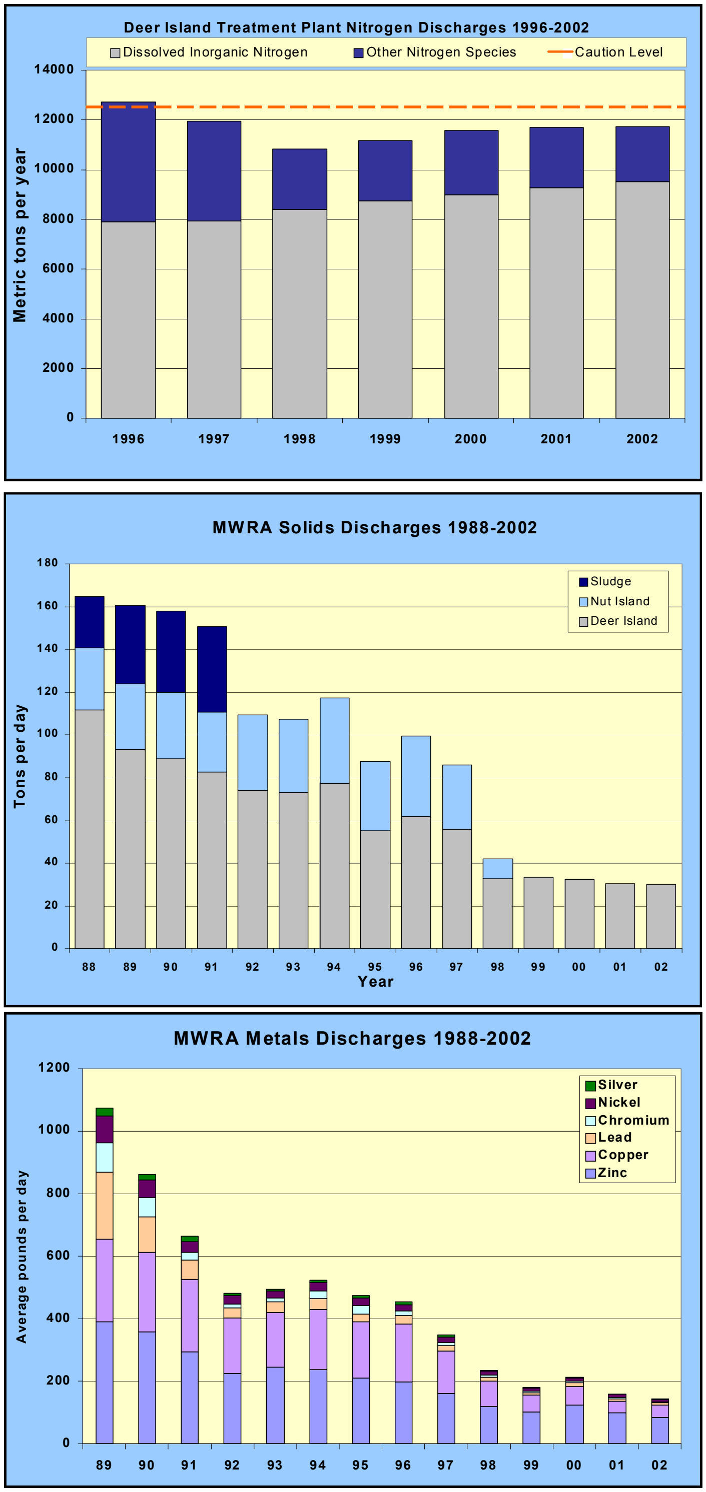

Figure 2-2. Annual solids, nitrogen, and metals discharges

Total solids discharged in the effluent remained low. Solids removal has steadily increased over the past 10 years. The discharge (load) of selected metals continued to decrease in 2002. TSS and cBOD concentrations remained low except during a treatment plant upset in August, reflecting the high level of secondary treatment (Figure 2-3).

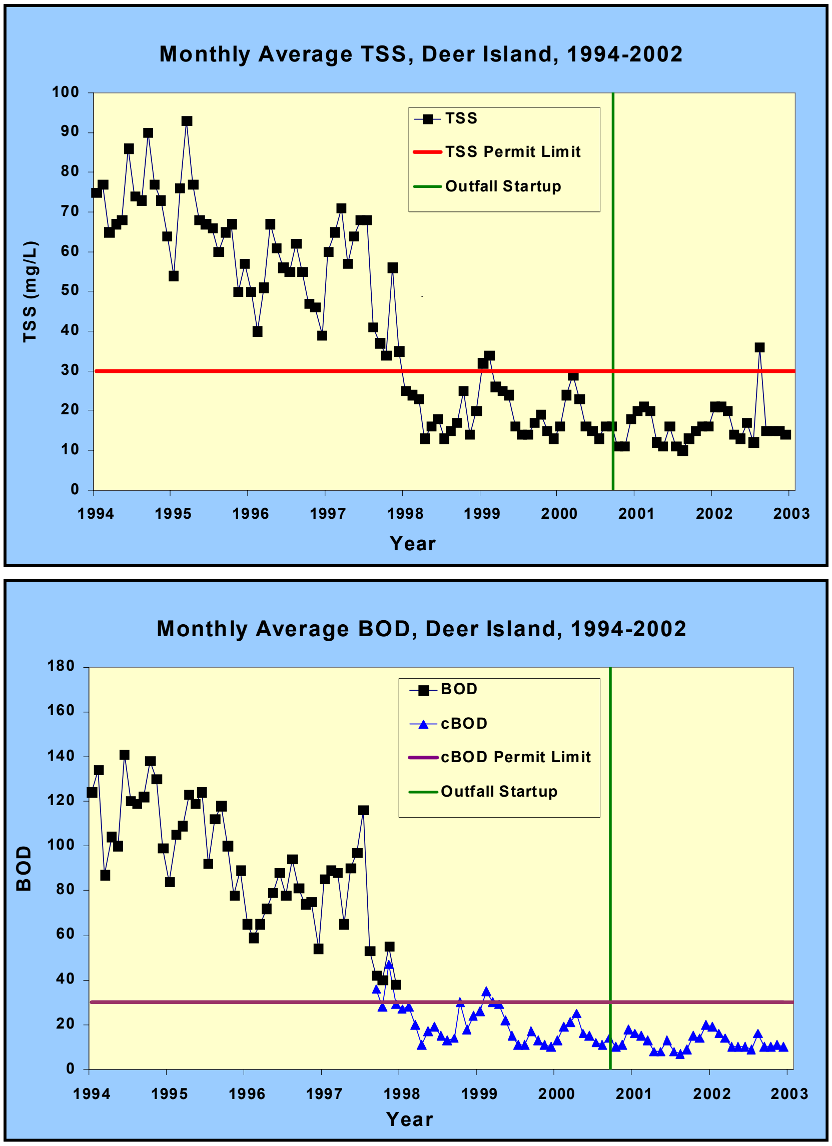

Figure 2-3. Monthly average TSS and monthly BOD (measured as cBOD since 1997) from 1994-2002

During the more than two years of discharge monitoring, measured contaminant concentrations have been lower than had been expected during the outfall planning process (Table 2-4). Even during 2000, when a relatively low percentage of the effluent received secondary treatment, concentrations of metals and organic compounds were lower than had been projected by the SEIS (EPA 1988).

Table 2-4. Projected vs. measured contaminant loadings (pounds per day unless noted)

	SEIS Projection	2000 actual (relatively low percentage secondary)	2002 actual (relatively high percentage secondary)
Flow (MGD)	390	381	336
Percent secondary	100	85	96
Cadmium	4.2	0.4	0.2
Chromium	2102	5.1	3.8
Copper	72	60.1	40.3
Lead	29.9	<10.4	<5.5
Mercury	1.3	0.11	0.07
Nickel	53.8	10.7	8.3
Silver	1.8	1.9	1.2
Zinc	207.9	124.8	84.7
Total DDT	0.033	0.005	0.004
Total PCB	0.3	0.02	0.006

Contingency Plan Thresholds

The Deer Island Treatment Plant had few permit violations during 2002 (Table 2-5), earning it the Association of Metropolitan Sewerage Agencies Silver Award for facilities that have had five or fewer violations during the year.

There were two exceedances of weekly limits and one exceedance of the monthly limit for total suspended solids. The elevated levels occurred when MWRA allowed the discharge of high-sulphate wastewater through the Alford Street Pumping Station as part of a study to determine the effect of a particular industrial discharge on odor and corrosion in MWRA's Framingham Extension Sewer and downstream sewers. The high sulfate influent caused a microbiological imbalance in the secondary treatment and a growth of filamentous bacteria, which impaired the ability of the plant to remove solids. There was no concurrent exceedance of BOD levels, indicating that secondary treatment, although compromised, was still removing oxygen-demanding constituents.

Table 2-5. Contingency plan threshold values and 2002 results for effluent monitoring

Parameter	Caution Level	Warning Level	2002 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	Two weekly exceedances, one monthly exceedance
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 revision pending
Oil and grease	None	15 mg/l weekly	Not exceeded

3. Water Column

Background

Circulation and Water Properties

Circulation, water properties, and consequently, the biology of Massachusetts and Cape Cod bays are driven by the larger pattern of water flow in the Gulf of Maine (Figure 3-1). A general coastal current flows southwestward and may enter the bays by Cape Ann to the north of Boston. Water flows back out of the bays to the north of Race Point at the tip of Cape Cod. During much of the year, a weak counterclockwise circulation persists within eastern Massachusetts Bay and Cape Cod Bay.

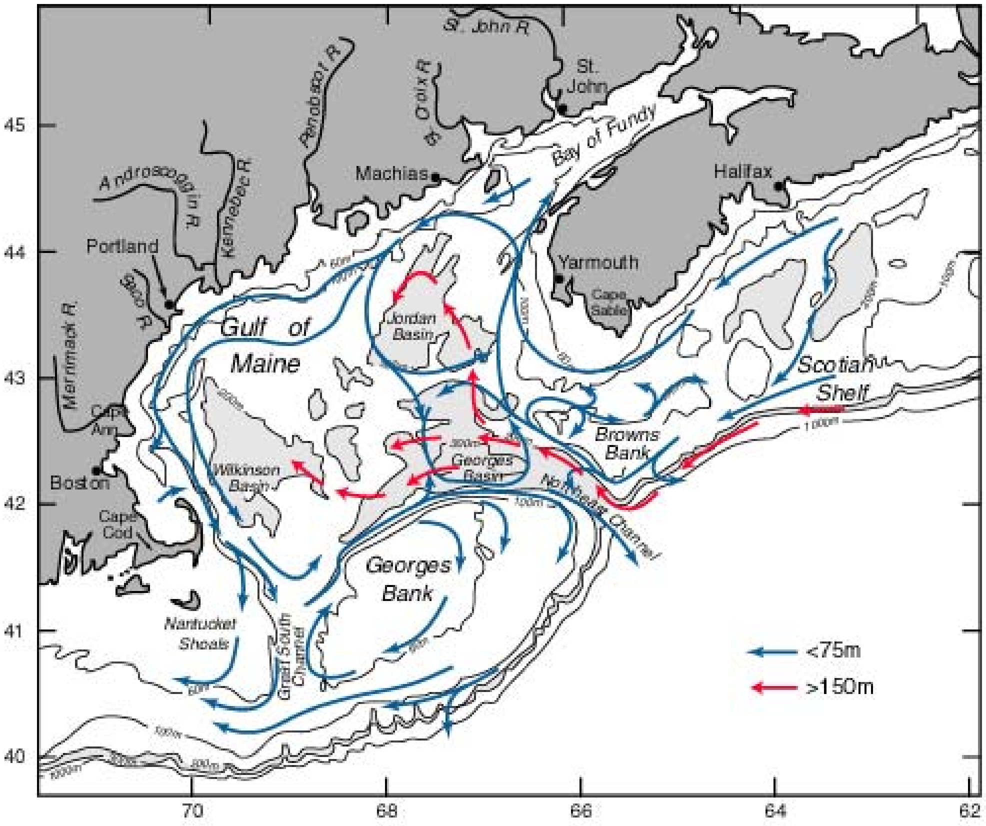

Figure 3-1. General circulation on Georges Bank and in the Gulf of Maine during the summer, stratified season (from Beardsley et al. *1997)*

The water quality and biology of the bays follow an annual cycle typical for coastal waters, although meteorological and oceanographic conditions greatly influence the timing, magnitudes, and spatial extent of the annual events. According to the typical cycle, waters in the winter are well mixed, and nutrient levels are high. As light levels increase in the early spring, phytoplankton often begin a period of rapid growth known as a spring bloom. 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.

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.

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 predischarge 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?

One concern is that excess nutrients, particularly nitrogen, could promote algal blooms followed by low levels of dissolved oxygen when the phytoplankton die, sink, and decompose. Another 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. *Pseudo-nitzschia multiseries* is one of a group of species that at high concentrations (more than 1 million cells per liter) may 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. *Phaeocystis pouchetii* is not toxic, but individual cells can aggregate in gelatinous colonies that are poor food for zooplankton.

Although it is effectively removed by secondary treatment, potential effects of organic material from the wastewater effluent remain a focus of study. Decomposition of organic matter consumes oxygen. 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 saltier bottom waters.

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. 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 2002, 17 surveys of the nearfield and 6 surveys of the farfield were conducted.

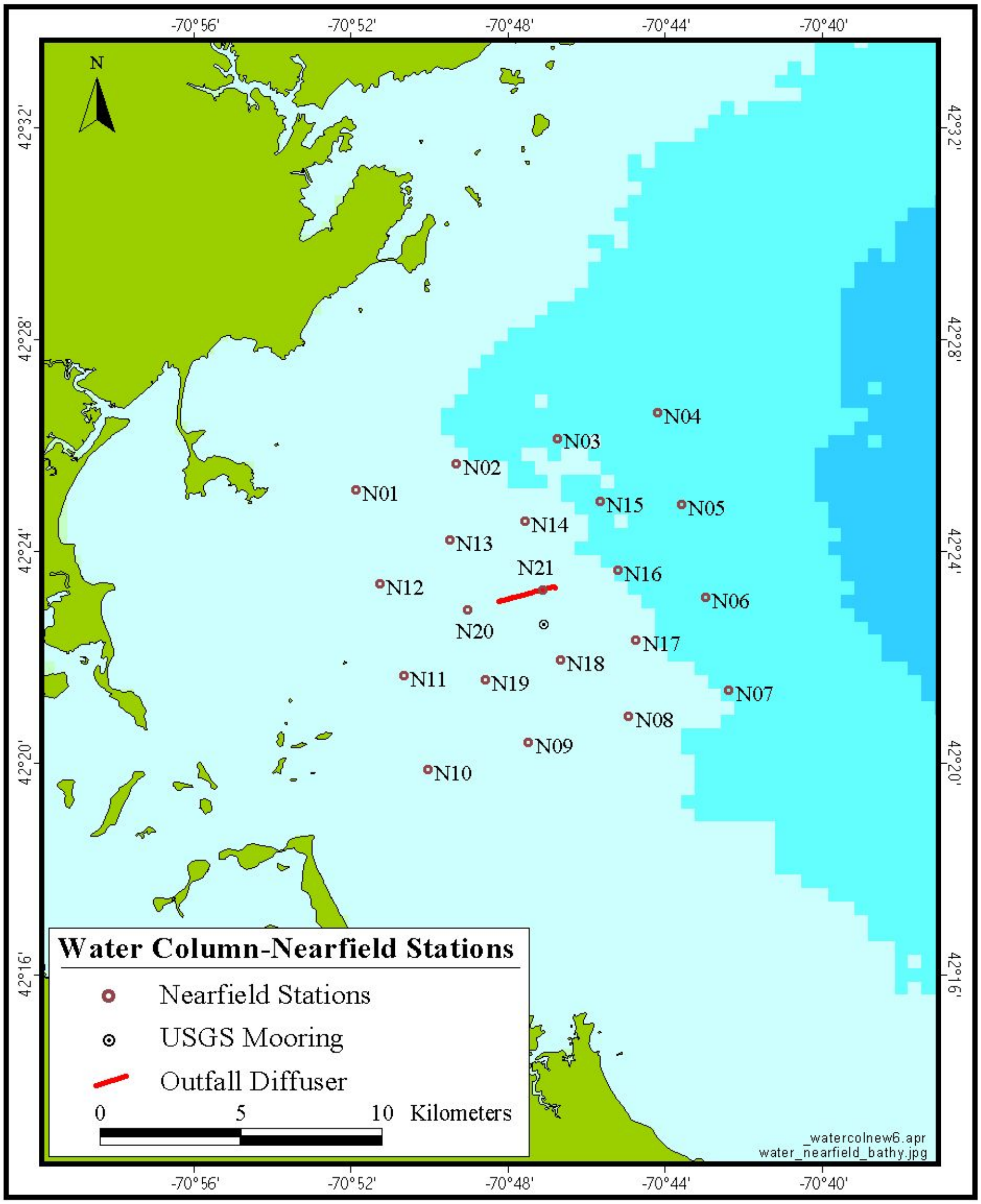

Figure 3-2. Nearfield sampling stations

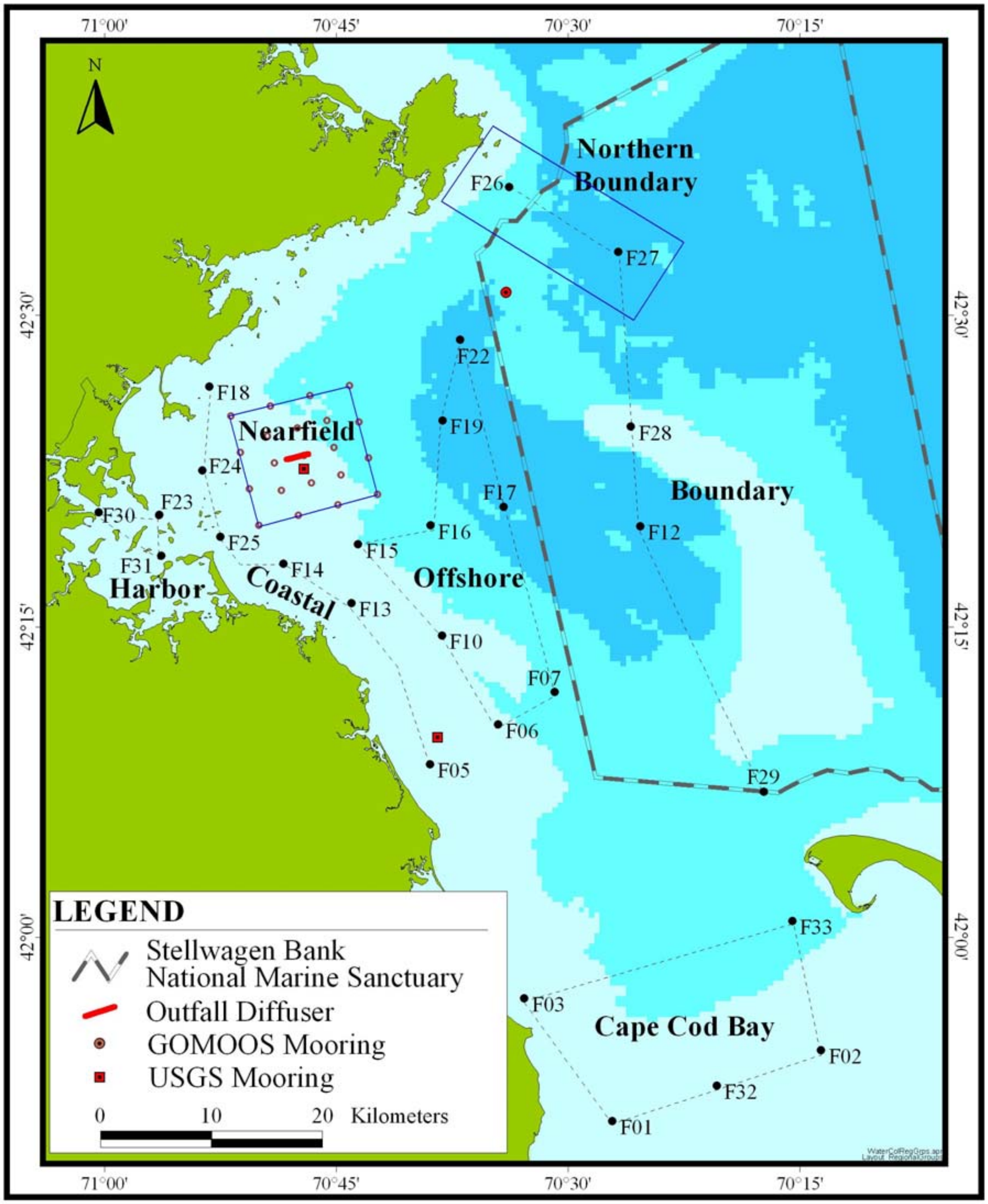

Figure 3-3. Farfield geographic regions and sampling stations

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

Dry conditions, which began in the fall of 2001, continued into 2002. Drought and unusual wind conditions in 2002 resulted in a delay in the onset of stratification until June and a decrease in transport of Gulf of Maine waters into Massachusetts Bay in the spring. Freshwater flow from the two principal sources influencing the bays, the Charles (Figure 3-4) and Merrimack (not shown) rivers, was unusually low in early 2002 (Libby *et al.* 2003). The summer and fall were also dry, and overall 2002 was the driest year of the decade, with about 65% of the normal freshwater flow.

Air temperatures in early 2002 continued a warmer than average period, which had begun during the fall of 2001. Surface water temperatures were also unusually warm through April, close to average during the summer, and warm during the fall (Figure 3-5, top). Bottom water temperatures remained above average through the summer and fall.

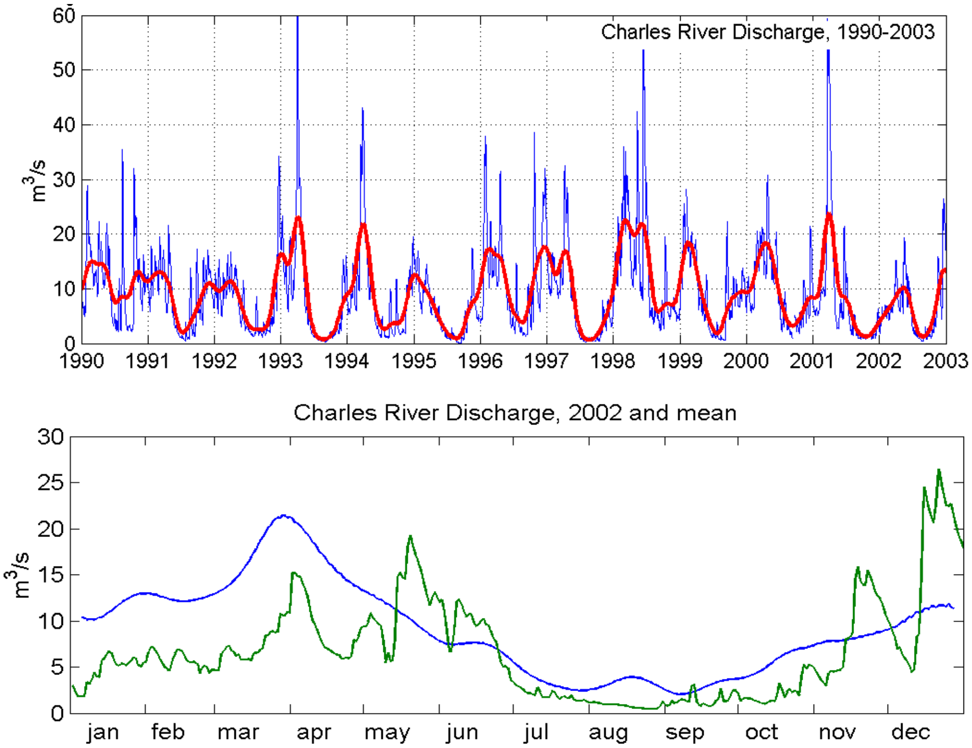

Figure 3-4. Above: Charles River discharge, 1990-early 2003 (recorded data from a gauge at Waltham and 3-month moving average); Below: 2002 discharge compared to the12-year historic mean

In 2001, salinity measurements had shown a normal seasonal progression, as the drought had not persisted for long enough to affect salinity patterns. In 2002, however, surface and bottom salinity measurements were the highest measured in the monitoring program (Figure 3-5, bottom). Because of a lack of freshwater input and the warm bottom water temperatures, stratification was unusually weak during the first half of 2002. Waters were not stratified until June.

Southerly winds promoted upwelling conditions during the winter and spring, but were generally unfavorable to upwelling during the summer. These conditions differed from the usual pattern of winter winds from the northeast, which induce downwelling, and regular upwelling events during the summer. The southerly winds that occurred during the winter and spring decreased the flow of Gulf of Maine waters into Massachusetts Bay.

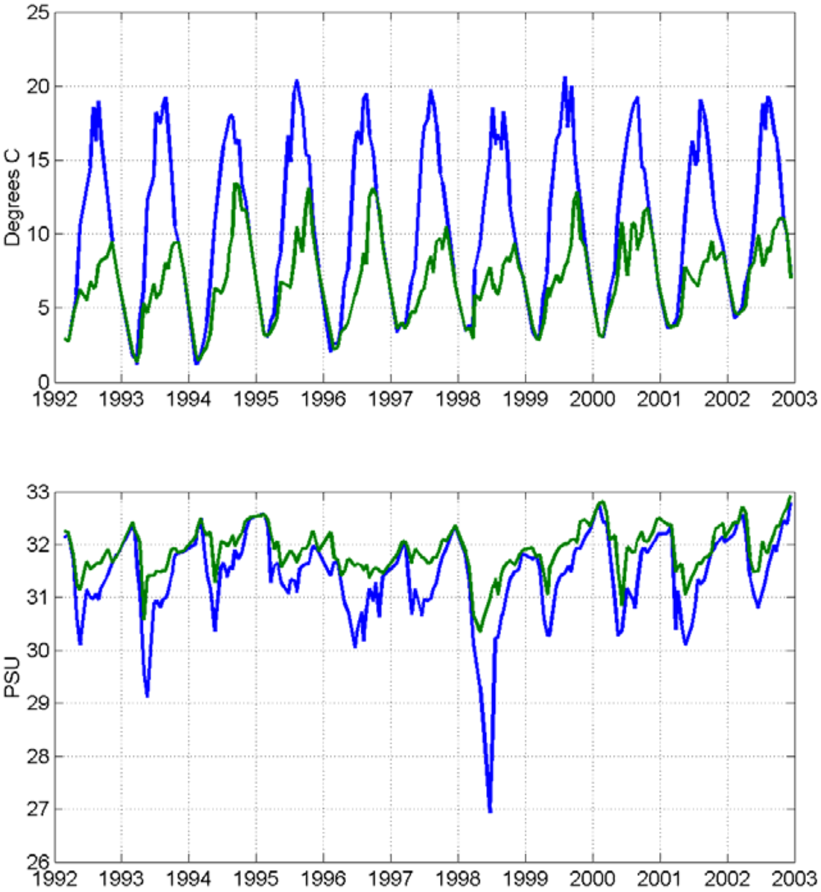

Figure 3-5. Nearfield surface and bottom water temperature and salinity, 1992-2002 (Surface measurements are the upper line for temperature and the lower line for salinity.)

Water Quality

Water quality measurements during 2002 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.* 2003).

Similar to 2001, elevated concentrations of ammonia, the form of nitrogen most readily taken up by phytoplankton, were observed in the nearfield over much of the year (Figure 3-6, top). These elevated levels were 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, 2001-2002, concentrations of ammonia in Boston Harbor, remained low, reflecting the dramatic drop in concentration following effluent diversion to Massachussetts Bay (Taylor 2003). 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 1998-2000.

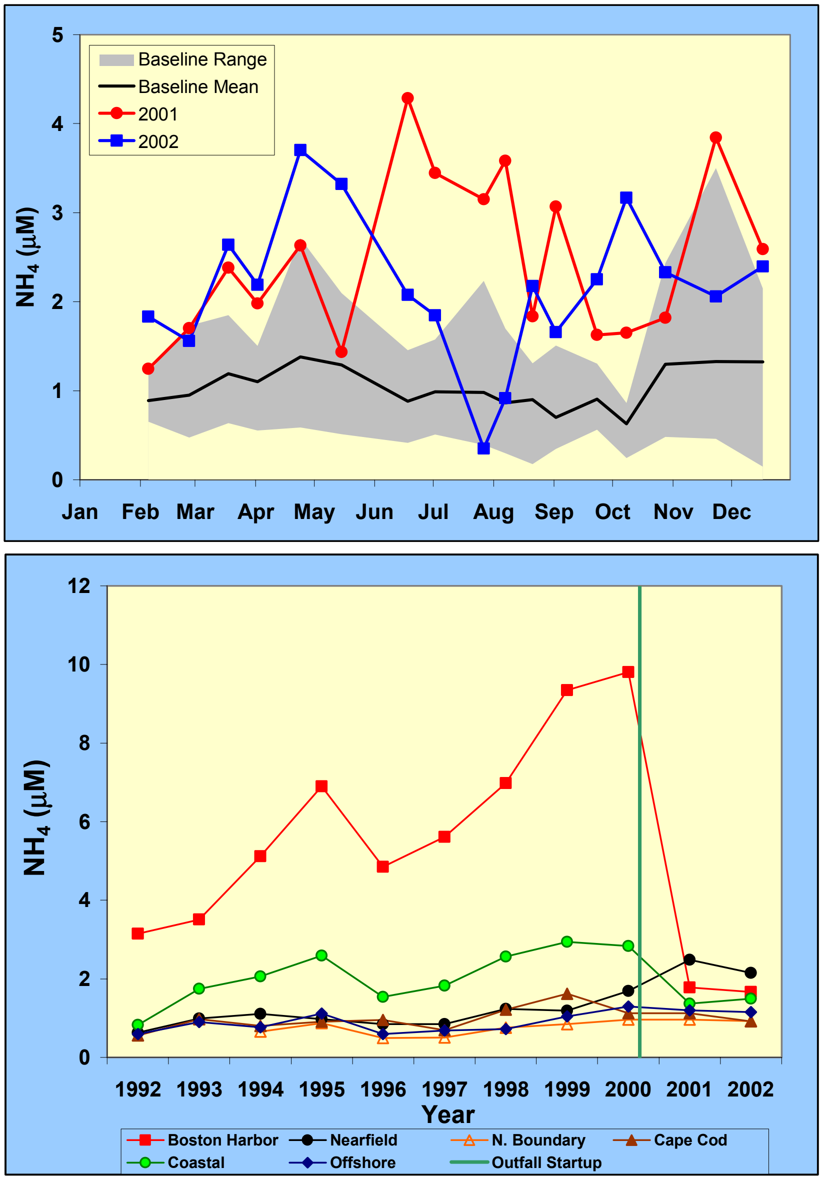

Figure 3-6. Above: 2002 nearfield ammonia concentrations compared to baseline range and mean; Below: annual mean ammonia concentrations in Massachusetts Bay regions

Concentrations of nitrate, another form of nitrogen readily used by phytoplankton and present in the effluent, continued to fall into the general range and show the same seasonal pattern that had been established during baseline monitoring (Figure 3-7, top). Just as during the baseline period, maximum 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 fall increase in nitrate concentrations was somewhat different in timing but within the same range as had been observed during the baseline period. The annual averages of nitrate concentrations showed no increase in the nearfield and no measurable effects on the farfield, with annual concentrations of nitrate falling within the baseline range for the boundary stations and in Cape Cod Bay (Figure 3-7, bottom).

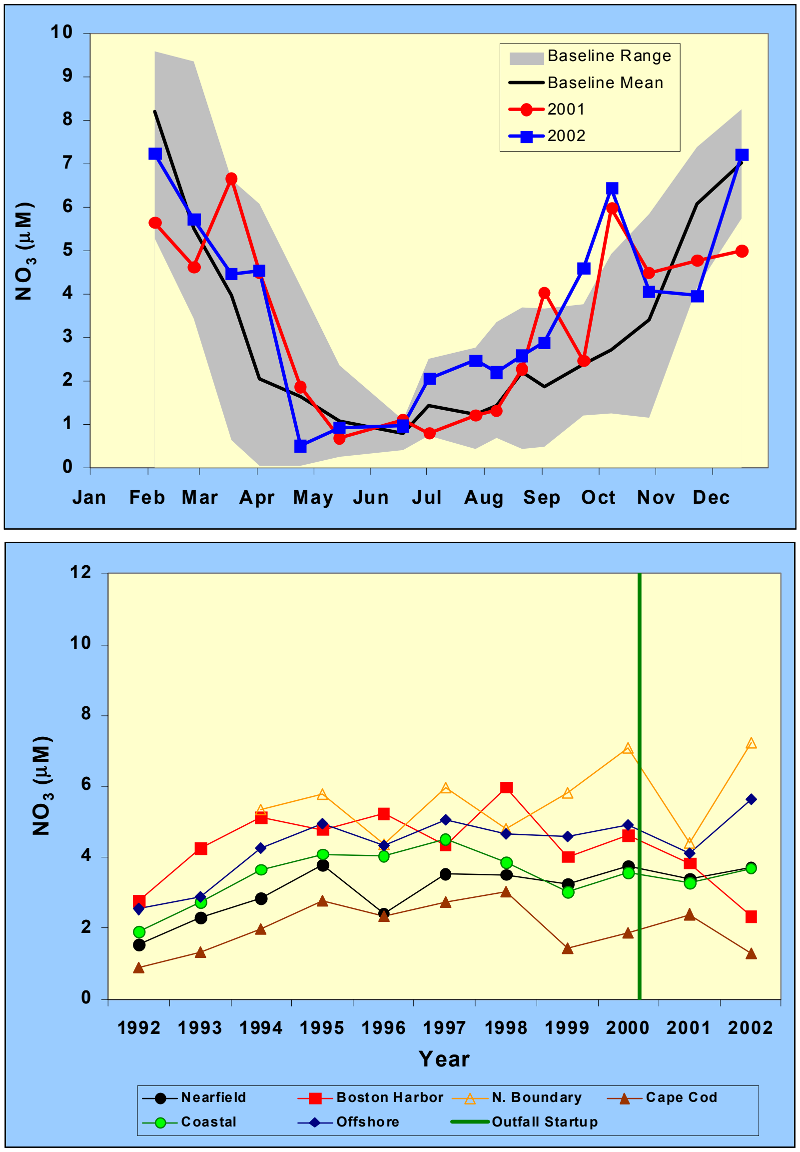

Figure 3-7. Above: 2002 nearfield nitrate concentrations compared to baseline range and mean; Below: annual mean nitrate concentrations in Massachusetts Bay regions

The typical pattern persisted, with highest concentrations at the northern boundary, lowest in Cape Cod Bay, and intermediate levels in the nearfield. The annual concentration of nitrate in Boston Harbor was the lowest measured for the monitoring program.

Concentrations of chlorophyll, a measure of phytoplankton biomass, continued to show no response to nutrient enrichment of the outfall, even in the nearfield (Figure 3-9, top). During most nearfield surveys, concentrations of chlorophyll were at or below the baseline mean. The annual (Figure 3-9, bottom) and seasonal (not shown) chlorophyll concentrations showed no response to the outfall in the nearfield or any region of the farfield.

Measurements of concentrations (Figure 3-9) and percent saturation (not shown) of dissolved oxygen in 2002 also showed 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. Survey mean concentrations and percent saturation of dissolved oxygen in bottom waters of the nearfield and Stellwagen Basin were relatively low in 2002, but within the range for the baseline period. The relatively low measurements were similar to those made in 1999, when drought conditions also predominated. Minimum concentrations and percent saturation were found in October, as is typical.

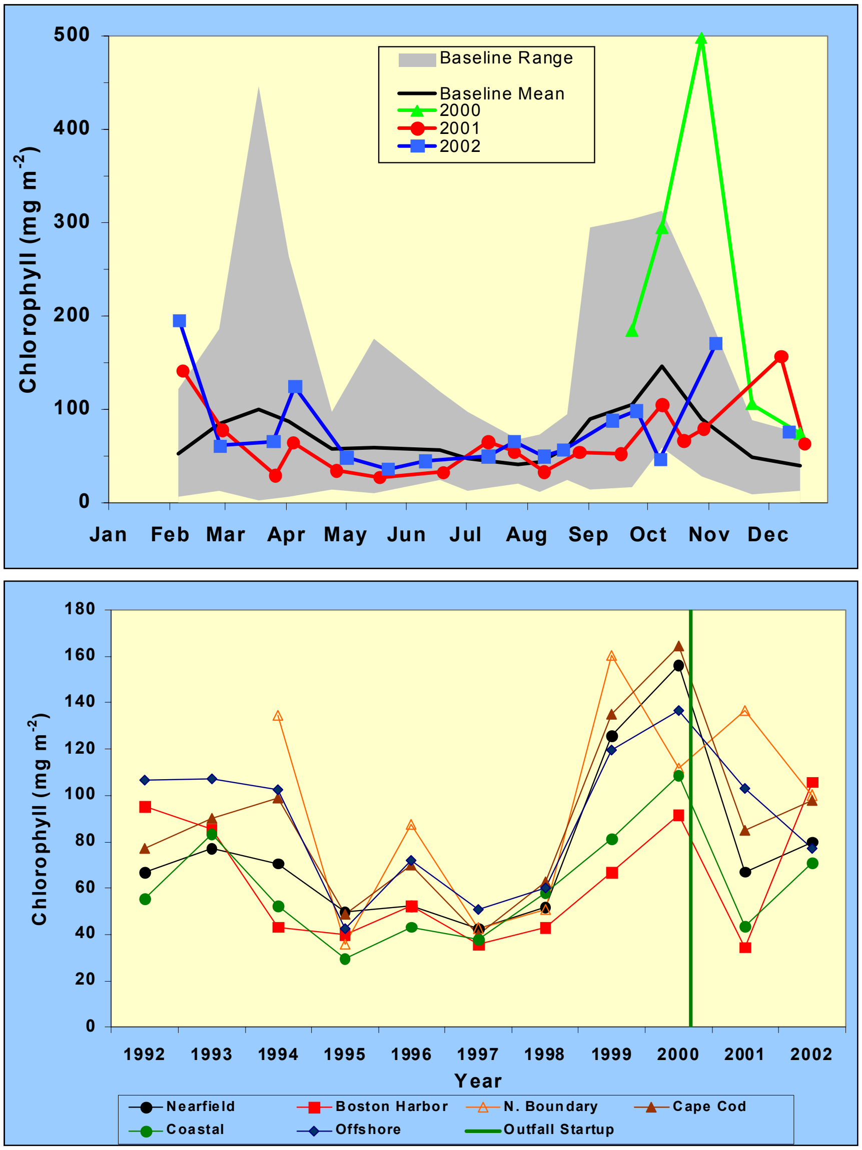

Figure 3-8. Above: 2002 nearfield chlorophyll concentrations compared to baseline range and mean; Below: annual mean chlorophyll concentrations in Massachusetts Bay regions

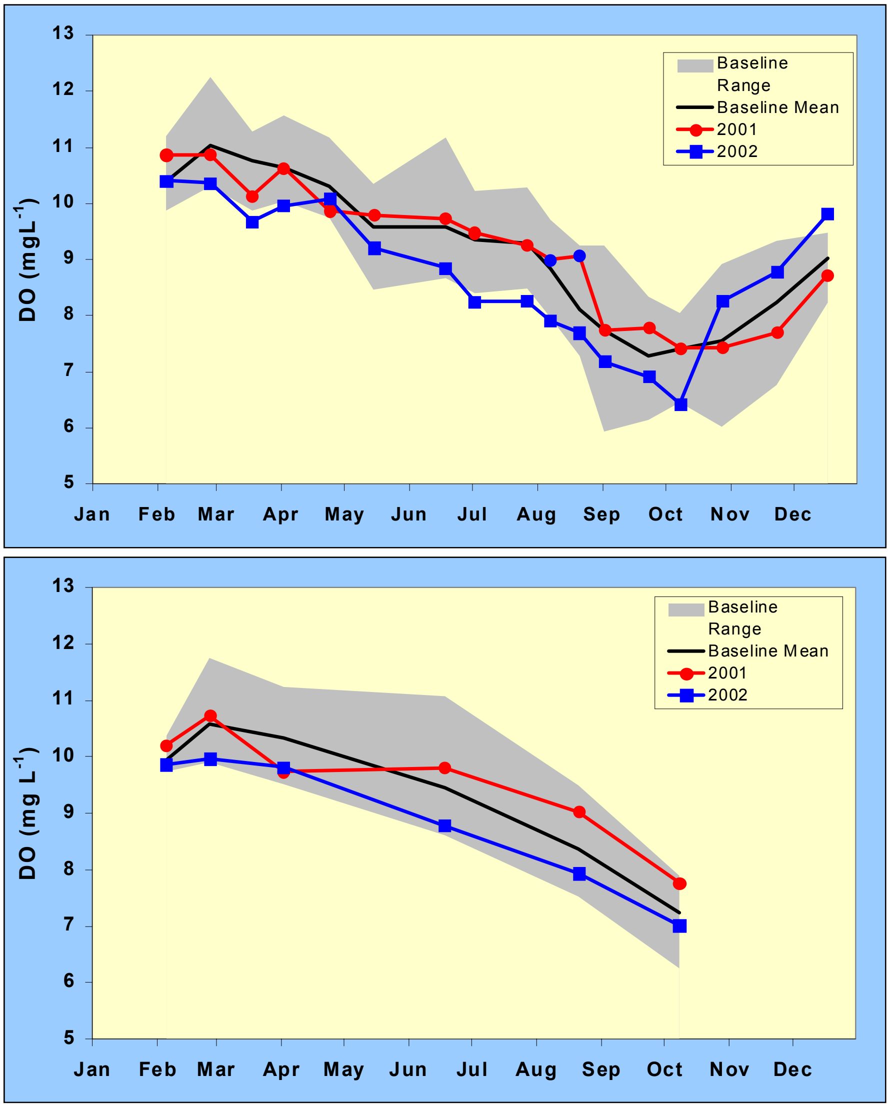

Figure 3-9. Above: 2002 nearfield dissolved oxygen concentrations compared to baseline range and mean; Below: Stellwagen Basin dissolved oxygen concentrations compared to baseline range and mean

Phytoplankton Communities

Abundance of phytoplankton and community structure during 2002 fell within the baseline range (Libby *et al.* 2003, Figure 3-10). Assemblages during both post-diversion years were generally similar to those found during baseline monitoring, with total nearfield abundance at or slightly below the baseline mean. A relatively early fall bloom occurred, possibly because a ctenophore bloom was present and decimated zooplankton populations (see Zooplankton Communities, below).

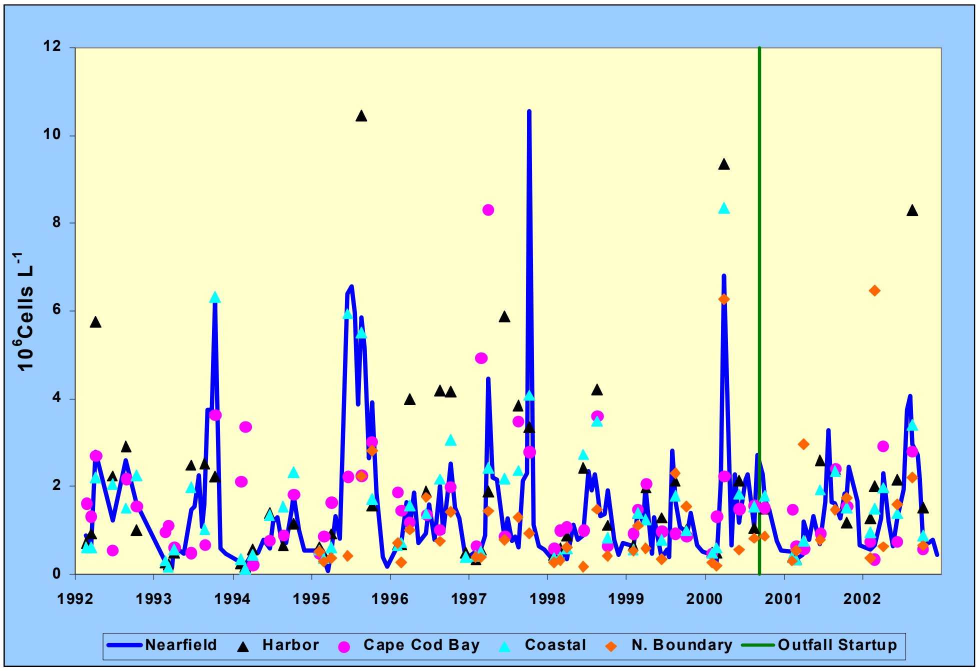

Figure 3-10. Total phytoplankton abundance by area, 1992-2002

Abundance of dinoflagellates in the genus *Ceratium* was lower than the baseline range from March until early August. *Ceratium* usually dominates screened-water samples during the warmer months. This result does not appear to be related to the outfall. Rather, the genus is dependent on well-stratified conditions, which were not present in 2002.

There continued to be no detectable increases in nuisance species compared to the baseline. *Alexandrium fundyense* was present during the late spring and early summer, but at levels well below what was periodically seen during the baseline period. *Phaeocystis pouchetii* occurred during the spring, and *Pseudo-nitzschia multiseries* appeared in the fall, both at levels lower than had been detected in baseline years.

Zooplankton Communities

For the first half of 2002, zooplankton abundance and community structure were similar to those of the baseline period (Libby *et al.*2003, Figure 3-11). There was, however, a precipitous decrease in zooplankton abundance in August, with the nearfield mean falling from 96,000 animals m^{-3} to 24,000 animals m^{-3}. This sharp decline was primarily due to the presence of unusually abundant ctenophores. Ctenophores *Mnemiopsis leidyi* were present during July-November, a longer period than they were present in 2000, the only other year in which *Mnemiopsis* occurred in the bay. Their presence is unlikely to be related to the outfall, as ctenophores were also abundant in Buzzards Bay and the Cape Cod Canal during 2000 and 2002.

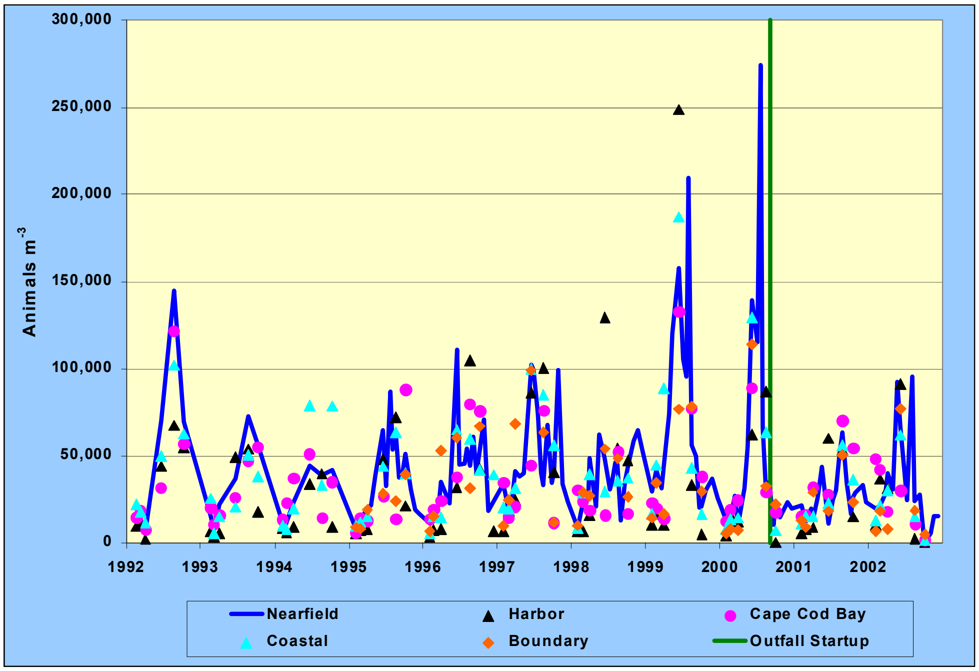

Figure 3-11. Zooplankton abundance by area, 1992-2002

No effects of the outfall on the typical zooplankton communities, which are dominated by copepod nauplii and copepodites and adults of the small copepod *Oithonus similis*, were seen. Broader-scale studies suggest that zooplankton communities may be shaped by wide-scale forcing factors, such as the North Atlantic Oscillation, rather than by local forces such as the MWRA outfall (Kropp *et al.* 2003).

Evaluation of Monitoring Program Design

As part of a review of the monitoring program, the chlorophyll and bottom water dissolved oxygen data were analyzed, using a linear mixed model regression analysis and analysis of residual variance. The regression analysis attempted to find seasonal patterns in the data and to identify long-term linear trends (for example, an increase in chlorophyll through time), outfall effects, and random effects. After accounting for any of these possible trends or effects, the analysis of residual variance was conducted to determine the extent of spatial and temporal redundancy in the data (MWRA 2003b).

The analysis of residual variance found a high level of spatial redundancy in both the chlorophyll and the dissolved oxygen data. On average, the chlorophyll and dissolved oxygen data from one nearfield station were very similar to data from nearby stations. The results indicated that two-thirds of the nearfield stations could be eliminated without greatly decreasing the ability of the monitoring program to detect changes.

Similarly, the analysis detected a moderately strong level of temporal redundancy in the data, that is, on average, data from adjacent surveys were somewhat similar. The results indicated that decreasing the number of nearfield surveys from 17 to 12 per year would have minimal effects on the monitoring results.

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 an exceedance of the summer *Phaeocystis* threshold (Table 3-2). 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. *Pseudo-nitzschia pseudodelicatissima*, a potentially toxic diatom that is not currently included in *Pseudo-nitzschia* threshold calculations, was present and at times abundant. All other monitoring results were within ranges that met the thresholds.

Table 3-2. Contingency plan threshold values for water column monitoring

Location/ Parameter	Specific Parameter	Baseline	Caution Level	Warning Level	2002 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 = 6.43 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 = 71.3%
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 = 7.01 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 = 75.1%
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	82 mg/m^2
	Winter/spring	81 mgml^2	182 mg/m^2	None	112 mg/m^2
	Summer	51 mg/m^2	80 mg/m^2	None	50 mg/m^2
	Autumn	90 mg/m^2	161 mg/m^2	None	100 mg/m^2
Nuisance algae nearfield *Phaeocystis pouchetii*	Winter/spring	470,000 cells/l	2,020,000 cells/l	None	269,000 cells/l
	Summer	72 cells/l	334 cells/l	None	14,900 cells/l
	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	900 cells/l
	Summer	13,000 cells/l	38,000 cells/l	None	200 cells/l
	Autumn	9,700 cells/l	37,900 cells/l	None	2,300 cells/l
Nuisance algae nearfield *Alexandrium fundyense*	Any nearfield sample	Baseline maximum = 163 cells/l	100 cells/l	None	7.5 cells/l maximum
Farfield	PSP toxin extent	Not applicable	New incidence	None	No toxicity or shellfish closures

The 2001 revision to the contingency plan (MWRA 2001) required MWRA to prepare a report on zooplankton populations and evaluate whether a scientifically valid threshold could be developed. That report (Kropp *et al.* 2003) found that zooplankton populations tend to respond to large-scale environmental factors on regional scales that dwarf the responses to local events. The report determined that no simple, meaningful threshold was possible. However, MWRA will continue to evaluate the zooplankton community and to report on possible outfall-related events. (See additional information about the report in Section 6. Special Studies.)

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 has 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 concern that bottom communities near the outfall could be affected by deposition.

Monitoring Design

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

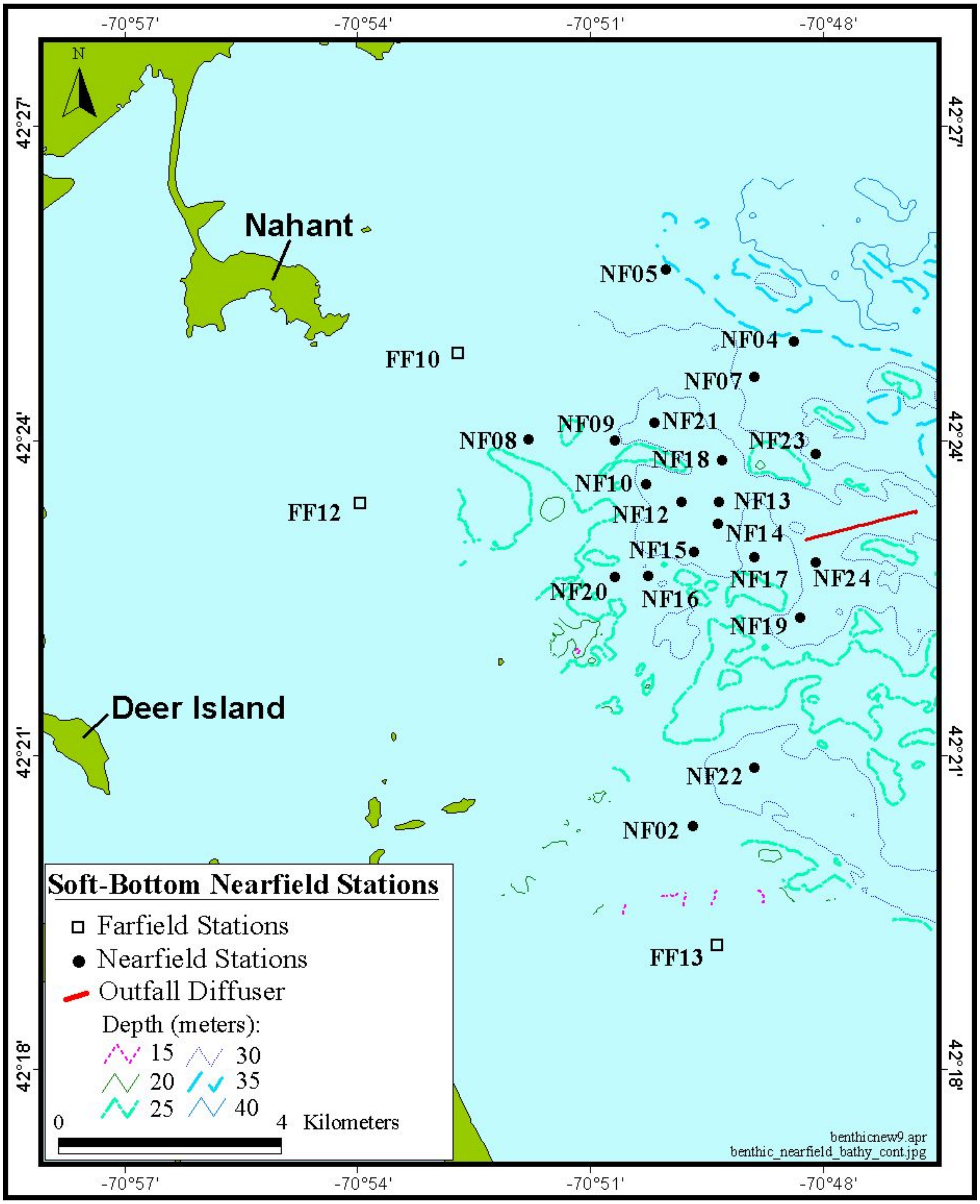

Figure 4-1. Locations of nearfield soft-bottom stations (NF12 and NF17 are also sampled by USGS.)

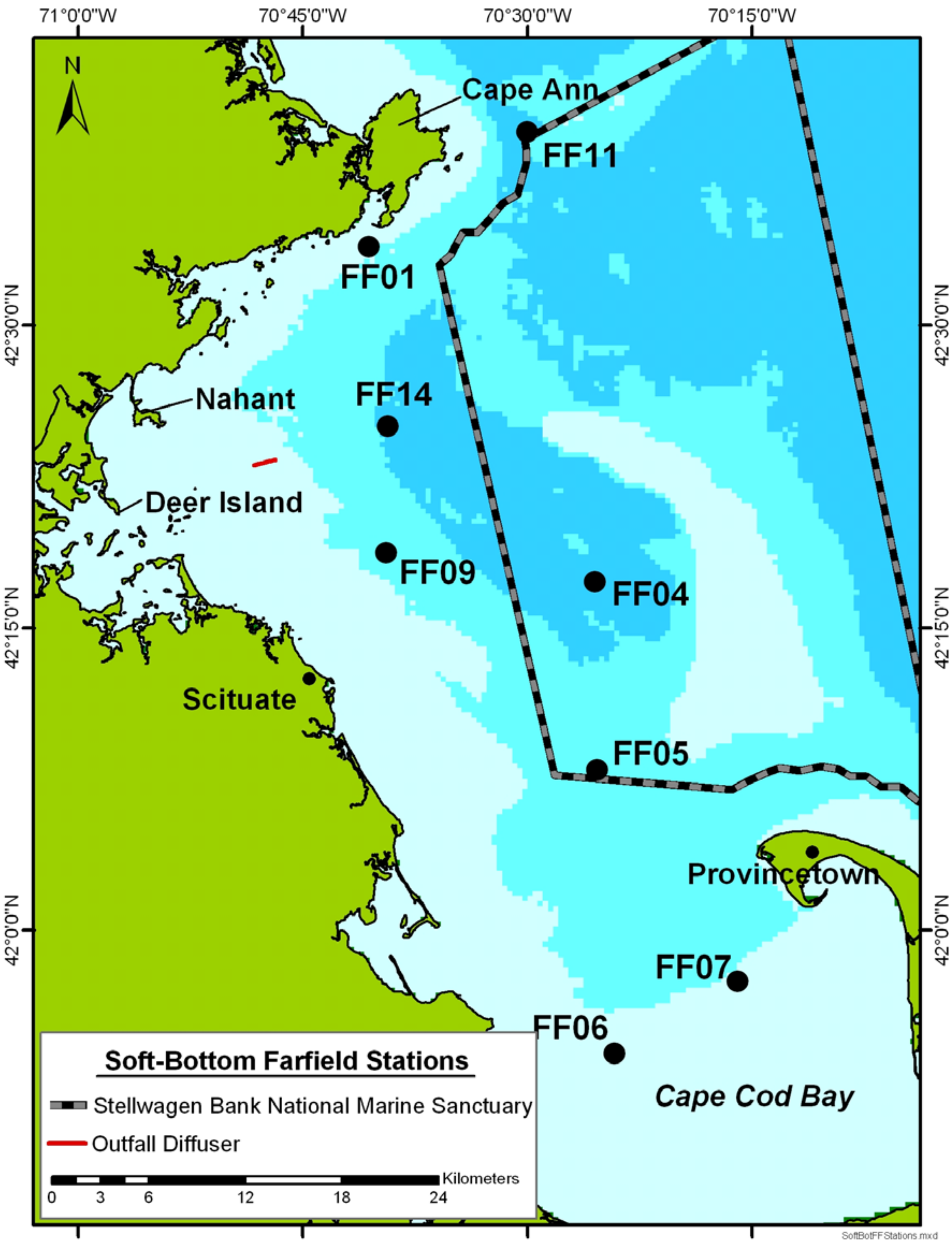

Figure 4-2. Locations of farfield soft-bottom stations

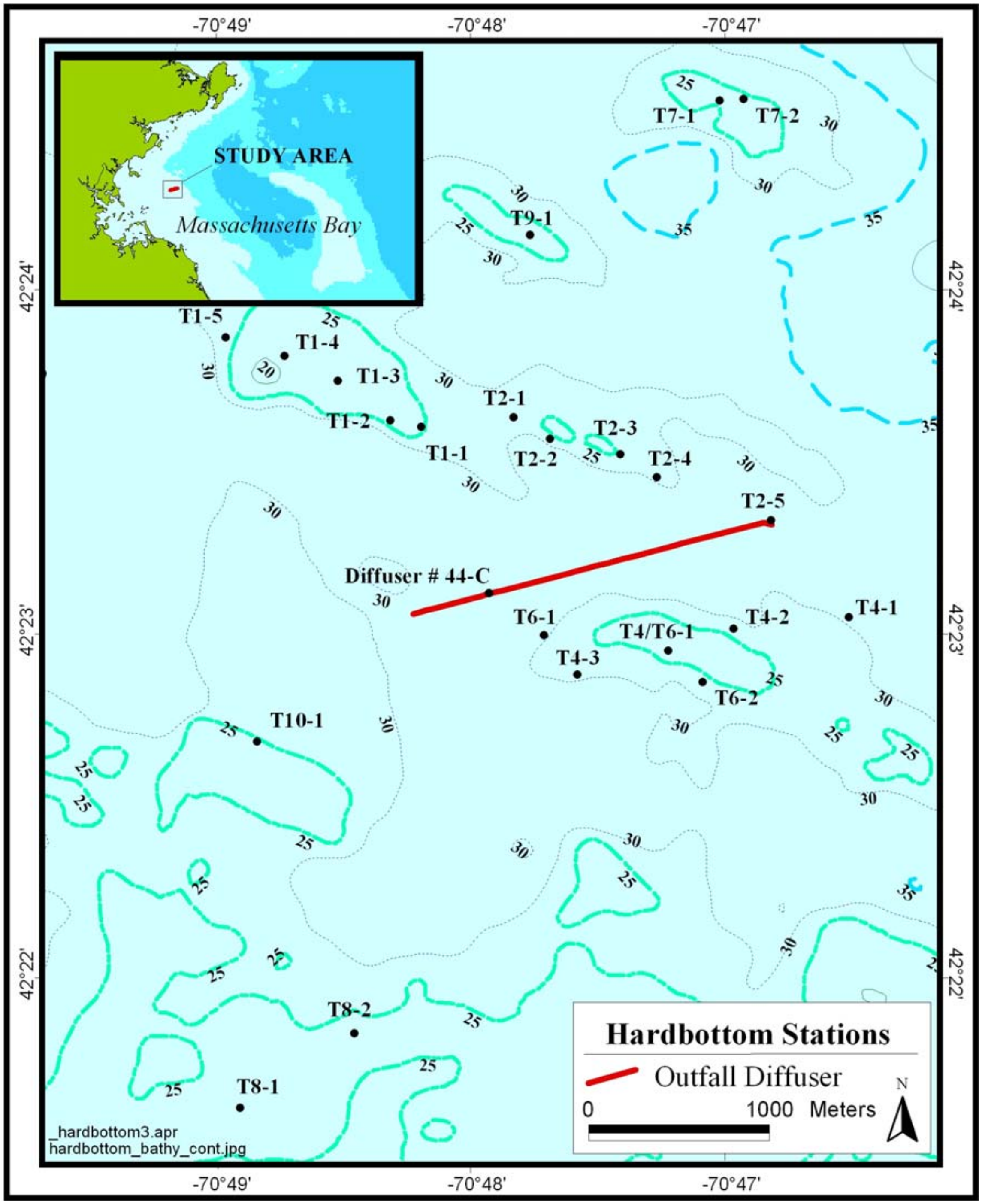

Figure 4-3. Locations of hard-bottom stations

The core of sediment contaminant monitoring consists of annual, mid-August sampling of sediments at 31 stations throughout Massachusetts and Cape Cod bays. Replicate field samples are taken at all farfield and selected nearfield stations. Single samples are taken at the remaining nearfield stations. Samples are analyzed for PAHs, PCBs, chlorinated pesticides, metals, grain size, total organic carbon (TOC), *Clostridium perfringens* spores, and linear alkyl benzenes.

Annual sediment-contaminant monitoring is complemented by two special studies. One study is a collaborative effort between MWRA and USGS to investigate 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 that deposits in sediment traps. Suspended matter samples are analyzed for metals, grain size, TOC, and effluent tracers.

The second special study was a 2-year program of more frequent sampling at three nearfield stations and one farfield station. These stations were selected because they had a high percentage of fine-grained material, with that percentage remaining stable throughout the baseline period, they had high TOC levels, and they were within the zone of effluent particle deposition predicted by the Bays Eutrophication Model. The data from this study were to provide an early indication of rapid organic carbon or contaminant build-up, should those conditions occur.

Sediment-profile image monitoring is conducted in August of each year at 23 nearfield stations to give an area-wide assessment of sediment quality and benthic community status. The sediment-profile images (for example, Figure 4-4) 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 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.

Figure 4-4. Example of a sediment profile image (Station NF24 in 2002)

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 in a 0.044 m^2 Young-Van Veen benthic grab, sieved on 300µm 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 21 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).

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.

Data from 2002 continued to show no rapid increase in contaminant concentrations following startup of the outfall. Using the most sensitive sewage tracers, silver and *Clostridium perfringens* spores, an effluent signal could be detected, but the signal was not pronounced. No generalized increase in contaminants in nearby sediments has been detected since the outfall began operation. These results indicate that, as predicted, the outfall has had a modest, localized effect on the sediments, but that concentrations of contaminants in the area have not increased.

Sediment Profile Imaging

Sediment profile imaging measurements in 2002 also showed no effects from the outfall (Figure 4-5).

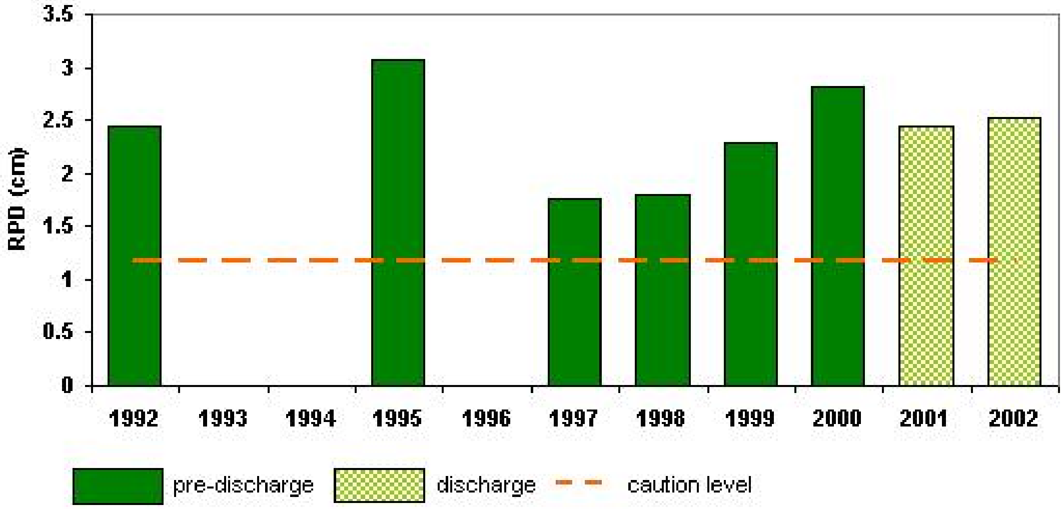

Figure 4-5. Apparent color RPD depth (cm) for all data from nearfield stations.

As in previous years, the deepest RPD layers were associated with mixed fine-sand-silt-clay sediments that had high levels of biogenic activity. At stations with coarse sediments, the apparent color RPD depths were deeper than prism penetration depths. There were no regional trends that could associate RPD depth with the outfall location. Neither the color nor the texture of the sediments in the images showed any changes that might have resulted from increased sedimentation of organic matter.

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.* 2003). 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 polychaetes *Exogenes hebes* and *E. verugera* and the amphipods *Crassicorophium crasssicorne* and representatives of the genus *Unciola*.

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 (Maciolek *et al.* 2003). 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 station. 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. While the two years of post-discharge monitoring have shown no patterns that can be related to the discharge, they have provided additional data to evaluate the broader patterns that had been detected in baseline monitoring.

Most dramatically, the abundance of soft-bottom fauna has increased 60% from 1992-2002 (Figure 4-6, top). The number of species (species richness) and log-series alpha (another measure of species richness) have also increased, suggesting a sine-wave pattern with an apparent seven-year cycle (Figure 4-6, middle and bottom).

Sophisticated statistical analyses (of a type known as generalized linear models) were carried out on the long-term benthic monitoring data. These analyses confirmed the significant increase in animal abundance and species richness and supported the apparent cycle in species richness that were observed in the raw data. The analyses did not detect a significant effect that could be attributed to the outfall. The analyses would have detected a potential outfall effect of as little as a 5% change in the average abundance or diversity. A significant change consistent with an outfall effect was found for a similar statistical analysis of the diversity measure that is sensitive to how evenly individual organisms are distributed among species. This extremely small change appears to represent be statistically but not ecologically significant, indicative of the sensitivity of the analyses and the monitoring design (MWRA 2003c, Maciolek *et al.* 2003).

Additional analyses were carried out to determine whether a discharge-related change in community composition could be detected. This evaluation found that the rates of change in benthic species and there patterns of relative abundance were moderately slow, requiring decades before a changeover in the dominant species would be observed. No difference in these rates were found between the baseline and the discharge monitoring data, documenting a lack of detectable effect of the outfall on the community composition in the nearfield (MWRA 2003c, Maciolek *et al.* 2003).

These highly sensitive analyses were strong arguments that the level of sampling in both the nearfield and the farfield could be reduced without unduly affecting the integrity of the monitoring program.

Population densities of specific organisms have also fluctuated. Although the numerically dominant species at many stations have tended not to change, one species (*Spio limicola*), which was dominant during siting studies and the early years of the monitoring program, has been replaced by another spionid polychaete (*Spio steenstrupi*).

There are several possible explanations for the long-term changes that have been observed (Maciolek *et al.* 2003):

- The *perfect-storm hypothesis*: Infauna communities are continuing to recover from the severe winter storms that occurred in 1992, after which nearfield infaunal abundances decreased dramatically.
- The *productivity hypothesis:* A long-term increase in the supply of organic matter to the benthos has led to increased abundance of infaunal organisms.
- The *climate-change hypothesis*: Infaunal communities are responding to long-term changes, perhaps related to the North Atlantic Oscillation.
- The *chance hypothesis*: Larvae of *Prionospio steenstrupi* settle earlier and/or outcompete *Spio limicola* and other possible dominants.

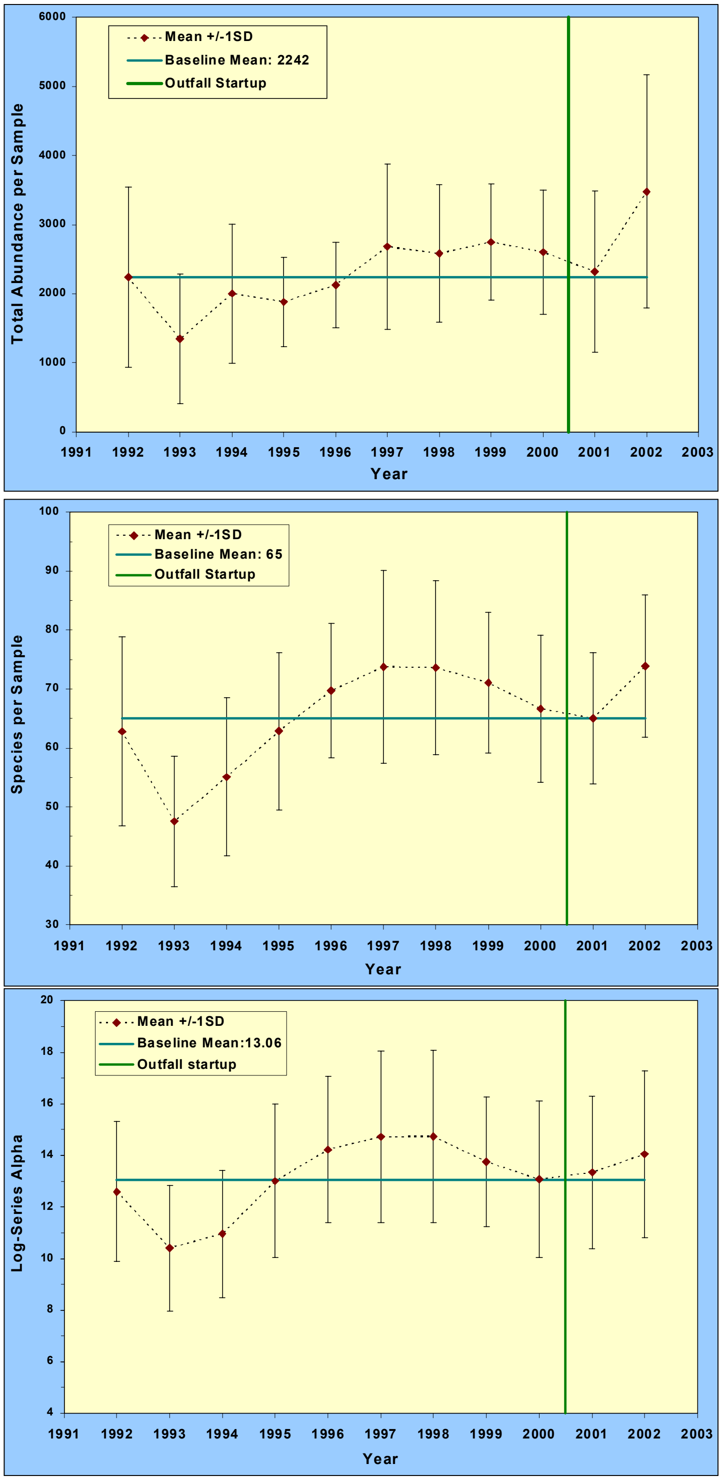

Figure 4-6. Community parameters in the nearfield, 1992-2002

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, ranging from large boulders to cobbles to gravel pavements. These patterns persisted in 2002, with only modest changes that could suggest some influence from the outfall. Several stations to the north of the outfall had an increased amount of sediment drape during 2001 and 2002, and it is possible that the increases could be due to the outfall. Nevertheless, lush epifaunal growth continues to thrive on the diffuser heads that are surveyed (Maciolek *et al.* 2003).

Several trends that appear to be regional rather than outfall-related have also been observed. Abundance of the green sea urchin *Strongylocentrotus droebachiensis* declined during 1996-2000 and then increased slightly in 2001 and 2002. Crabs in the genus *Cancer* and the cod *Gadus morhua* have increased in numbers since the mid 1990s. A general increase in the abundance of lobsters has also been noted.

Contingency Plan Thresholds

No contingency plan threshold parameters for sea floor monitoring were exceeded in 2002. Those parameters include contaminant concentrations, RPD depth, and benthic diversity and species composition in soft-bottom communities (Table 4-2).

Table 4-2. No contingency plan baseline and threshold values for sea floor monitoring were exceeded in 2002.

Location	Parameter	Caution Level	Warning Level	2002 Results
Sediment toxic contaminants, nearfield	Acenaphthene	None	500 ppb dry	45.6 ppb dry
	Acenaphylene	None	640 ppb dry	83.4 ppb dry
	Anthracene	None	1100 ppb dry	264 ppb dry
	Benzo(a)anthracene	None	1600 ppb dry	362 ppb dry
	Benzo(a)pyrene	None	1600 ppb dry	300 ppb dry
	Cadmium	None	9.6 ppm dry	0.0909 ppm dry
	Chromium	None	370 ppm dry	78.9 ppm dry
	Chrysene	None	2800 ppb dry	362 ppb dry
	Copper	None	270 ppm dry	25.1 ppm dry
	Dibenzo(a,h)anthracene	None	260 ppb dry	59.1 ppb dry
	Fluoranthene	None	5100 ppb dry	821 ppb dry
	Fluorene	None	540 ppb dry	75.5 ppb dry
	Lead	None	218 ppm dry	68 ppm dry
	Mercury	None	0.71 ppm dry	0.202 ppm dry
	Naphthalene	None	2100 ppb dry	103 ppb dry
	Nickel	None	51.6 ppb dry	17.2 ppb dry
	p,p'-DDE	None	27 ppm dry	0.64 ppm dry
	Phenanthrene	None	1500 ppb dry	630 ppb dry
	Pyrene	None	2600 ppb dry	847 ppb dry
	Silver	None	3.7 ppm dry	0.486 ppm dry
	Total DDTs	None	46.1 ppb dry	2.3 ppb dry
	Total HMWPAH	None	9600 ppb dry	4820 ppb dry
	Total LMWPAH	None	3160 ppb dry	2140 ppb dry
	Total PAH	None	44792 ppb dry	6950 ppb dry
	Total PCBs	None	180 ppb dry	18.2 ppb dry
	Zinc	None	410 ppm dry	64.2 ppm dry
Sediments, nearfield	RPD depth	1.18 cm	None	2.5 cm
Benthic diversity, nearfield	Species per sample	<47.97 or >81.09	None	73
	Fisher's log-series alpha	<10.13 or >15.58	None	13.84
	Shannon diversity	<3.32 or >4.02	None	3.60
	Pielou's evenness	<0.56 or >0.67	None	0.58
Species composition, nearfield	Percent opportunists	10%	25%	0.14%

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, rendering them unfit for human consumption. Another concern about relocating sewage effluent offshore, into relatively clean waters, is that contaminants could adversely affect resource species through 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. These shellfish are themselves resource species and are prey to other fisheries species. Consumption of these animals by predators could result in transferring contaminants up the food chain and ultimately to humans.

Monitoring Design

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

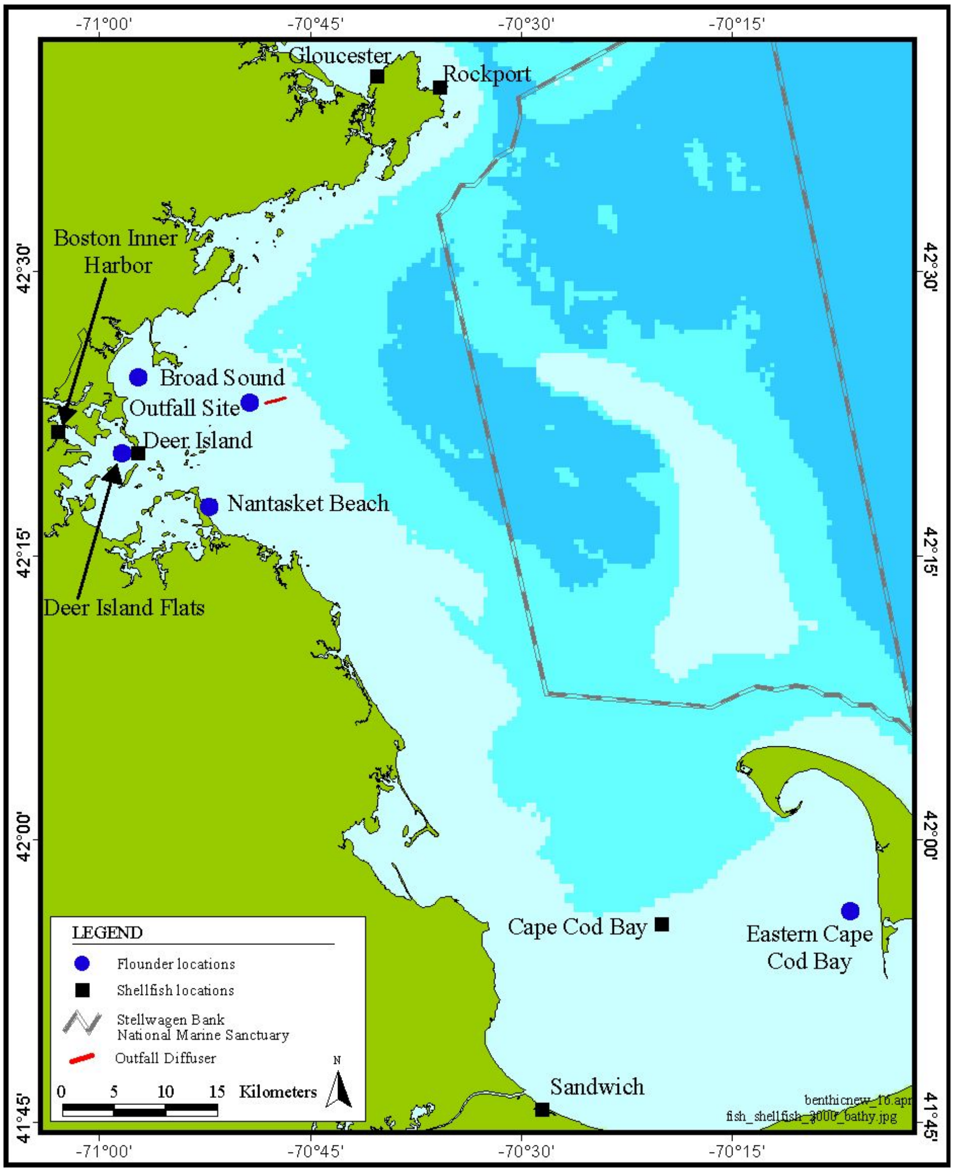

Figure 5-1. Sampling areas for fish and shellfish monitoring. (See text for sample locations of individual species.)

Winter Flounder

Like all flatfish, winter flounder live on and eat food from the bottom, often lying with all but their eyes 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 to obtain specimens for age determination, gross examination of health, and liver histology: Deer Island Flats, Broad Sound, off Nantasket Beach, the outfall site, and eastern Cape Cod Bay. Livers are examined to quantify three types of vacuolation (centrotubular, tubular, and focal, representing increasing severity), microphage aggregation, biliary duct proliferation, and neoplasia or tumors. Neoplasia and vacuolation have been associated with chronic exposure to contaminants.

Chemical analyses of winter flounder tissues from Deer Island Flats, the outfall site, Cape Cod Bay, Broad Sound, and Nantasket were 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, with on-board scientists verifying the sampling locations. Lobsters are taken from Deer Island Flats, the area near the new outfall, and eastern Cape Cod Bay to determine specimen health and tissue contaminant burden. Chemical analyses are performed on composite samples. Meat (from the tail and claw) and hepatopancreas are analyzed for lipids, PCBs, pesticides, and mercury. Hepatopancreas samples are also analyzed for PAHs, lead, silver, cadmium, chromium, copper, nickel, and zinc.

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 in 2002, Harpswell, Maine). They are placed in cages and deployed in replicate arrays at as many as four sites, including Boston Inner Harbor, Deer Island, 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 five sampling sites in April and May 2002 (Pala *et al.* 2003). Each of the fish was examined for physical characteristics. Fifteen fish from each site were designated for chemical analyses. All fish were used for histological and age analyses.

Overall, the fish appeared healthy, with no evidence of effects of relocating the discharge. Tumors were absent and incidence of fin erosion was low. As in previous years, the milder centrotubular hydropic vacuolation (CHV) was the most common form of vacuolation.

The increase in CHV prevalence at Deer Island Flats that had been detected in 2000 and 2001 was not sustained, while prevalence at the outfall site rose from a low in 2001 to a level approximately the same as the baseline mean (Figure 5-2).

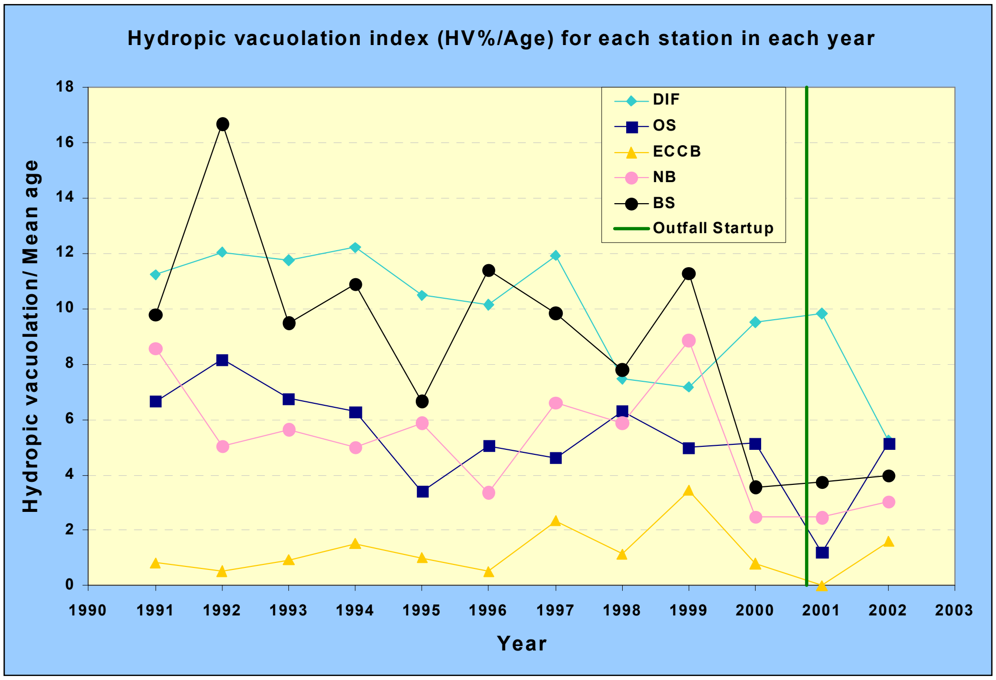

Figure 5-2. Prevalence of centrotubular hydropic vacuolation (CHV) normalized for age (DIF = Deer Island Flats, OS = Outfall Site, ECCB = Eastern Cape Cod Bay, NB = Nantasket Beach, and BS = Broad Sound)

Body burdens of organic contaminants in edible tissues were similar to burdens in previous years, and no response to the relocated outfall was detected (Figure 5-3). No concentrations of contaminants in flounder fillets taken from the outfall site were significantly different from those taken during baseline monitoring. Concentrations of contaminants in flounder livers were also within the baseline ranges.

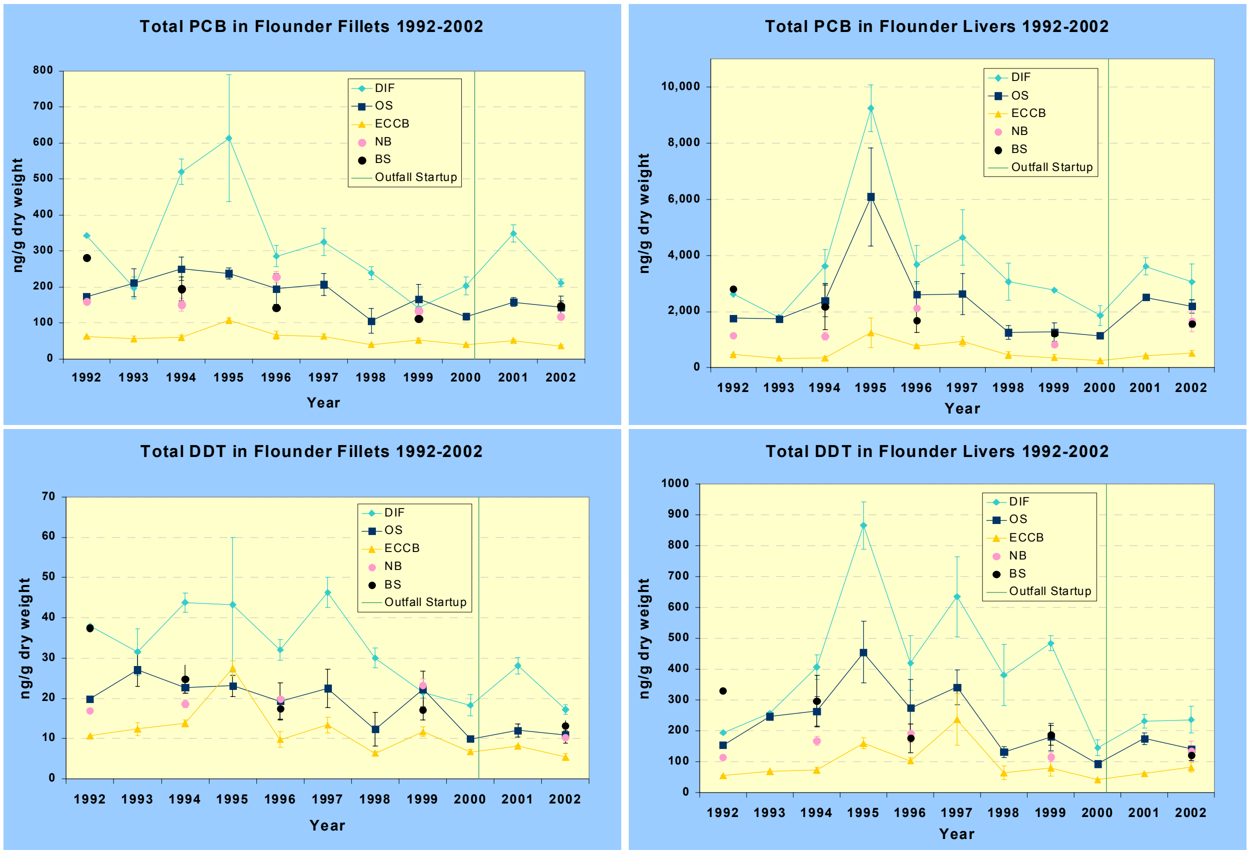

Figure 5-3. Selected contaminant concentrations in flounder fillets and livers. (DIF = Deer Island Flats, OS = Outfall Site, BS = Broad Sound, NB = Nantasket Beach, and ECCB = Eastern Cape Cod Bay)

Lobster

Fourteen lobsters from Deer Island Flats and fifteen from each of the other stations, the outfall site and eastern Cape Cod Bay, were purchased from commercial lobstermen in 2002 (Pala *et al.* 2002). The lobsters were approximately the same size at all sites, but those from eastern Cape Cod Bay weighed about 100 g less. Only males were collected at eastern Cape Cod Bay and mostly females were taken at the other two sites. No gross abnormalities were noted in any of the lobsters collected during 2002.

As in previous years, contaminant concentrations in lobster meat were low, and no effects of relocating the outfall were detected. For most contaminants, concentrations fell below the baseline range. Similarly, concentrations of contaminants in lobster hepatopancreas were low, with most results being well within the baseline range (Figure 5-4).

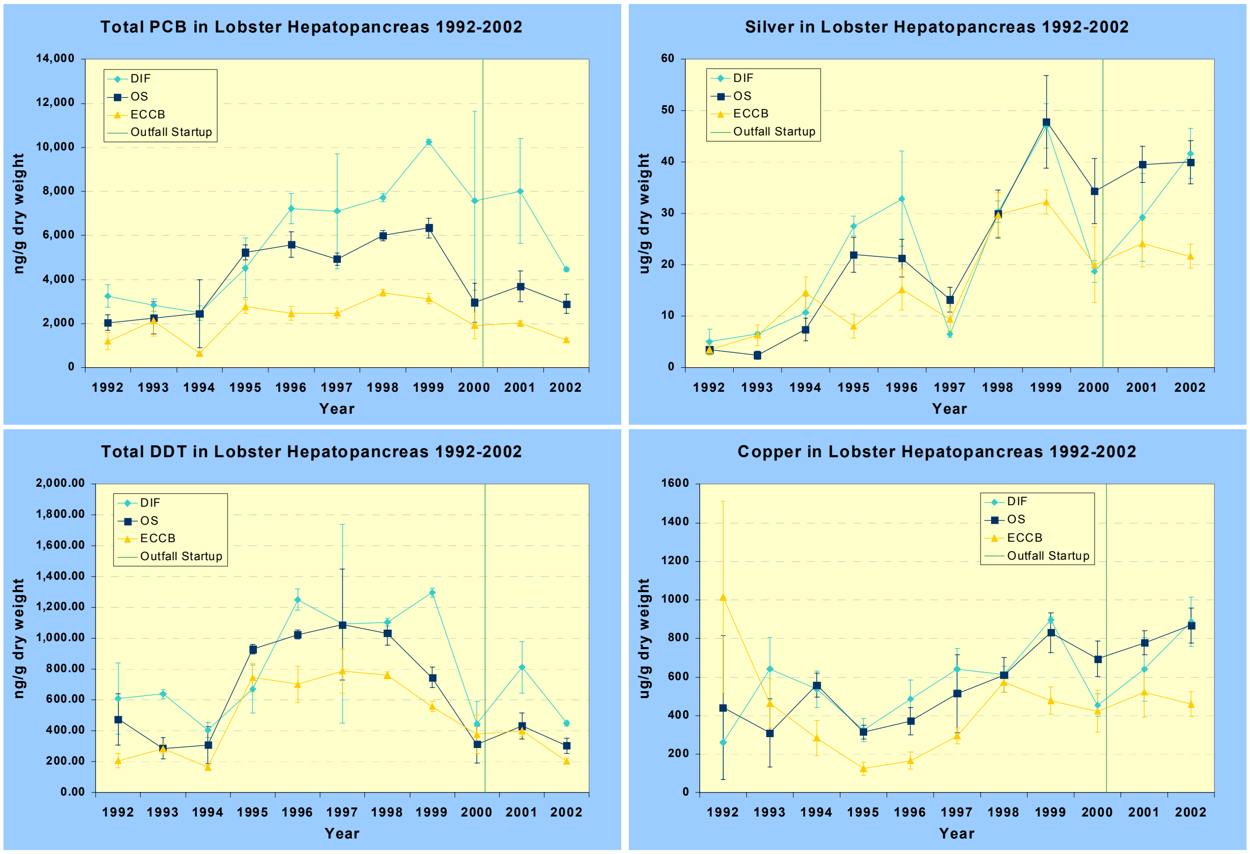

Figure 5-4. Selected contaminants concentrations in lobster hepatopancreas. (DIF = Deer Island Flats, OS = Outfall Site, and ECCB = Eastern Cape Cod Bay)

Blue Mussel

Full mussel arrays were recovered after 40 and 60 days (Pala *et al.* 2002). Survival was high, ranging from 98 to 100% for both 40- and 60-day deployments.

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 shows the greatest degree of bioaccumulation (Figure 5-5).

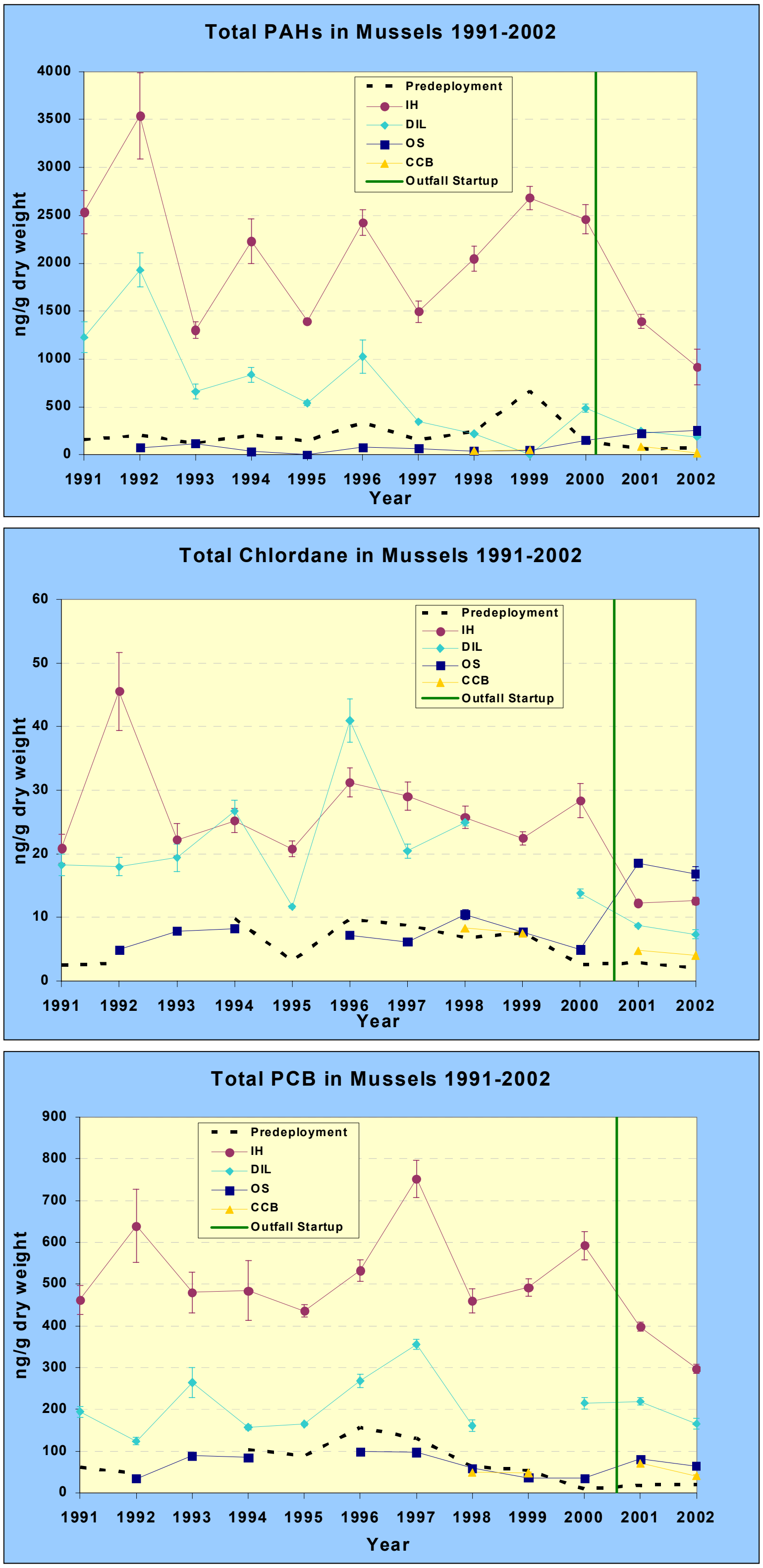

Figure 5-5. Selected contaminant concentrations in mussels. (IH = Inner Harbor, DIL = Deer Island Light, OS = Outfall Site, CCB = Cape Cod Bay)

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 5-2). 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.

Table 5-2. Contingency plan baseline, threshold, and 2002 values for fish and shellfish monitoring

Parameter Type/ Location	Parameter	Baseline	Caution Level	Warning Level	2002 Results
Flounder tissue nearfield	PCB	0.033 ppm	1 ppm wet weight	1.6 ppm wet weight	0.024 ppm
	Mercury	0.074 ppm	0.5 ppm wet weight	0.8 ppm wet weight	0.065 ppm
Flounder tissue, lipid normalized, nearfield	Chlordane	242 ppb	484 ppb	None	73.7 ppb
	Dieldrin	63.7 ppb	127 ppb	None	10.6 ppb
	DDT	775.9 ppb	1552 ppb	None	254 ppb
Flounder nearfield	Liver disease (CHV)	24.4%	44.9%	None	24%
Lobster tissue nearfield	PCB	0.015 ppm	1 ppm wet weight	1.6 ppm wet weight	0.0086 ppm
	Mercury	0.148 ppm	0.5 ppm wet weight	0.8 ppm wet weight	0.113 ppm
Lobster tissue, lipid normalized, nearfield	Chlordane	75 ppb	150 ppb	None	48.1 ppb
	Dieldrin	161 ppb	322 ppb	None	132 ppb
	DDT	341.3 ppb	683 ppb	None	289 ppb
Mussel tissue nearfield	PCB	0.011 ppm	1 ppm wet weight	1.6 ppm wet weight	0.0084 ppm
	Lead	0.415 ppm	2 ppm wet weight	3 ppm wet weight	0.33 ppm
	Mercury	0.019 ppm	0.5 ppm wet weight	0.8 ppm wet weight	0.023 ppm
Mussel tissue, lipid normalized, nearfield	Chlordane	102.3 ppb	205 ppb	None	210 ppb, caution level exceedance
	Dieldrin	25 ppb	50 ppb	None	25.6 ppb
	DDT	241.7 ppb	483 ppb	None	223 ppb
	PAH	1080 ppb	2160 ppb	None	3140 ppb, caution level exceedance

During 2002, the caution thresholds for PAHs and chlordane were exceeded in mussels. Similar exceedances in 2001 had prompted evaluation of treatment plant operations, the mussel deployments, and the chemical analyses (Hunt *et al.* 2002c). The review found that the exceedances did not represent a problem with the discharge, rather that the initial expectations of mussel uptake were based on outdated information, and that the chlordane and PAH concentrations did not present a risk to human health or marine organisms. Even in the undiluted effluent, concentrations of chlordane were, at most, near the water quality criteria for marine receiving waters.

A focus group was convened to evaluate the 2001 and 2002 threshold exceedances. That panel concluded that the chlordane and PAH concentrations measured in the mussels were very low (OMSAP 2003).

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 2002, MWRA continued to monitor water quality in Boston Harbor, study nutrient cycling in Boston Harbor and Massachusetts Bay, and make observations of marine mammals. As directed by the 2001 contingency plan (MWRA 2001), MWRA conducted an evaluation of zooplankton communities. Also, MWRA began to prepare for refocusing the monitoring program onto the potential for long-term effects.

Improved Water Quality in Boston Harbor

Since 1993, MWRA has monitored the recovery of Boston Harbor in response to the Boston Harbor Project (Taylor 2003). Ten stations within the harbor have been sampled weekly from May through October and once every two weeks from November through April. Table 6-1 and Figure 6-1 summarize the changes in the harbor during the two years since effluent discharge to the harbor was ended.

During those two years, there have been significant reductions in average concentrations of nitrogen, phosphorus, and the molar ratios of nitrogen to phosphorus. Nitrogen concentrations decreased more than phosphorus, and for all three variables, the decreases were larger in the dissolved inorganic fraction. The decreases were significant for the harbor as a whole and for all ten individual stations.

During the first year after diversion, there was a significant decrease in chlorophyll, a measure of phytoplankton biomass. That change was not sustained in the second year, when chlorophyll concentrations did not differ from the baseline. At two stations in the outer harbor, concentrations were significantly elevated during a localized bloom of centric diatoms that occurred during the spring of 2002.

Increases in midsummer bottom-water dissolved oxygen compared to the baseline were detected in 2001 and were more pronounced in 2002. In 2002, improvements were significant throughout the harbor, and percent dissolved oxygen saturation was also significantly elevated.

Salinity was also slightly elevated over baseline levels, particularly in 2002 when drought conditions prevailed. This increase was in the same order as had been predicted and was significant at nine of the ten stations sampled.

Table 6-1. Significant changes in the water column during the first and second years following discharge. (Solid arrows indicate that changes were significant at all stations; hollow arrows indicate that changes were significant only at specific stations; black arrows indicate that the changes can be considered improvements.TN=total nitrogen; DIN=dissolved inorganic nitrogen; TP=total phosphorus; Chl-a=chlorophyll a; PC=particulate organic carbon; k=light attenuation coefficient; DO=dissolved oxygen.)

VARIABLE	CHANGE DURING FIRST 12-MONTHS		CHANGE DURING SECOND 12-MONTHS	
TN (µmol l^{-1})	⬇	-10.1 (-32%)	⬇	-11.3 (-36%)
DIN (µmol l^{-1})	⬇	-6.4 (-54%)	⬇	-8.1 (-69%)
TP (µmol l^{-1})	⬇	-0.23 (-13%)	⬇	-0.31 (-17%)
DIP (µmol l^{-1})	⬇	-0.32 (-31%)	⬇	-0.34 (-33%)
TN:TP	⬇	-5 (-27%)	⬇	-4 (-21%)
DIN:DIP	⬇	-4 (-39%)	⬇	-7 (-60%)
CHL-A (ug l^{-1})	⬇	-2.3 (-50%)	⇑	+0.3 (+6%)
PC (µmol l^{-1})	⬇	-16.3 (-38%)	⬇	-8.4 (-20%)
k (m^{-1})	⬇	-0.8 (-15%)	⇑	+0.03 (+5%)
SECCHI DEPTH (m)	⬆	+0.3 (+10%)	⇧	+0.1 (+3%)
DO CONC. (mid-summer) (mg l^{-1})	⇧	+0.4 (=6%)	⬆	+0.4 (+6%)
DO % SAT. (mid-summer)	⇧	+4.9 (+6%)	⇧	+4.1 (+5%)
ENTEROCOCCUS (cfu 100 ml^{-1})	⬇	-20 (-77%)	⬇	-21 (-81%)
SALINITY (ppt)	⇧	+0.5 (+2%)	⬆	+0.9 (+3%)

Black arrows = changes that might be viewed as improvements,
Hatched arrows = changes that might be viewed as 'non-beneficial',
Gray arrows = changes that cannot be assesed in either of these ways.

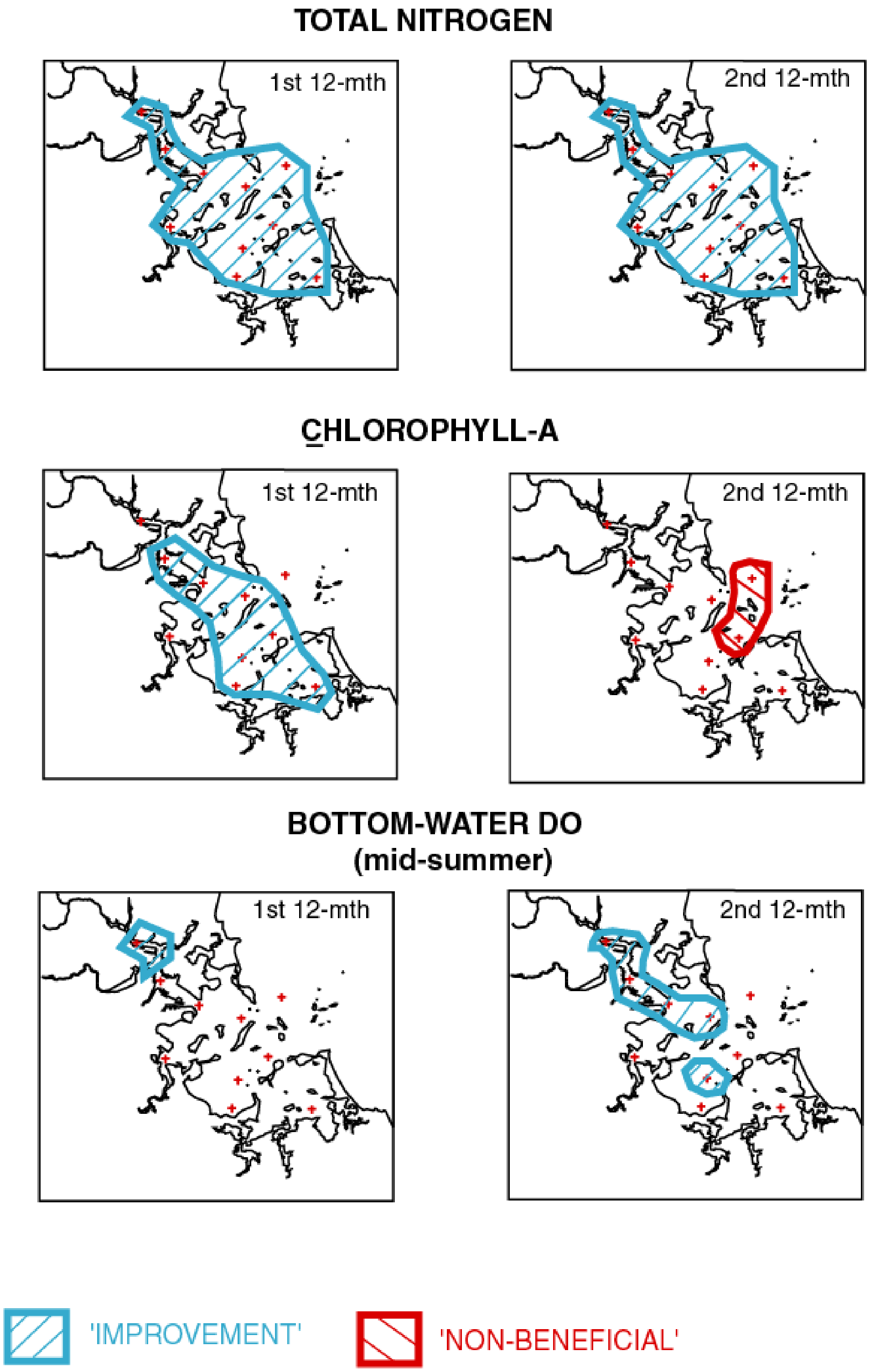

Figure 6-1. Spatial patterns of changes in the water column during the first and second years after transfer of discharge from Boston Harbor to Massachusetts Bay. (Shaded areas enclose stations at which changes were significant.)

Nutrient Flux

One public 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. Higher rates of benthic respiration or sediment oxygen demand might lead to lower levels of oxygen in the sediments and the water column. The monitoring plan (MWRA 1991) required that MWRA measure the rates of denitrification, sediment oxygen demand, and the flux of nutrients in the vicinity of the outfall and assess the importance of these processes on nutrient and oxygen levels (Table 6-2).

Table 6-2. 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 2002, studies were conducted at four sites in the harbor, three sites in the nearfield, and one site in Stellwagen Basin (Tucker *et al.* 2003). In the years 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.

There have been small, but inconsistent, changes in measures of sediment organic matter. Organic matter content in surface sediments in the nearfield has increased since the outfall began operation, but has remained within the baseline range. Small increases in total organic carbon at the farfield station included in the study suggest that the changes may be region-wide rather than related to the outfall.

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. These changes, along with the water quality data, reflect the ongoing recovery of Boston Harbor following the diversion of effluent discharge.

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. Marine mammals that are not endangered or threatened also occur, including the minke whale, harbor porpoise, gray seal, harbor seal, and several species of dolphins.

Since 1995, MWRA has included endangered species observers on monitoring surveys. In 2002, observers were included on 29 surveys (McLeod *et al.* 2003). 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.

During the 2002 surveys, 16-18 individual whales, 4 harbor porpoise, and 10-13 Atlantic white-sided dolphins were directly observed by the trained observers and other members of the monitoring team. The total number of whales sighted during 2001 and 2002 is lower than in earlier years. Although the MWRA program is not designed to be able to detect differences among years, the Whale Center of New England sighting records showed that numbers of humpback and minke whales in Massachusetts Bay were low in 2002. Surveys conducted by the Center for Coastal Studies indicated that abundance of right whales was lower and duration of stay was shorted in 2002 than in recent years, but not as low as 1999, a pre-discharge year (Brown *et al.* 2002).

Plankton Studies

Another concern about the effluent discharge into Massachusetts Bay was that it would adversely change the zooplankton community. A change in zooplankton abundance or community parameters could alter the food web in the bays (MWRA 1991, Table 6-3).

Table 6-3. Monitoring questions related to zooplankton

Are natural/living resources protected? *Will nutrient enrichment in the water column contribute to changes in plankton community structure?* ▪ 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?

Initially, MWRA planned for a contingency plan threshold that would monitor a shift in the community from species typically found in offshore habitats to those found inshore (MWRA 1997a, 1997b). Specifically, a threshold was developed to measure an increase in two species of copepods, *Acartia hudsonica* and *Acartia tonsa*, which were abundant in Boston Harbor but not present in the bays.

Subsequent research found, however, that presence of the two *Acartia* species would not be a good indicator of nutrient enrichment in the bays. The two species are restricted to harbors and estuaries not because of a competitive advantage in a nutrient-rich environment but because their development requires a lower salinity environment.

Therefore, in the revised contingency plan (MWRA 2001), EPA and MADEP approved deletion of the existing zooplankton threshold and directed MWRA to prepare a report on zooplankton populations that evaluated whether an appropriate new threshold could be developed. As part of this evaluation, OMSAP recommended analyzing data spatially and temporally to contrast the northern boundary stations with those in Cape Cod Bay. The idea, dubbed the “conveyor belt hypothesis,” was that a population of zooplankton would be advected into Massachusetts Bay at the northern boundary, transported through the nearfield (potentially being affected by nutrients) and ultimately arrive in Cape Cod Bay. A sequential timing of peaks in zooplankton species could reflect this conveyer belt system of transport.

MWRA used graphical analyses to examine seasonal variations and the conveyer belt hypotheses, principal components analyses to evaluate biotic and abiotic variables, and cluster analyses to compare similarities among samples and species (Kropp *et al.* 2003).

The graphical analyses did not confirm a link between abundance at the northern boundary and in Cape Cod Bay that would support the conveyer belt hypothesis. No large-scale transport of species from north to south was detected.

The principal components analyses found that temperature is probably the most important abiotic factor affecting the zooplankton community in Massachusetts Bay. Dissolved oxygen concentrations also influenced the community, but other abiotic factors, including salinity, fluorescence, and transmissivity, did not.

Cluster analyses indicated that zooplankton populations in the harbor differed from those in Massachusetts Bay and that the nearfield and Cape Cod Bay were similar. An analysis of nearfield stations showed no difference between pre- and post-discharge samples. Samples from the fall of 2002 were different from all others, reflecting the decimation of populations by ctenophores.

Overall, the report found that the zooplankton communities throughout the region responded simultaneously to large-scale factors rather than individually to local events. No meaningful threshold that would measure effects of nutrient enrichment from the outfall on zooplankton population in the nearfield or the farfield could be recommended.

Revisions to the Monitoring Plan

At the end of 2002, MWRA had completed nearly ten years of baseline monitoring, which provided abundant data to use in evaluating possible effects of the outfall, and two years of post-discharge monitoring, which have documented minimal short-term effects of the relocated discharge. The years of data have also provided a resource for evaluating the effectiveness and efficiency of sampling designs. Therefore, following National Research Council recommendations and the MWRA monitoring plans (NRC 1990, MWRA 1991, 1997a), MWRA began to review the program and to refocus it on the detection of potential for long-term chronic effects.

Changes have been suggested for the water column, sea floor, and fish and shellfish portions of the program. These plans were presented to OMSAP at a series of meetings that took place in 2003 (MWRA 2003a, 2003b, 2003c); OMSAP voted to endorse the proposed changes.

Water Column

MWRA has proposed no changes to the farfield monitoring program, but does propose changes in the nearfield program. Stations at which only hydrocast and dissolved nutrients have been measured would be dropped, leaving 7 of the 21 existing nearfield stations. MWRA has also proposed dropping 5 of the 17 surveys. Surveys would continue to be conducted in February, February/March, March, April, May, June, July, August, early and late September, and early and late October.

Sea Floor

MWRA has proposed changes in sediment contaminant and benthic infauna studies, with no changes to the sediment profile imaging studies and minor refinements to the hard-bottom assessments. Annual contaminant sampling and analyses would continue at the two USGS/MWRA stations, and sediment trap samples would continue to be analyzed for effluent tracers. Contaminant sampling and analysis at other stations would be decreased to once every third year. Annual sediment infauna samples would continue to be taken and analyzed at the two USGS/MWRA stations. Other stations would be randomly split into two subsets, and each subset would be monitored in alternate years.

Fish and Shellfish

Monitoring results have shown that there have been no short-term changes in flounder health, flounder contaminant body burdens, or lobster body burdens at the outfall site. With the exception of PAHs and chlordanes, no changes in mussels deployed at the outfall have been measured, and the PAH and chlordane results do not pose a public health risk. MWRA therefore has proposed to focus on long-term changes, with individual stations being sampled every several years. Annual monitoring would continue to include flounder liver histology at core sites. Sampling for contaminant levels would occur once every three years for all three species.

7. Stellwagen Bank National Marine Sanctuary

Background

The Gerry E. Studds Stellwagen Bank National Marine Sanctuary 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 create 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 programs include stations within and near the sanctuary. Five water-column stations, including four within the sanctuary and one just outside the northern border are considered "boundary" stations, that is, they mark the boundary between Massachusetts Bay and the 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.

In 2001 and 2002, the sanctuary managers, in conjunction with MWRA's contractor Battelle, developed 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 (Hunt *et al.* 2003).

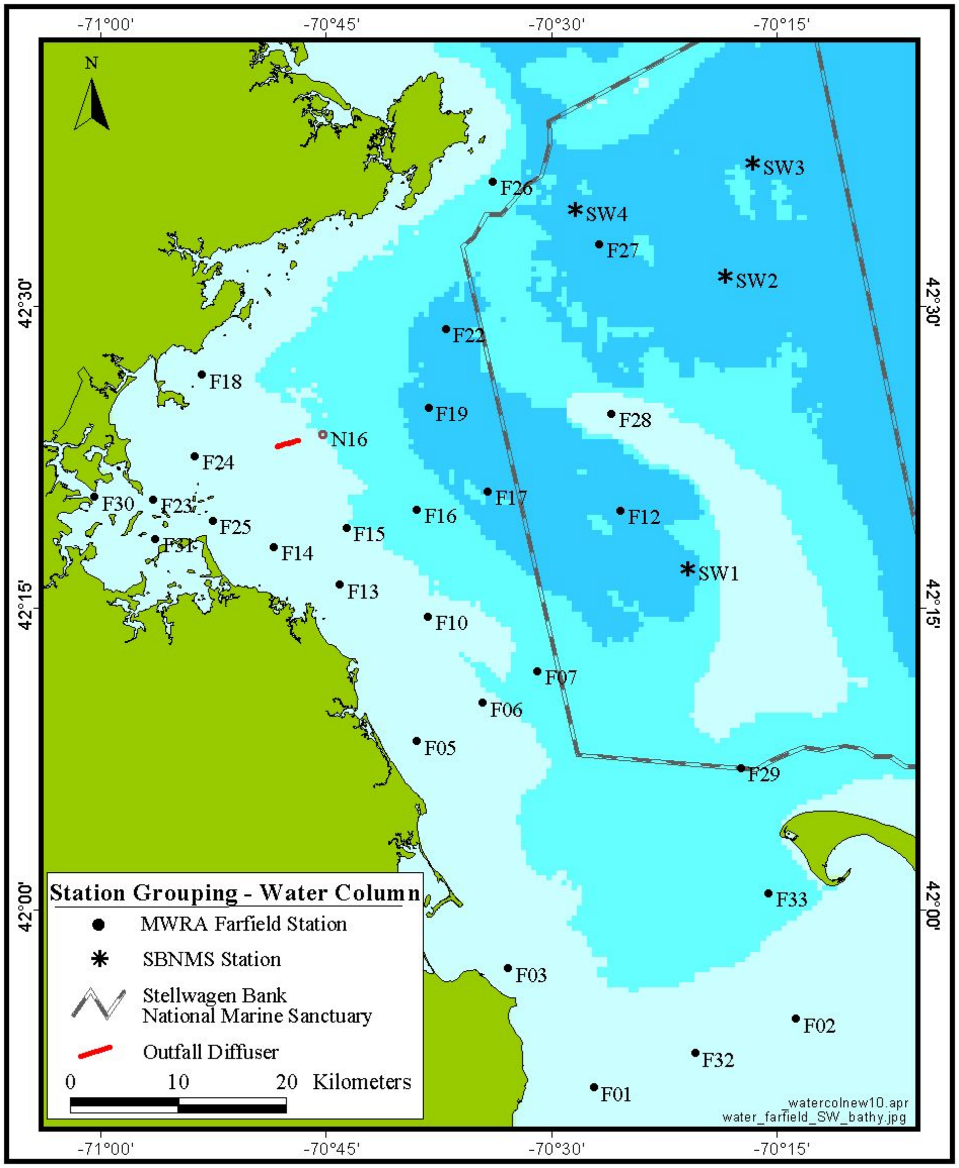

Figure 7-1. Water column stations, including the additional Stellwagen Bank National Marine Sanctuary (SBNMS) stations sampled in August and October 2001 and 2002

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 total organic carbon concentrations. 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 2002, with no indication of any effects of the MWRA outfall. Elevated concentrations of ammonia were measured at offshore and boundary stations in October. Currents at the time were not transporting water masses from the outfall to offshore, and phosphate concentrations did not follow the same pattern, so the elevated ammonia concentrations were not likely to be associated with the outfall.

Mean concentrations of dissolved oxygen in bottom waters of Stellwagen Basin were within the baseline ranges and somewhat higher than those found in the nearfield, typical of the pattern observed throughout baseline monitoring. The survey minimum concentration measured in Stellwagen Basin in 2002 was 7.01 mg/l, well above the 6.2 mg/l contingency plan background (Figure 7-2). The survey minimum percent saturation was 75.1%, above the 66.3% contingency plan background.

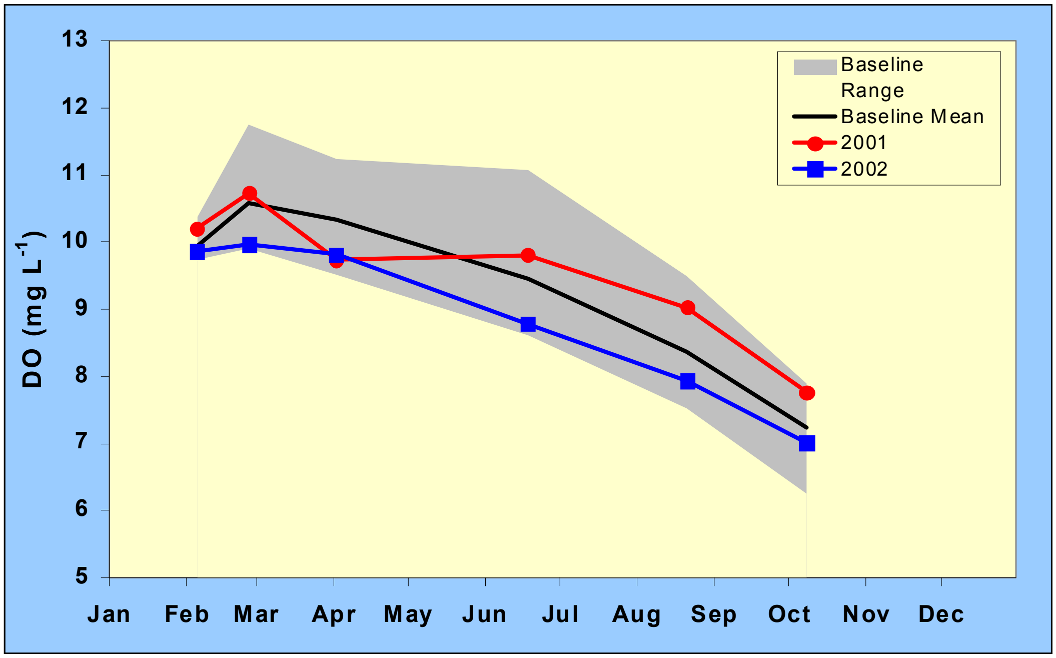

Figure 7-2. Survey mean dissolved oxygen concentrations in Stellwagen Basin, baseline mean and range and post discharge years, 2001 and 2002

As in previous years, levels of nutrients and chlorophyll within the sanctuary were at the upper end but not significantly different from levels at other monitoring stations, and no changes could be attributed to the outfall (Figure 7-3).

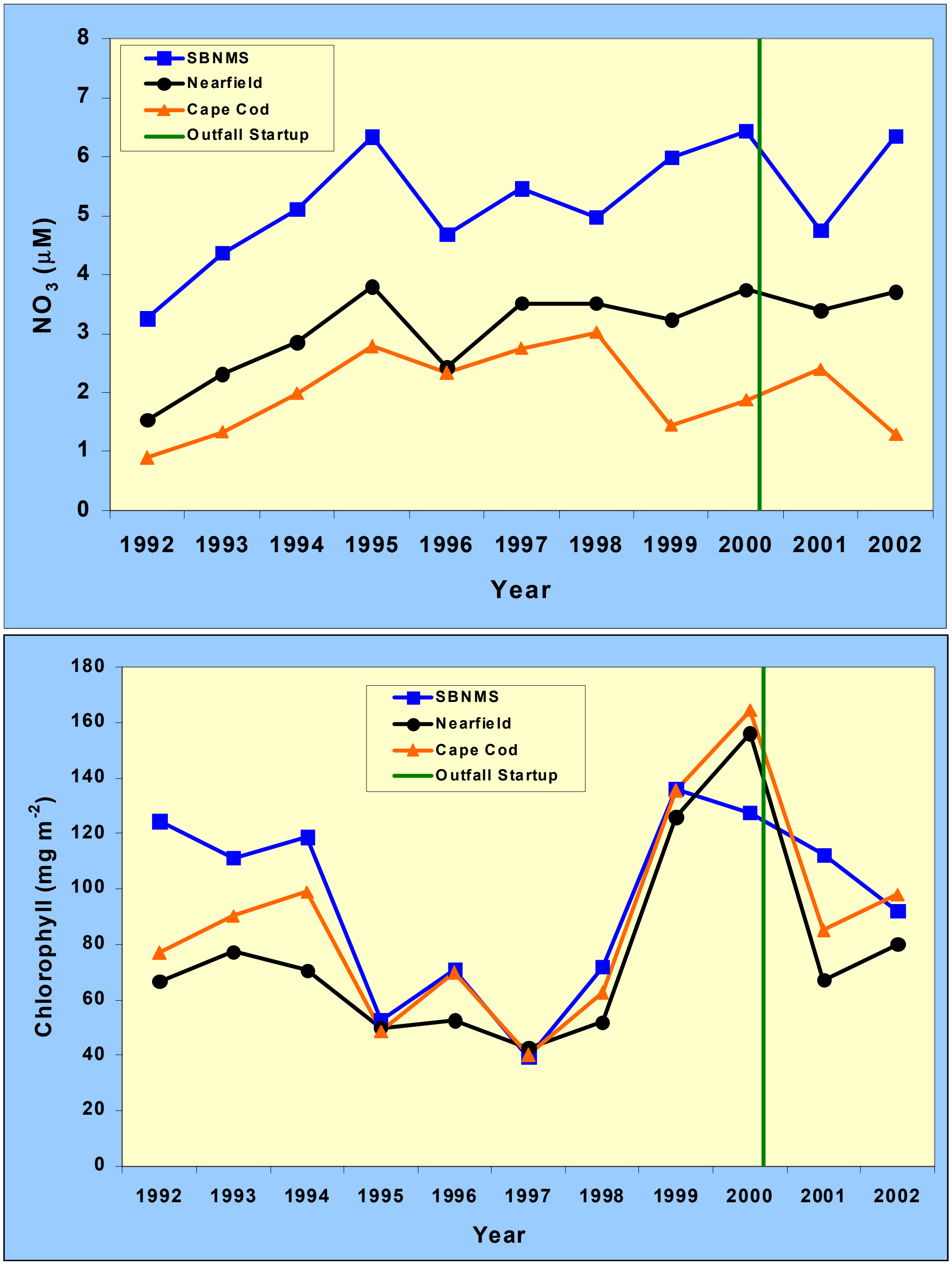

Figure 7-3. Survey mean nitrate and chlorophyll in and near the Stellwagen Bank National Marine Sanctuary (Stations F27, F28, F12) and other regions of Massachusetts and Cape Cod bays, 1992-2002

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 2002 (Maciolek *et al.*2003). Contaminant concentrations in the sediments remained consistently low. For example, PCB concentrations in sediments in 2002 were similar to or lower than those measured in 1995. Concentrations of *Clostridium perfringens* spores remained at or below levels measured in the early 1990s.

Benthic community parameters at individual stations showed no pattern of change following start-up of the outfall in 2000 (Figure 7-4). Overall, the number of species per sample increased during 1995-1998, paralleling results from throughout Massachusetts Bay. At Station FF14, number of individuals and species decreased, while at FF11, number of species increased. No consistent pattern could be related to outfall operation.

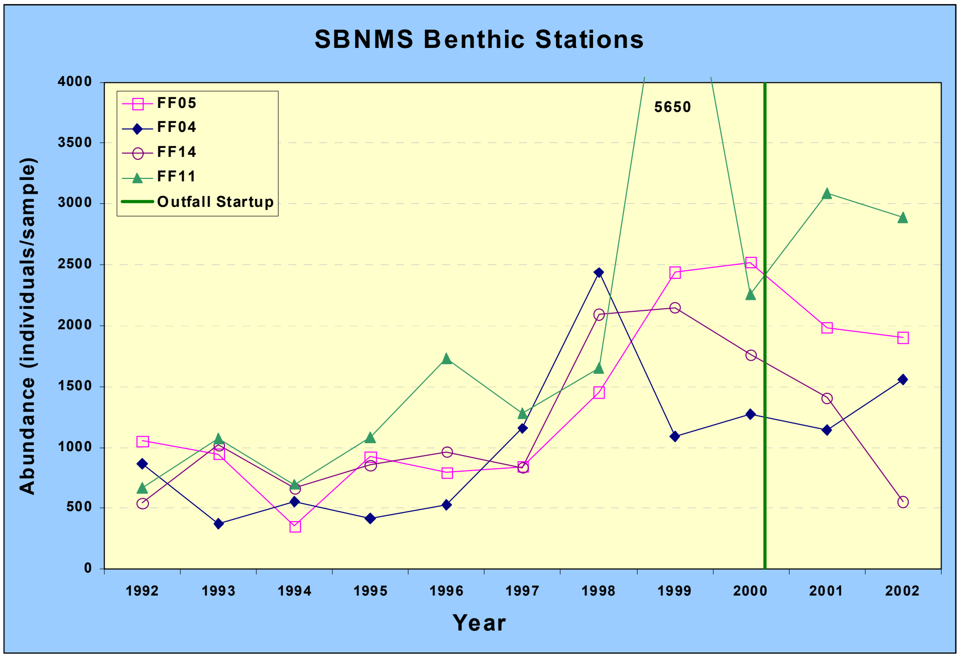

Figure 7-4. Abundance of individuals at stations within the boundary region, 1992-2002

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.

References

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

Brown MW, Nichols O, Marx MK, Ciano JN. 2002. Surveillance monitoring and management of North Atlantic right whales (*Eubalena glacialis*) in Cape Cod Bay, Massachusetts: 2002. Final report to Division of Marine Fisheries, Commonwealth of Massachusetts and Massachusetts Environmental Trust. September 2002. 28p.

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

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

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

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

Hunt CD, Steinhauer WS, Mansfield AD, Albro C, Roberts PJ, Geyer R, Mickelson M. 2002a. Evaluation of the Massachusetts Water Resources Authority outfall effluent plume initial dilution: Synthesis of results from the April 2001 survey. Boston: Massachusetts Water Resources Authority. Report ENQUAD 2002-06. 69p.

Hunt CD, Mansfield M, Albro C, Roberts PJ, Geyer R, Steinhauer W, Mickelson M. 2002b. Evaluation of the Massachusetts Water Resources Authority outfall effluent plume initial dilution: Synthesis of results from the July 2001 survey. Boston: Massachusetts Water Resources Authority. Report ENQUAD 2002-07. 77.

Hunt C, Abramson S, Lefkovitz L, Neff J, Durell G, Keay K, Hall M. 2002c. Evaluation of 2001 mussel tissue contaminant threshold exceedance. Boston: Massachusetts Water Resources Authority. Report ENQUAD 2002-05. 48.

Hunt C, Boyle JD, Inglin D. 2003. 2002 Stellwagen Bank water quality monitoring report. Prepared for the Stellwagen Bank National Marine Sanctuary. Battelle, Duxbury, MA. 40p.

Kropp RK, Turner JT, Borkman D, Emsbo-Mattingly S, Hunt CD, Keay KE. 2003. A review of zooplankton communities in the Massachusetts Bay/Cape Cod Bay system. Boston: Massachusetts Water Resources Authority. Report ENQUAD 2003-06. 39p.

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

Libby PS, Geyer WR, Keller AA, Turner JT, Borkman D, Oviatt CA. Hunt CD. 2003. 2002 annual water column monitoring report. Boston: Massachusetts Water Resources Authority. Report ENQUAD 2003-07. Draft.

Maciolek NJ, Diaz RJ, Dahlen D, Hecker B, Gallagher ED, Blake JA, Williams IP, Emsbo-Mattingly S, Hunt C, Keay KE. 2003. 2002 outfall benthic monitoring report. Boston: Massachusetts Water Resources Authority. Report ENQUAD 2003-13.. Draft.

McLeod LA, Short LM, Smith JK. 2003. Summary of marine mammal observations during 2002 surveys. Boston: Massachusetts Water Resources Authority. Report ENQUAD 2003-01. 21p.

MWRA. 1991. Massachusetts Water Resources Authority effluent outfall monitoring plan: Phase I baseline studies. Boston: Massachusetts Water Resources Authority. Report ENQUAD ms-02. 95p.

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

MWRA. 1997b. Massachusetts Water Resources Authority contingency plan. Boston: Massachusetts Water Resources Authority. Report ENQUAD ms-069. 41p.

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

MWRA 2003a. Briefing for OMSAP workshop on ambient monitoring program revisions, March 31-April 1, 2003. Boston: Massachusetts Water Resources Authority. Report ENQUAD ms-083. 96p.

MWRA 2003b. Briefing for OMSAP workshop on ambient monitoring program revisions, June 18-19, 2003. Boston: Massachusetts Water Resources Authority. Report ENQUAD ms-085. 250p.

MWRA 2003c. Briefing for OMSAP workshop on ambient monitoring program revisions, July 24, 2003. Boston: Massachusetts Water Resources Authority. Report ENQUAD ms-086. 64p.

NRC. 1990. Managing Troubled Waters: The Role of Marine Monitoring. National Research Council. National Academy Press, Washington, DC. 125p.

OMSAP. 2003. Mussel tissue contaminant focus group minutes, March 5, 2003.

Pala S, Lefkovitz L, Moore M, Shaub E. 2003. 2002 annual fish and shellfish report. Boston: Massachusetts Water Resources Authority. Report ENQUAD 2003-05. 176p.

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

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

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

Rex AC, Wu D, Coughlin K, Hall M, Keay KE, Taylor DI. 2002. The state of Boston Harbor: mapping the harbor's recovery. Boston:

Massachusetts Water Resources Authority. Report ENQUAD 2002-09. 42p.

Roberts PJW, Snyder WH, Baumgartner DJ. 1989. Ocean outfalls. *Journal of Hydraulic Engineering, ASCE* 115:1-70.

Roberts PJW, Snyder WH. 1993a. Hydraulic model study for the Boston outfall. I: Riser configuration. *Journal of Hydraulic Engineering, ASCE* 119:970-987.

Roberts PJW, Snyder WH. 1993a. Hydraulic model study for the Boston outfall. II: Environmental performance. *Journal of Hydraulic Engineering, ASCE* 119:988-1002.

Taylor DI. Water quality improvements in Boston Harbor during the first year after offshore transfer of Deer Island flows. Boston: Massachusetts Water Resources Authority. Report ENQUAD 2002-04. 61p.

Taylor DI. 2003. 24 months after "offshore transfer": an update of water quality improvements in Boston Harbor. Boston: Massachusetts Water Resources Authority. Report ENQUAD 2003-04. 94p.

Tucker J, Kelsey S, Giblin A, Hopkinson C. 2002. Benthic metabolism and nutrient cycling in Boston Harbor and Massachusetts Bay: summary of baseline data and observations after one year of harbor-to-bay diversion of sewage effluent. Boston: Massachusetts Water Resources Authority. Report ENQUAD2002-13. 83p.

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

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

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

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

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

Werme C, Hunt CD. 2001. 2000 Outfall monitoring overview. Boston: Massachusetts Water Resources Authority. Report ENQUAD 2001-10. 92p.

Werme C, Hunt CD. 2002. 2001 Outfall monitoring overview. Boston: Massachusetts Water Resources Authority. Report ENQUAD 2002-18. 84p.

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
DIF	Deer Island Flats
DIL	Deer Island Light
DIN	Dissolved inorganic nitrogen
DIP	Dissolved inorganic phosphorus
DO	Dissolved oxygen
ECCB	Eastern Cape Cod Bay
EPA	U.S. Environmental Protection Agency
FDA	U.S. Food and Drug Administration
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
MGD	Million gallons per day
MWRA	Massachusetts Water Resources Authority
NB	Nantasket Beach
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
PAH	Polycyclic aromatic hydrocarbon
PC	Particulate carbon
PCB	Polychlorinated biphenyl
PIAC	Public Interest Advisory Committee
RPD	Redox potential discontinuity
PSP	Paralytic shellfish poisoning
SBNMS	Stellwagen Bank National Marine Sanctuary
SEIS	Supplemental Environmental Impact Statement
TN	Total nitrogen
USGS	U.S. Geological Survey
TOC	Total organic carbon
TSS	Total suspended solids

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