November 9, 2010

Ms. Ann Lowery
Acting Assistant Commissioner
Bureau of Resource Protection
Department of Environmental Protection
1 Winter Street
Boston, MA 02108

Mr. Stephen Perkins, Director
Office of Ecosystem Protection
U.S. Environmental Protection Agency
Water Technical Unit “SEW”
5 Post Office Square, Suite 100
Boston, MA 02109-3912

Re: Massachusetts Water Resources Authority, Permit Number MA0103284
Report Pursuant to Part I.8. Contingency Plan: Outfall Monitoring Overview
and Part I.20.f Notification to the Stellwagen Bank National Marine Sanctuary

Dear Ms. Lowery and Mr. Perkins:

I am pleased to enclose the report, *2009 Outfall Monitoring Overview Results,* in compliance with Part I.8.a of MWRA’s NPDES Permit which requires, “The results of any monitoring, required by the contingency plan shall be reported to EPA, MADEP and the public on a yearly basis by November 15…”

MWRA’s ocean outfall began operation September 6, 2000. Therefore, 2009 was the ninth complete year of ambient monitoring of the discharge. The enclosed report focuses on 2009 results in the context of the baseline monitoring, and discusses Contingency Plan results for effluent, water column, sediment, flounder health, and fish and shellfish chemistry. Section 6, Special Studies, describes an upgrade to the Bays Eutrophication Model, changes in water quality in Boston Harbor, predicting the severity of red tides, benthic nutrient flux in Boston Harbor and Massachusetts Bay, and marine mammal observations.

Section 7 of the *2009 Outfall Monitoring Overview* reports on monitoring results relative to the Stellwagen Marine Sanctuary (“SBNMS”). This section, together with any additional data requested by SBNMS for the year 2009, comprises the report required by the permit in Part I.20.f:

> “On or before January 1st of each year, for the life of this permit, MWRA shall submit a report to the SBNMS that: (1) includes all monitoring and related data from the Ambient Monitoring Plan that relates to the SBNMS, and (2) documents the effects of the Deer Island discharge on Sanctuary resources and qualities regarding the previous year.”

Overall, the ninth complete year of monitoring continued to show no adverse impacts from the outfall, and no impacts on SBNMS were detected. The results are consistent with previous years. Region-wide events such as red tides and *Phaeocystis* blooms as well as regional variations in water chemistry over time have been observed; these are attributable to large-scale oceanographic and climatic factors and not to the discharge.

The report is available online as report number 2010-19 from MWRA's Technical Reports List at http://www.mwra.state.ma.us/harbor/enquad/trlist.html

Please let me know if any of MWRA's staff can give you additional assistance regarding this submittal.

Sincerely,

Michael J. Hornbrook
Chief Operating Officer

Attachment:
Werme C et al. 2010. *2009 Outfall Monitoring Overview* Boston: Massachusetts Water Resources Authority. Report 2010-19. 69p.

Cc:
Hyannis Library
Ann-Louise Harries

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Rebecca Kenney

National Marine Fisheries Service
Chris Mantzaris

Stellwagen Bank National Marine Sanctuary
Craig MacDonald

Environmental Protection Agency, Region I
Matthew Liebman

Massachusetts Department of Environmental Protection
Cathy Vakalopoulos

Cc: Cover letter only, please contact MWRA at (617) 788-4940 if you would like a hard copy.

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2009
Outfall Monitoring Overview

Environmental Quality Department
Report 2010-19

Massachusetts Water Resources Authority

Citation:
Werme C, Rex AC, Hall MP, Keay KE, Leo WS, Mickelson MJ, Hunt CD. 2010. **2009 outfall monitoring overview**. Boston: Massachusetts Water Resources Authority. Report 2010-19. 69p.

2009
Outfall Monitoring Overview

prepared by

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November 5, 2010

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Norbert Jaworski, retired (Environmental Protection Agency)
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Massachusetts Coastal Zone Management: Todd Callaghan, Jan Smith
US Army Corps of Engineers: Thomas Fredette
Stellwagen Bank National Marine Sanctuary: Ben Haskell
US Environmental Protection Agency: Matthew Liebman
Massachusetts Division of Marine Fisheries: Jack Schwartz
Massachusetts Department of Environmental Protection: Catherine Vakalopoulos

Public Interest Advisory Committee (PIAC)

Save the Harbor/Save the Bay: Patty Foley (chair), Bruce Berman
MWRA Wastewater Advisory Committee: Edward Bretschneider
Conservation Law Foundation: Priscilla Brooks
Massachusetts Audubon Society: Robert Buchsbaum
MWRA Advisory Board: Joseph Favaloro
Association to Preserve Cape Cod: Maggie Geist, Tara Nye
Safer Waters in Massachusetts: Sal Genovese
The Boston Harbor Association: Vivian Li

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Summary

Each year, the Massachusetts Water Resources Authority (MWRA) prepares this report, an overview of environmental monitoring related to the Massachusetts Bay municipal effluent outfall. It presents information relevant to the MWRA Contingency Plan, including threshold exceedances, responses, and corrective actions. The overview also includes sections on special studies and on the Stellwagen Bank National Marine Sanctuary. Special studies in 2009 included updating the Massachusetts Bay hydrodynamic model and ongoing studies of water quality in Boston Harbor, red tides, marine mammals, and nutrient fluxes at the sediment-water interface.

This year's outfall monitoring overview marks eight years of baseline monitoring and more than nine years since discharge was diverted from the shallower, more confined, waters of Boston Harbor to the deeper waters of Massachusetts Bay. Results continue to confirm the predictions that the outfall would have only limited and localized effects on the Massachusetts Bay ecosystem, while greatly benefiting Boston Harbor.

Throughout 2009, monitoring results were consistent with previous years, with no unanticipated effects associated with the outfall. There were no exceedances of Contingency Plan thresholds for effluent, sea floor, or fish and shellfish. There was one exceedance of a water-column threshold, when concentrations of the red tide phytoplankton species *Alexandrium fundyense* exceeded the caution level (Table 1). The 2009 *Alexandrium* bloom followed the historically typical pattern for red tides in the region, beginning off the coast of Maine and moving southward along the coast with winds from the northeast. The pattern suggests no effect of the outfall on the timing or magnitude of the bloom. Occurrence of *Alexandrium* blooms since 2005 suggests that the region has entered a period of regular blooms, similar to conditions during the 1970s. As in other years, no effects of the outfall on the Stellwagen Bank National Marine Sanctuary were detected. No effects on the water column or sea floor in or near the sanctuary had been anticipated, and none have been measured.

Table 1. Contingency Plan thresholds and exceedances as of 2009. (NA = not applicable, ✔ = no exceedance, **C** = caution level exceedance, **W** = warning level exceedance)

Effluent											
Location/ Parameter Type	Parameter	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
	pH	**W**	✔	✔	✔	✔	✔	✔	✔	✔	✔
	Fecal coliform bacteria, monthly	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
	Fecal coliform bacteria, weekly	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
	Fecal coliform bacteria, daily	✔	**W**	✔	✔	**W**	✔	✔	✔	✔	✔
	Fecal coliform bacteria, 3 consecutive days	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
	Chlorine residual, daily	**W**	✔	✔	✔	✔	✔	✔	✔	✔	✔
	Chlorine residual, monthly	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
	Total suspended solids, weekly	✔	✔	**W**	✔	✔	✔	✔	✔	✔	✔
	Total suspended solids, Monthly	✔	✔	**W**	✔	✔	✔	✔	✔	✔	✔
	cBOD, weekly	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
	cBOD, monthly	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
	Acute toxicity, mysid shrimp	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
	Acute toxicity, fish	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
	Chronic toxicity, fish	✔	**W**	✔	✔	✔	✔	**W**	✔	✔	✔
	Chronic toxicity, sea urchin	✔	**W**	✔	✔	✔	**W**	✔	✔	✔	✔
	PCBs	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
	Plant performance	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
	Flow	NA	✔	✔	✔	✔	✔	✔	✔	✔	✔
	Total nitrogen load	NA	✔	✔	✔	✔	✔	✔	✔	✔	✔
	Floatables	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Oil and grease	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔

Table 1, continued. Contingency Plan thresholds and exceedances as of 2009. (NA = not applicable, ✔ = no exceedance, **C** = caution level exceedance, **W** = warning level exceedance)

Location/ Parameter Type	Parameter	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Water Column											
Nearfield bottom water	Dissolved oxygen concentration	C	✔	✔	✔	✔	✔	✔	✔	✔	✔
	Dissolved oxygen saturation	C	✔	✔	✔	✔	✔	✔	✔	✔	✔
Stellwagen Basin bottom water	Dissolved oxygen concentration	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
	Dissolved oxygen saturation	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
Nearfield bottom water	Dissolved oxygen depletion rate (June–October)	NA	✔	✔	✔	✔	✔	✔	✔	✔	✔
Nearfield chlorophyll	Annual	NA	✔	✔	✔	✔	✔	✔	✔	✔	✔
	Winter/spring	NA	✔	✔	✔	✔	✔	✔	✔	✔	✔
	Summer	NA	✔	✔	✔	✔	✔	C	✔	✔	✔
	Autumn	C	✔	✔	✔	✔	✔	✔	✔	✔	✔
Nearfield nuisance algae *Phaeocystis pouchetii*	Winter/spring	NA	✔	✔	✔	C	✔	✔	C	✔	✔
	Summer	NA	✔	C	C	C	C	C	✔	✔	✔
	Autumn	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
Nearfield nuisance algae *Pseudonitzschia*	Winter/spring	NA	✔	✔	✔	✔	✔	✔	✔	✔	✔
	Summer	NA	✔	✔	✔	✔	✔	✔	✔	✔	✔
	Autumn	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
Nearfield nuisance algae *Alexandrium*	Any sample	✔	✔	✔	✔	✔	C	C	✔	C	C
Farfield shellfish	PSP toxin extent	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
Plume	Initial dilution	NA	✔	Complete							

Table 1, continued. Contingency Plan thresholds and exceedances as of 2009. (NA = not applicable, ✔ = no exceedance, **C** = caution level exceedance, **W** = warning level exceedance)

Sea Floor											
Location/ Parameter Type	Parameter	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Nearfield sediment contaminants	Acenaphthene	NA	✔	✔	NA	NA	✔	NA	NA	✔	NA
	Acenaphylene	NA	✔	✔	NA	NA	✔	NA	NA	✔	NA
	Anthracene	NA	✔	✔	NA	NA	✔	NA	NA	✔	NA
	Benzo(a)anthracene	NA	✔	✔	NA	NA	✔	NA	NA	✔	NA
	Benzo(a)pyrene	NA	✔	✔	NA	NA	✔	NA	NA	✔	NA
	Cadmium	NA	✔	✔	NA	NA	✔	NA	NA	✔	NA
	Chromium	NA	✔	✔	NA	NA	✔	NA	NA	✔	NA
	Chrysene	NA	✔	✔	NA	NA	✔	NA	NA	✔	NA
	Copper	NA	✔	✔	NA	NA	✔	NA	NA	✔	NA
	Dibenzo(a,h)anthracene	NA	✔	✔	NA	NA	✔	NA	NA	✔	NA
	Fluoranthene	NA	✔	✔	NA	NA	✔	NA	NA	✔	NA
	Fluorene	NA	✔	✔	NA	NA	✔	NA	NA	✔	NA
	Lead	NA	✔	✔	NA	NA	✔	NA	NA	✔	NA
	Mercury	NA	✔	✔	NA	NA	✔	NA	NA	✔	NA
	Naphthalene	NA	✔	✔	NA	NA	✔	NA	NA	✔	NA
	Nickel	NA	✔	✔	NA	NA	✔	NA	NA	✔	NA
	p,p'-DDE	NA	✔	✔	NA	NA	✔	NA	NA	✔	NA
	Phenanthrene	NA	✔	✔	NA	NA	✔	NA	NA	✔	NA
	Pyrene	NA	✔	✔	NA	NA	✔	NA	NA	✔	NA
	Silver	NA	✔	✔	NA	NA	✔	NA	NA	✔	NA
	Total DDTs	NA	✔	✔	NA	NA	✔	NA	NA	✔	NA
	Total HMW PAH	NA	✔	✔	NA	NA	✔	NA	NA	✔	NA
	Total LMW PAH	NA	✔	✔	NA	NA	✔	NA	NA	✔	NA
	Total PAHs	NA	✔	✔	NA	NA	✔	NA	NA	✔	NA
	Total PCBs	NA	✔	✔	NA	NA	✔	NA	NA	✔	NA
	Zinc	NA	✔	✔	NA	NA	✔	NA	NA	✔	NA
Nearfield sediment	RPD depth	NA	✔	✔	✔	✔	✔	✔	✔	✔	✔
Nearfield benthic diversity	Species per sample	NA	✔	✔	✔	✔	✔	✔	✔	✔	✔
	Fisher's log-series alpha	NA	✔	✔	✔	✔	✔	✔	✔	✔	✔
	Shannon diversity	NA	✔	✔	✔	✔	✔	✔	✔	✔	✔
	Pielou's evenness	NA	✔	✔	✔	✔	✔	✔	✔	✔	✔
Nearfield species composition	Percent opportunists	NA	✔	✔	✔	✔	✔	✔	✔	✔	✔

Table 1, continued. Contingency Plan thresholds and exceedances as of 2009. (NA = not applicable, ✓ = no exceedance, **C** = caution level exceedance, **W** = warning level exceedance)

Fish and Shellfish											
Location/ Parameter Type	Parameter	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Nearfield flounder tissue	Total PCBs	NA	✓	✓	✓	NA	NA	✓	NA	NA	✓
	Mercury	NA	✓	✓	✓	✓	NA	✓	NA	NA	✓
	Chlordane	NA	✓	✓	✓	NA	NA	✓	NA	NA	✓
	Dieldrin	NA	✓	✓	✓	NA	NA	✓	NA	NA	✓
	Total DDTs	NA	✓	✓	✓	NA	NA	✓	NA	NA	✓
Nearfield flounder	Liver disease (CHV)	NA	✓	✓	✓	✓	✓	✓	✓	✓	✓
Nearfield lobster tissue	Total PCBs	NA	✓	✓	✓	NA	NA	✓	NA	NA	✓
	Mercury	NA	✓	✓	✓	NA	NA	✓	NA	NA	✓
	Chlordane	NA	✓	✓	✓	NA	NA	✓	NA	NA	✓
	Dieldrin	NA	✓	✓	✓	NA	NA	✓	NA	NA	✓
	Total DDTs	NA	✓	✓	✓	NA	NA	✓	NA	NA	✓
Nearfield mussel tissue	Total PCBs	NA	✓	✓	✓	NA	NA	✓	NA	NA	✓
	Lead	NA	✓	✓	✓	NA	NA	✓	NA	NA	✓
	Mercury	NA	✓	✓	✓	NA	NA	✓	NA	NA	✓
	Chlordane	NA	**C**	**C**	✓	NA	NA	✓	NA	NA	✓
	Dieldrin	NA	✓	✓	✓	NA	NA	✓	NA	NA	✓
	Total DDTs	NA	✓	✓	✓	NA	NA	✓	NA	NA	✓
	Total PAHs	NA	**C**	**C**	**C**	NA	NA	✓	NA	NA	✓

1. Introduction

For more than two decades, the Massachusetts Water Resources Authority (MWRA) has worked to minimize the effects of wastewater discharge on the marine environment. One important part of that mission has been a diversion of the municipal wastewater discharge from Boston Harbor to the deeper, less confined waters of Massachusetts Bay. A monitoring program assesses compliance with the National Pollutant Discharge Elimination System (NPDES) permit to discharge effluent from the Deer Island Treatment Plant (DITP) into Massachusetts Bay, assures that there are no unanticipated environmental effects of the discharge, and provides information for management of the outfall.

Results from most of the baseline-monitoring years and each post-diversion year have been documented in annual reports such as this one, the **Outfall Monitoring Overview**. Background information for these overviews and a complete description of the monitoring program can be found in Werme and Hunt (2008). That document, the monitoring plans (MWRA 1991, 1997a, 2004), the Contingency Plan (MWRA 1997b, 2001), area-specific technical reports, and past outfall monitoring overviews are available on the technical report list at MWRA's website, www.mwra.com/harbor/enquad/trlist.html.

Overviews for 1994 through 1999 included only baseline information. After the Massachusetts Bay outfall became operational in September 2000, reports have included post-diversion data relevant to the outfall permit, including Contingency Plan threshold exceedances, responses, and corrective actions. This year's overview presents monitoring results for effluent, water column, sea floor, and fish and shellfish. It also includes sections on special studies and the Stellwagen Bank National Marine Sanctuary.

Eight years of baseline monitoring and nine years of post-diversion monitoring have confirmed the predictions that the outfall would have only limited and localized effects on the Massachusetts Bay ecosystem, while the benefits to Boston Harbor have been dramatic.

2. Effluent

2009 Characterization

Throughout 2009, DITP continued to operate as designed, and contaminant loads remained low. It was a relatively wet year in the Boston area, although there was less rainfall than in 2008, and flows from the treatment plant were correspondingly lower. Almost all the flow received both primary and secondary treatment (Figure 2-1).

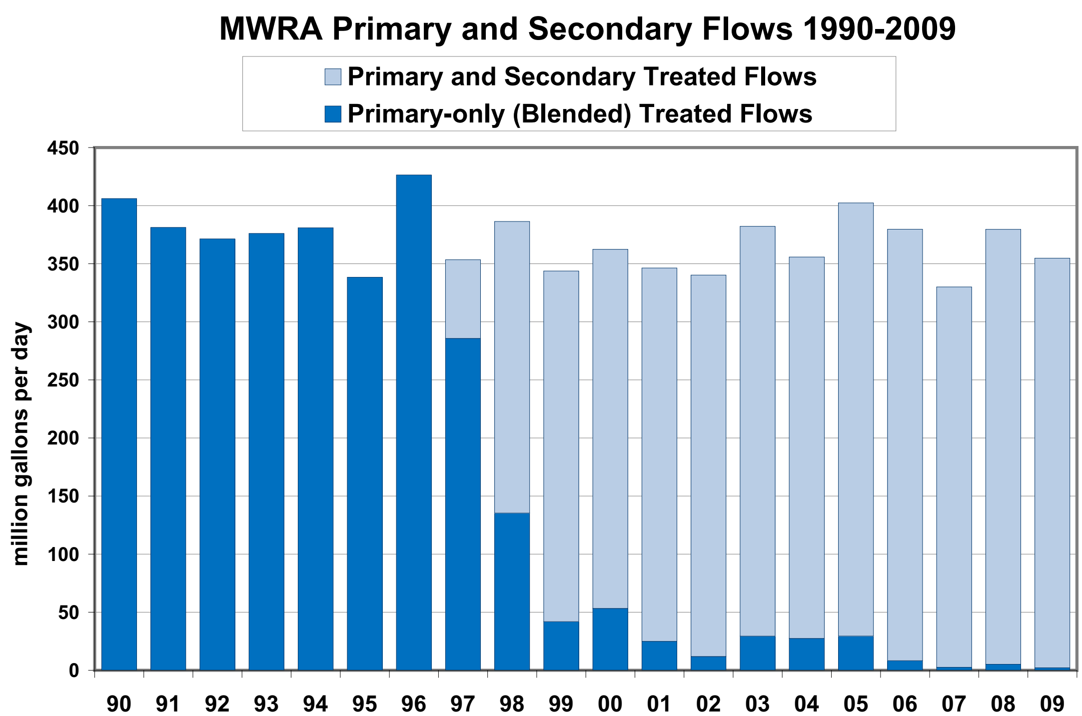


Figure 2-1. MWRA primary and secondary effluent flows. Almost all the flow from the treatment plant received primary and secondary treatment. (Primary-only flows are blended with secondary flows, and the blended flows meet permit limits.)

Contaminant loads in the effluent remained low. Solids discharges reached a record low (Figure 2-2). Biochemical oxygen demand (BOD), regulated as carbonaceous BOD, decreased slightly in 2009 in comparison to 2008 (Figure 2-3), remaining well below levels that might be expected to affect ambient waters at the discharge site.

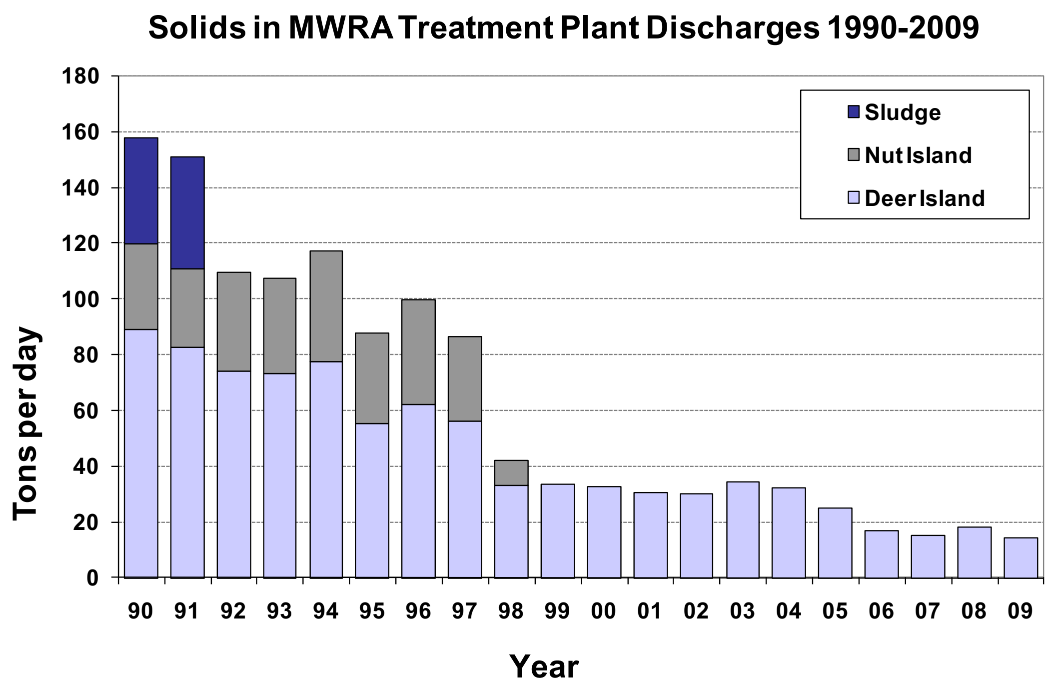


Figure 2-2. Solids in MWRA treatment plant discharges. Solids discharges reached a record low in 2009.

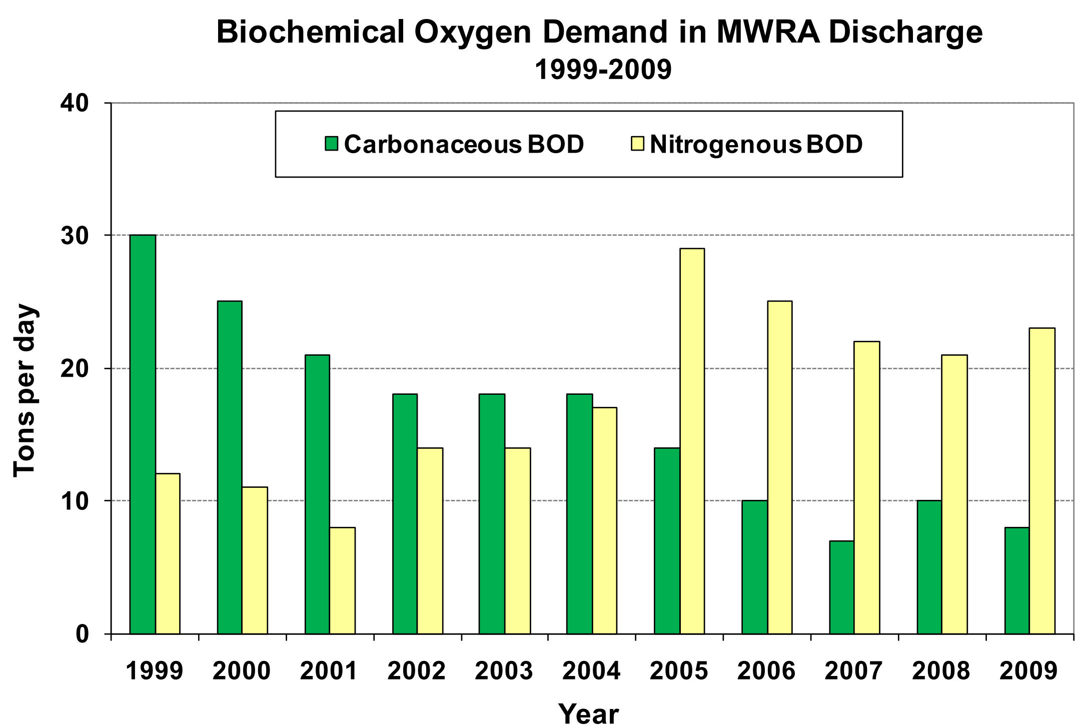


Figure 2-3. Biochemical oxygen demand in MWRA discharge. MWRA's permit limits carbonaceous BOD, which remained low in 2009. Nitrogenous BOD is the result of microbiological breakdown that occurs as a result of secondary treatment.

Nitrogenous BOD (also shown in Figure 2-3), which is a result of the biological processes in secondary treatment and not a permit limit or Contingency Plan parameter, remained higher than historic levels, as it has since the full implementation of secondary treatment. This increase has not proved deleterious to the dissolved oxygen levels in the environment (see Section 3, Water Column).

Total nitrogen loads were slightly higher in 2009 than in 2008, and the proportion of the load made up of ammonium increased, as it has each year since 2005 (Figure 2-4). About 10% of the ammonium in the sewage influent is removed by secondary treatment, but the biological treatment process converts some nitrate, nitrite, and other forms of nitrogen to ammonium. MWRA continually evaluates nitrogen-removal technologies, so that nitrogen removal could be implemented at DITP if the need arose (Bigornia-Vitale 2010). However, nitrogen loads have remained below the Contingency Plan threshold, and nitrogen removal has not been implemented.

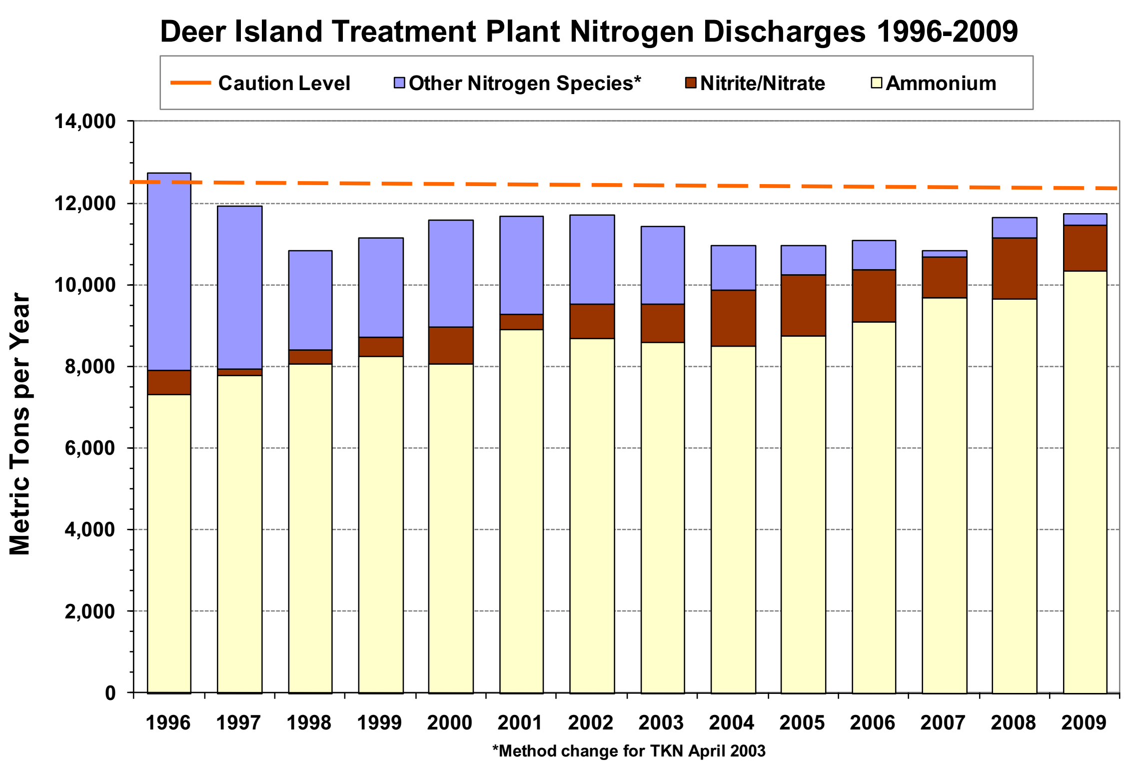


Figure 2-4. Deer Island Treatment Plant nitrogen discharges. Discharges of ammonium remained relatively high, a result of the secondary treatment process. (TKN = total Kjeldahl nitrogen, a measure of total nitrogen in the effluent)

Among the metals, only copper and zinc remain in notable, though reduced, quantities, with other metals present in only trace amounts (Figure 2-5). In fact, except for copper, the metals meet receiving water quality criteria in the effluent. Mercury levels were especially low in 2009 (Figure 2-6). Extremely sensitive methods are used in mercury analysis but mercury is now only rarely detected in effluent samples, the consequence of efforts on the part of MWRA and the New England states to reduce mercury use, handle workplace spills, and discourage disposal practices that introduce mercury into the sewer system.

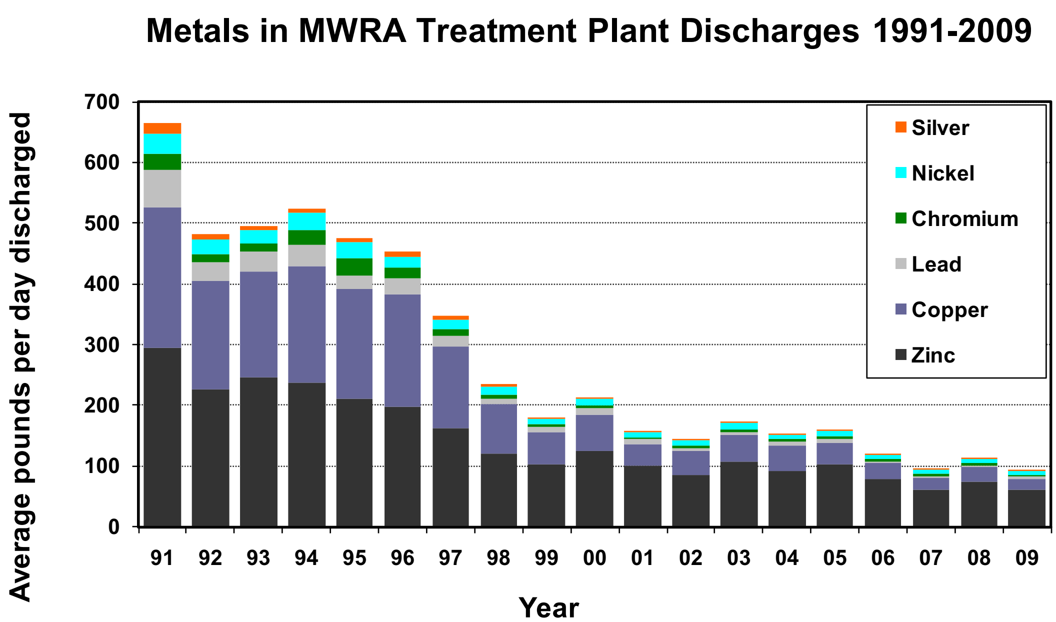


Figure 2-5. Metals in MWRA treatment plant discharges. Total metals discharges remained low in 2009.

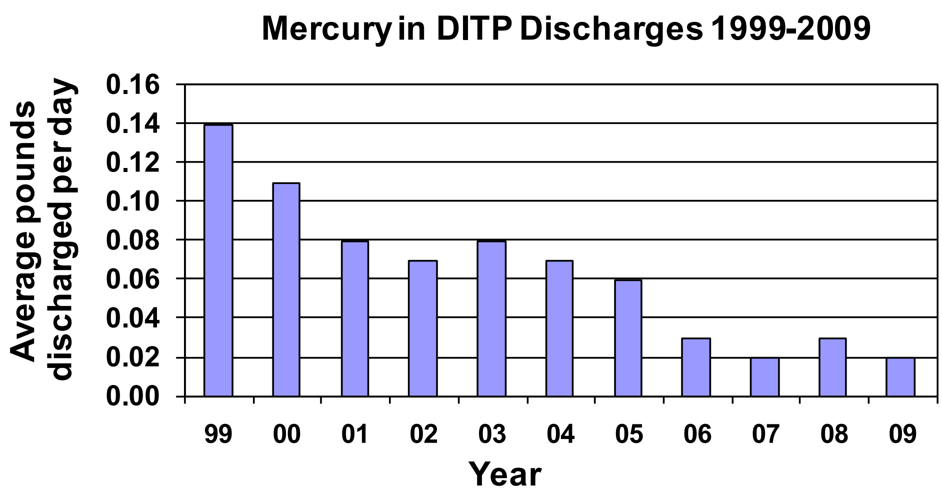


Figure 2-6. Mercury in Deer Island Treatment Plant discharges.

Loads of organic contaminants also continued to be low in 2009. Metals and organic contaminant data from August 2005 through December 2009 (Delaney 2010) show that the contaminant levels in DITP effluent are substantially lower than had been predicted in the U.S. Environmental Protection Agency (EPA) Supplemental Environmental Impact Statement (SEIS, EPA 1988), which was prepared during planning and permitting of the Massachusetts Bay outfall (Table 2-1). For example, annual loadings of polychlorinated biphenyls (PCBs) were only 0.53 kg/year, compared to the SEIS estimate of 50 kg/year. In 2009, PCBs were never detected in DITP effluent as Aroclor mixtures, the only PCB measures limited in the NPDES permit.

Table 2-1. Projected and actual mean annual contaminant loads.

Parameter	Projected Load kg/year	Actual Load kg/year
Cadmium	697	29
Chromium	3,517	481
Copper	11,945	3,253
Lead	4,961	674
Mercury	216	5.1
Nickel	8,926	1,150
Silver	299	67
Total PCB	50	0.52
4-4' DDT	28	0.31

Contingency Plan Thresholds

As in 2007 and 2008, DITP had no permit violations and no exceedances of the Contingency Plan thresholds in 2009 (Table 2-2). Of thousands of measurements, there have been only eleven effluent Contingency Plan exceedances since the permit went into effect and no exceedances of overall plant performance, total nitrogen load, or oil and grease. Floatables, for which there are no caution or warning levels, are present at extremely low levels, measured in parts per billion.

Table 2-2. Contingency Plan threshold values and 2009 results for effluent monitoring. (cBOD=carbonaceous biological oxygen demand, NOEC=no observable effect concentration, LC50=50% mortality concentration, MGD=million gallons per day; NA=not applicable)

Parameter	Caution Level	Warning Level	2009 Results
pH	None	<6 or >9	Not exceeded
Fecal coliform bacteria	None	14,000 fecal coliforms/100 ml (monthly 90th percentile, weekly geometric mean, maximum daily geometric mean, and minimum of 3 consecutive samples)	Not exceeded
Chlorine, residual	None	631 µg/L daily, 456 µg/L monthly	Not exceeded
Total suspended solids	None	45 mg/L weekly 30 mg/L monthly	Not exceeded
cBOD	None	40 mg/L weekly, 25 mg/L monthly	Not exceeded
Toxicity	None	Acute: effluent LC50<50% for shrimp and fish Chronic: effluent NOEC for fish survival and growth and sea urchin fertilization <1.5% effluent	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 MGD for annual average of dry days	Not exceeded
Total nitrogen load	12,500 mtons/year	14,000 mtons/year	Not exceeded
Floatables	NA		
Oil and grease	None	15 mg/L weekly	Not exceeded

3. Water Column

The monitoring program measures water quality and studies phytoplankton and zooplankton at stations in Boston Harbor, Massachusetts Bay, and Cape Cod Bay (Figures 3-1, 3-2).

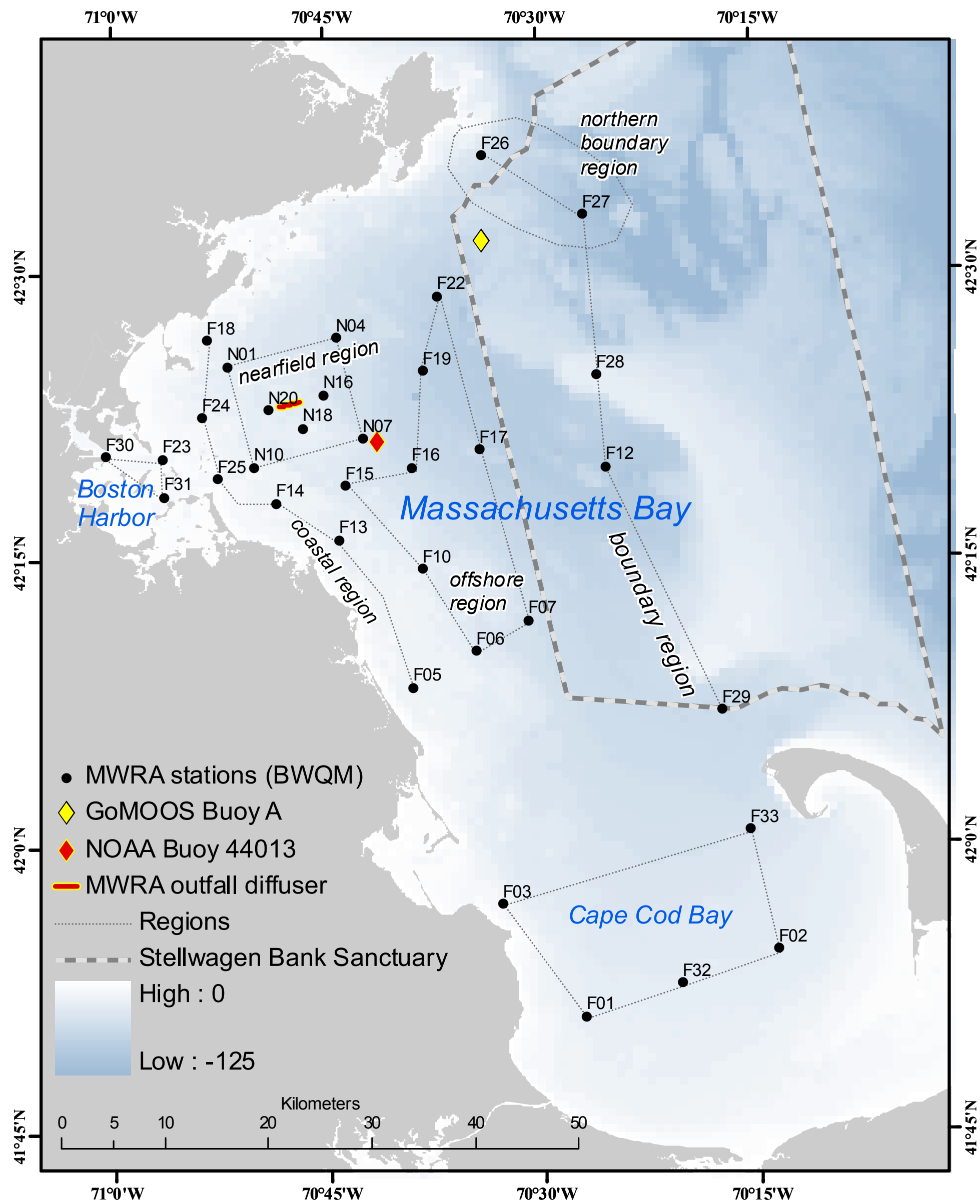


Figure 3-1. MWRA Bay Water Quality Monitoring (BWQM) stations and regional groupings. "Farfield" stations include all stations in Boston Harbor; the coastal, offshore, and northern boundary regions; and Cape Cod Bay. Also shown are the MWRA outfall; two instrumented buoys, one operated by the Gulf of Maine Ocean Observing System (GoMOOS) and the other by the National Oceanic and Atmospheric Administration (NOAA) National Data Buoy Center (NDBC); and the Stellwagen Bank National Marine Sanctuary.

The Massachusetts Bay stations located within seven kilometers of the outfall diffusers are called nearfield stations. Those beyond are grouped into regions, which together are called farfield stations. Twelve surveys of seven nearfield stations and six surveys of 27 farfield stations were completed in 2009. Sampling was augmented by instrumented buoys and remote sensing. A separate Boston Harbor program contributed additional data.

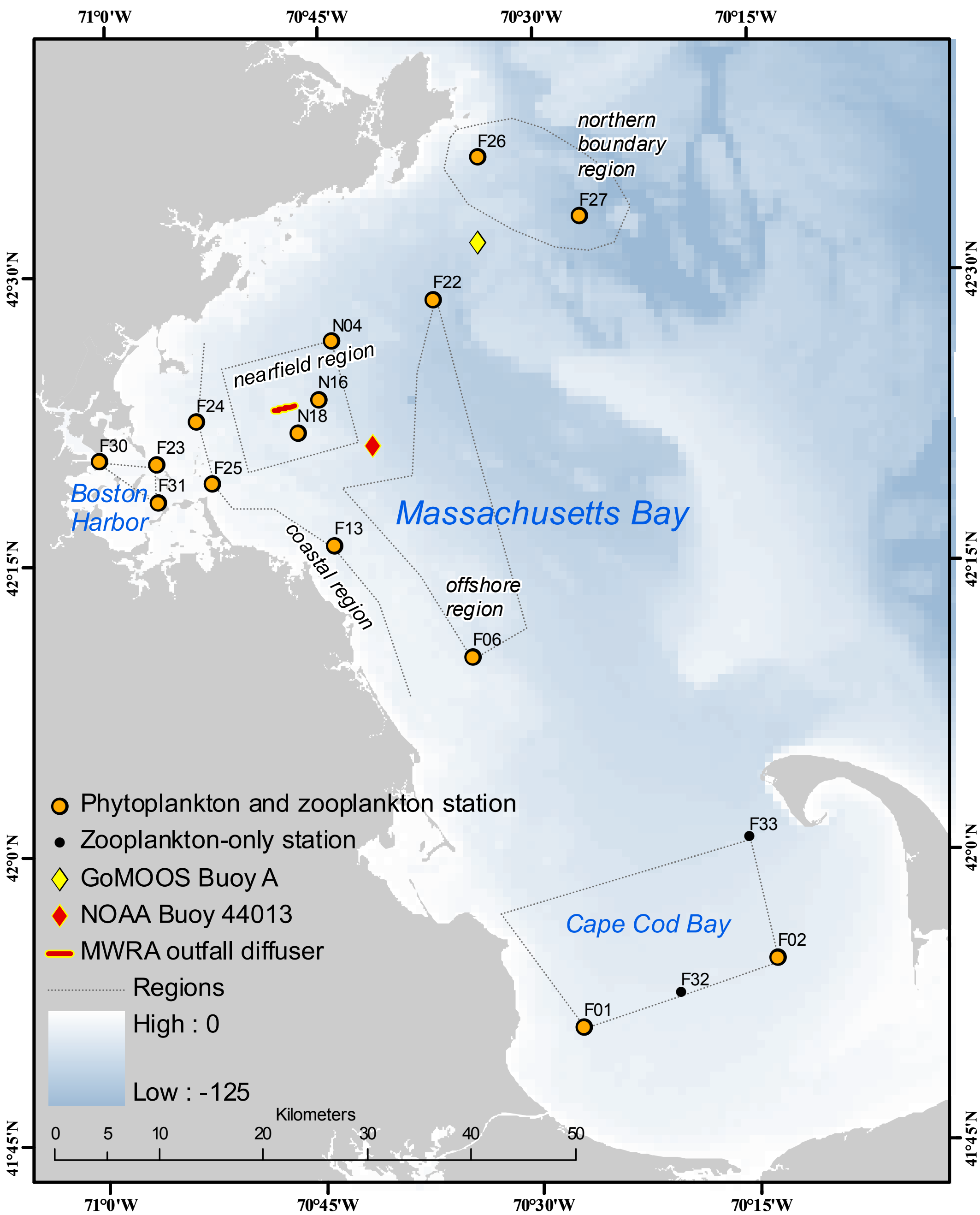


Figure 3-2. MWRA plankton stations. The stations are a subset of those included in water quality monitoring. Regional groupings, the instrumented buoys, and the MWRA outfall are also shown.

Physical Conditions

Baseline and post-diversion monitoring have found that the water column in the vicinity of the outfall and throughout Massachusetts and Cape Cod bays is heavily influenced by river inflows, weather, and other physical factors. Information about physical conditions has proven to be key to interpreting the annual monitoring data.

Although the annual precipitation in the Boston area was lower in 2009 than in 2008, relatively wet conditions continued, particularly during the summer and fall (Libby et al. 2010). The wet summer resulted in record summer maximum flows from the Merrimack and Charles rivers (Figures 3-3 and 3-4). (Flow from the Merrimack River tends to reflect regional conditions and affects the salinity of bottom waters. Flow from the Charles River reflects local conditions and may influence surface salinity.)

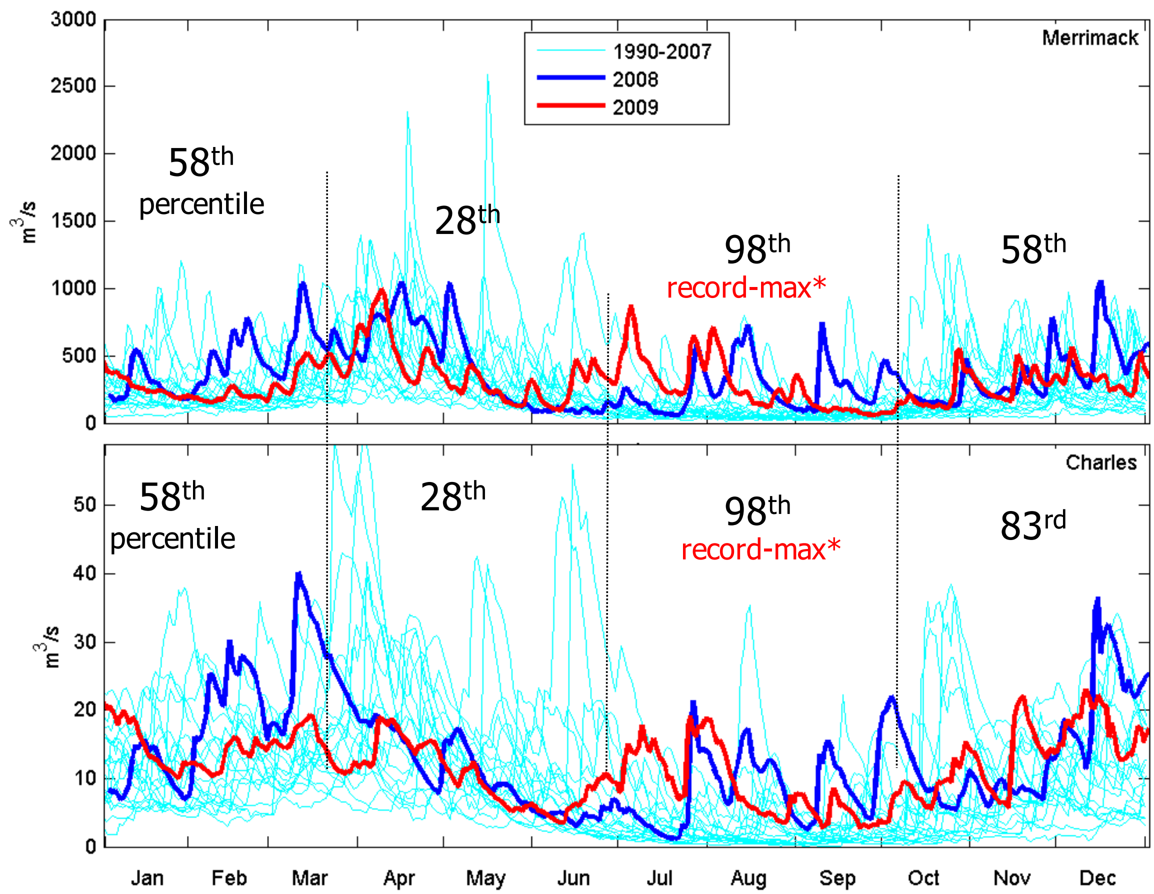


Figure 3-3. Flows of the Merrimack (top) and Charles (bottom) rivers reached record levels during the summer of 2009. Flows from the Charles River were also high during the stormy fall. The average July–September flows in both rivers were the greatest measured by the monitoring program, translating to the 98th percentile, record highs. Flows during 2008, shown for contrast, reached record highs during January–March.

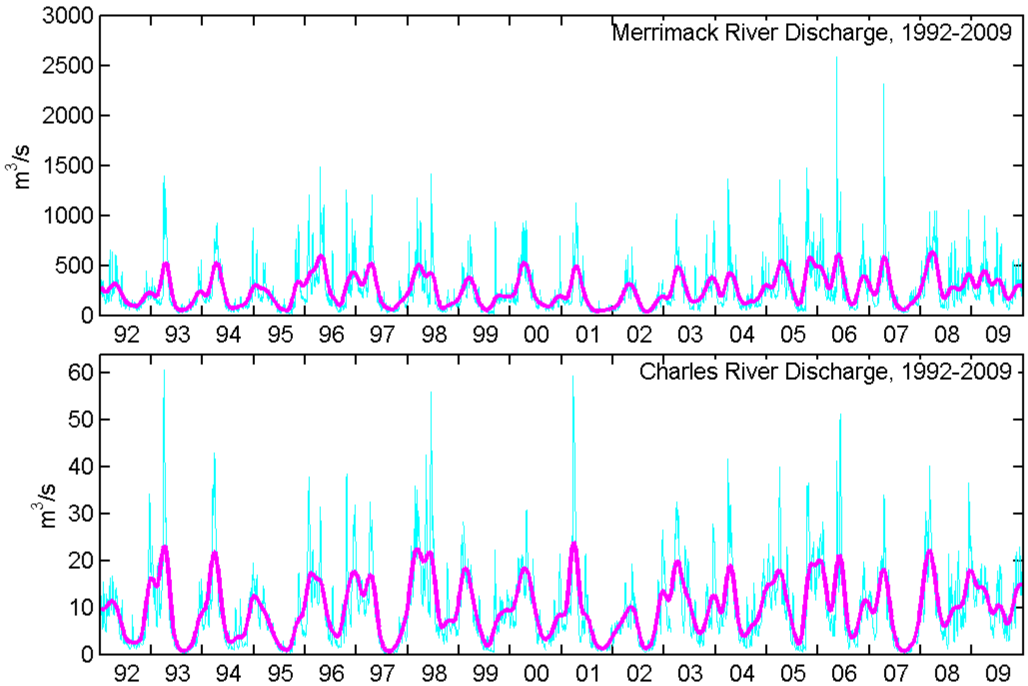


Figure 3-4. Merrimack River (top) and Charles River (bottom) discharges to the ocean. Note the lack of a spring freshet (a rise in water flow due to snow melt) during 2009. (Data are from gauges at Lowell and Waltham, Massachusetts; smooth lines are 3-month moving averages; note the differences in scale for the rivers.)

The wind-forcing conditions in 2009 also reflected the rainy summer, with downwelling conditions, which are marked by winds pushing water toward the coast, dominating in June (Figure 3-5). In most years, spring is a transitional period between winter downwelling and spring upwelling conditions. In 2009, upwelling occurred during May and July, but, but over the course of the year, downwelling conditions predominated, as they have in recent years. Wave heights were also greatest in June, with late June average wave heights reaching levels that might be expected to resuspend sediments in Boston Harbor. An early May storm from the northeast was not large but may have been sufficient to bring the *Alexandrium fundyense* red tide phytoplankton species into the bay (Figure 3-6).

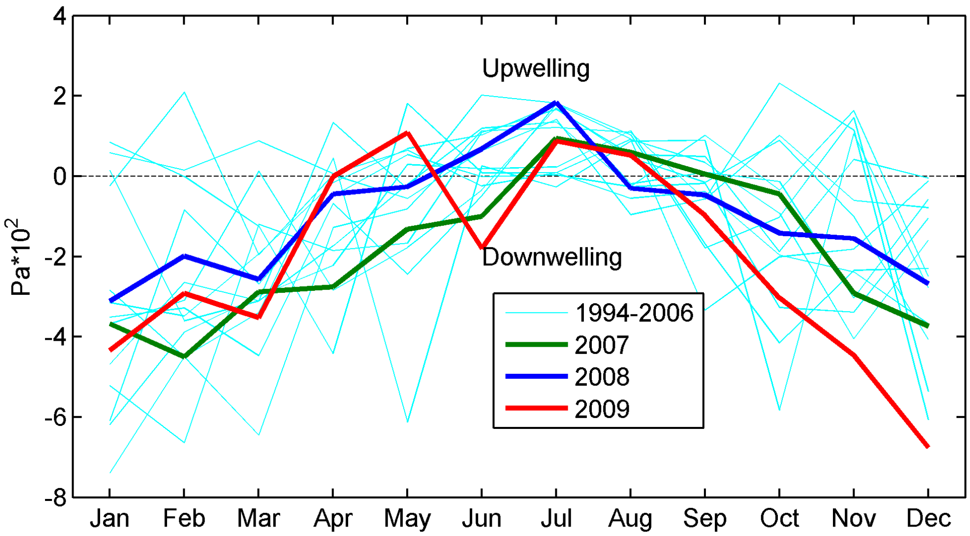


Figure 3-5. Monthly average wind stress at the Boston Buoy. Positive values indicate winds from the south or southwest, which result in upwelling-favorable wind stress; negative values indicate winds from the north or northeast, which favor downwelling. Downwelling conditions in June 2009 were consistent with poor weather conditions. Data from 2007 and 2008 are shown for comparison.

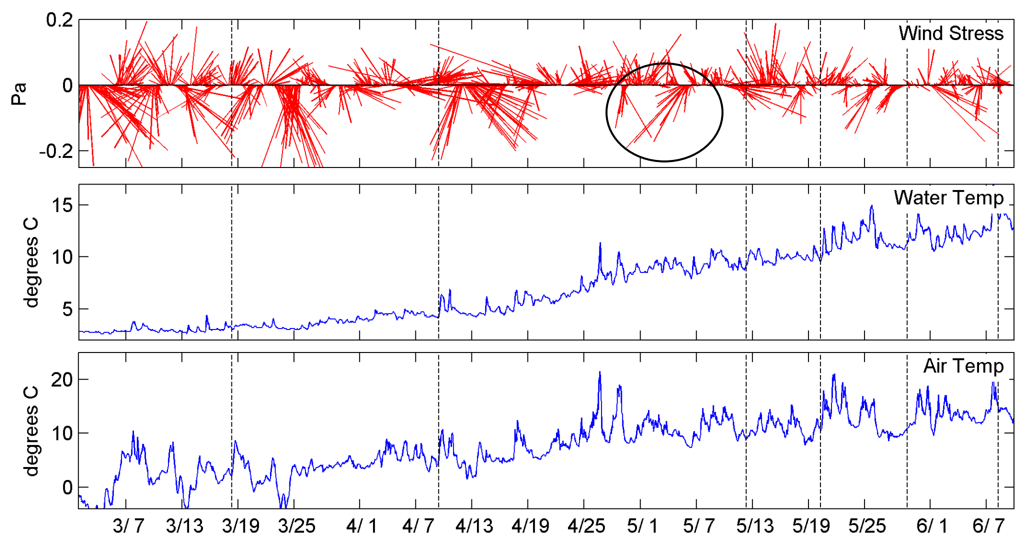


Figure 3-6. Wind stress, water temperature, and air temperature at GoMOOS Buoy A in March–June 2009. The wind stress figure shows a weak storm with winds from the northeast in early May (circled), which may have been sufficient to bring *Alexandrium fundyense* into Massachusetts Bay. The vertical dashed lines indicate the timing of water column surveys.

Surface water temperatures were warmer than average, particularly during the summer, in response to the downwelling conditions, which prevented cooler waters from being brought to the surface (Figure 3-7). Similar to 2008, bottom waters were cooler than average during the spring but were relatively warm during the fall.

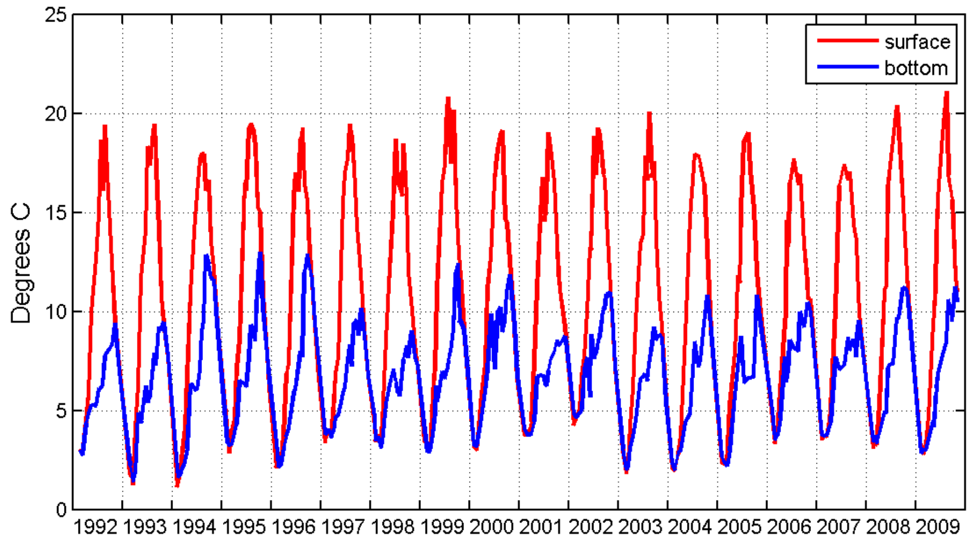


Figure 3-7. Nearfield surface and bottom water temperature. Surface measurements are the upper line. Summer surface temperatures were warm, a result of the downwelling conditions.

Salinity was affected by the continued wet conditions compared to other summers (Figure 3-8). Surface salinity was particularly low during the rainy summer but did not reach the extreme late summer to fall lows of 2005–2008.

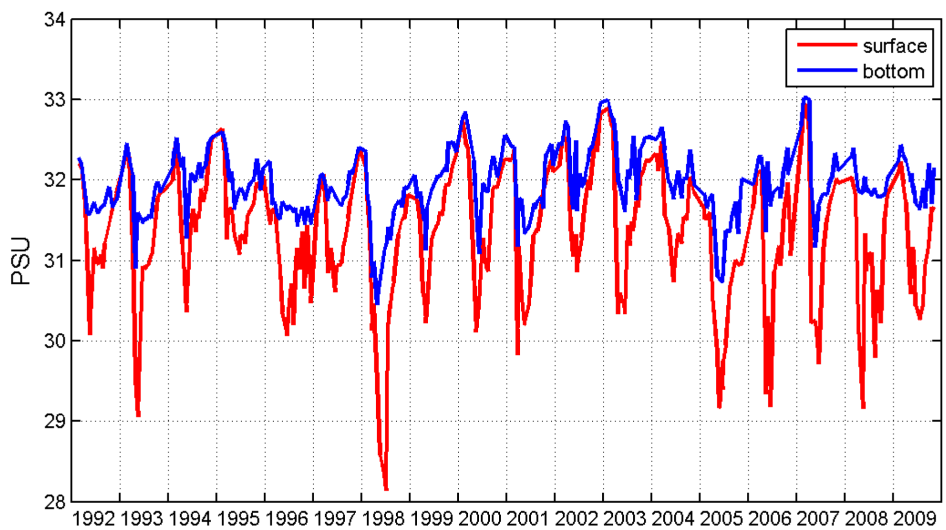


Figure 3-8. Nearfield surface and bottom water salinity. Surface measurements are the lower line. Surface salinity has been low in 2005–2009, reflecting a period of wet years.

Water Quality

Water quality measurements for 2009, including measurements of nutrients, dissolved oxygen, and phytoplankton biomass (measured as chlorophyll), followed typical annual cycles and continued to confirm predictions that there would be detectable local effects of the discharge for certain parameters and no detectable adverse effects for other parameters or for any measurements outside the immediate vicinity of the discharge (Libby et al. 2010). Similar measurements in Boston Harbor continued to show improvements.

Ammonium is the major component of total inorganic nitrogen in the effluent, and a variety of dilution models had suggested that, following the diversion, increased concentrations of ammonium would be detectable in the nearfield. As anticipated, there have been increases in ammonium at the stations closest to the discharge compared to baseline conditions and relative to regional background conditions (Figure 3-9). At the same time, much greater decreases in ammonium concentrations have been measured in Boston Harbor and in the coastal area.

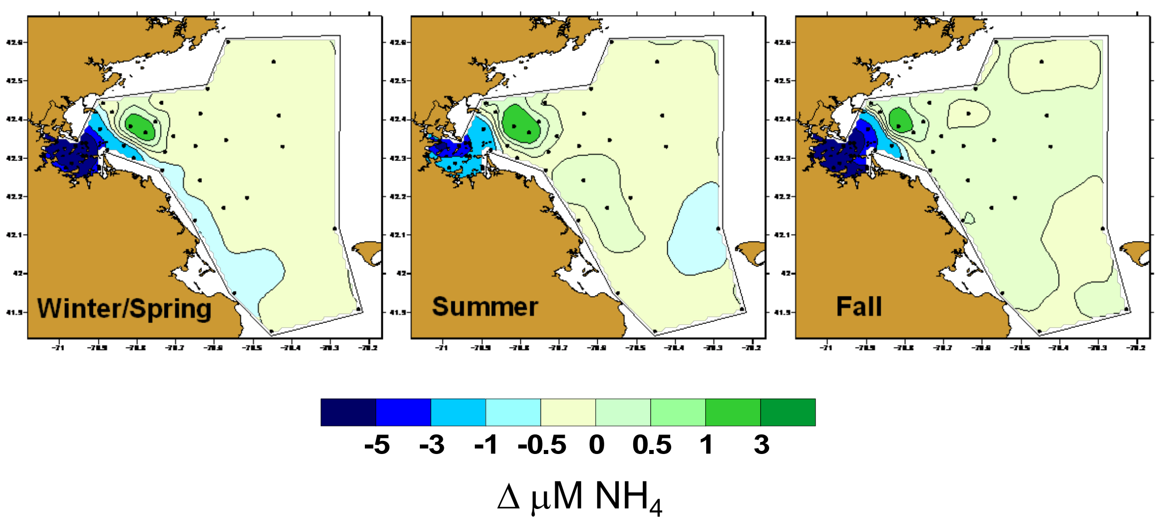


Figure 3-9. Changes in seasonal ammonium concentrations (µM) from the baseline to the post-diversion period. There have been localized increases in ammonium concentrations near the outfall with concurrent decreases in ammonium concentrations in Boston Harbor.

The increased ammonium concentrations in the nearfield have become less apparent in 2005–2009 (Figure 3-10). Ammonium concentrations have also decreased in the coastal and northern boundary regions, suggesting that the change is region-wide and not related to the outfall.

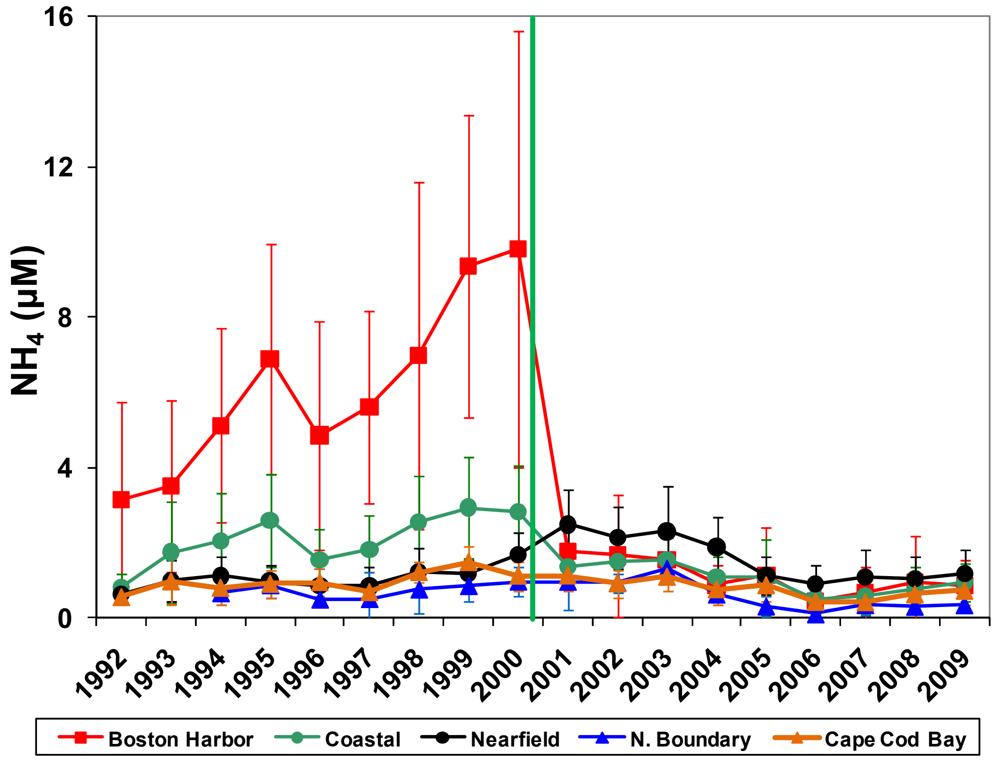


Figure 3-10. Annual mean ammonium concentrations (µM). Data represent all depths and all stations sampled within each region. Vertical line shows the diversion of the discharge from Boston Harbor to Massachusetts Bay. Error bars represent ±1 standard deviation.

Increases in winter/spring and fall nitrate levels have occurred since the outfall diversion (Figure 3-11). These changes are also region-wide, with no indication of an effect of the outfall. In Boston Harbor, levels have declined in response to the outfall diversion (Tian et al. 2009).

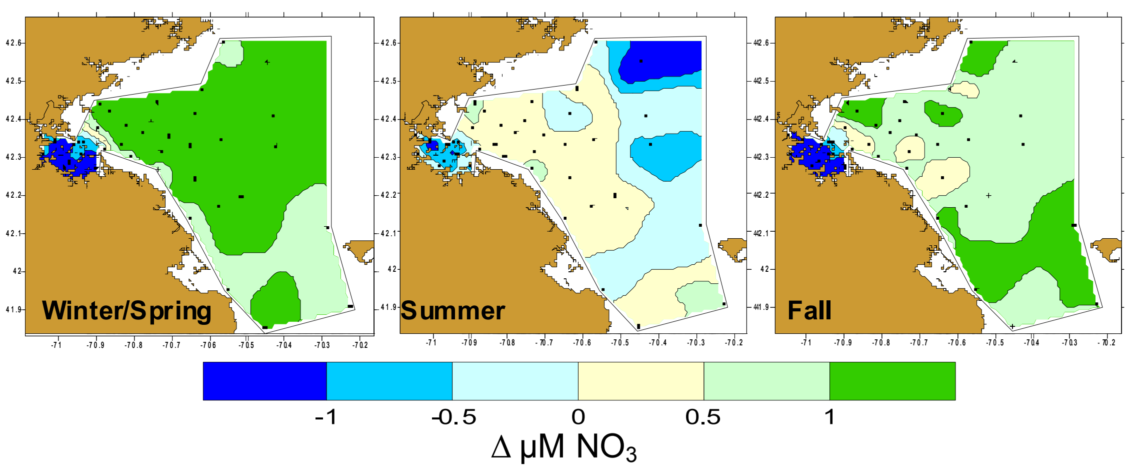


Figure 3-11. Changes in seasonal nitrate concentrations (µM) from the baseline to the post-diversion period. Changes across Massachusetts Bay have not been attributed to the outfall.

Similarly, there have been region-wide changes in chlorophyll (Figure 3-12) and particulate organic carbon (not shown). *Phaeocystis* blooms have caused winter/spring concentrations of chlorophyll to increase throughout Massachusetts Bay, while summer concentrations of chlorophyll have remained close to what they were during the baseline period. Fall concentrations have declined, particularly at the offshore and northern boundary stations. These changes have occurred across broad regional areas. Changes due to the outfall relocation are local and not adverse.

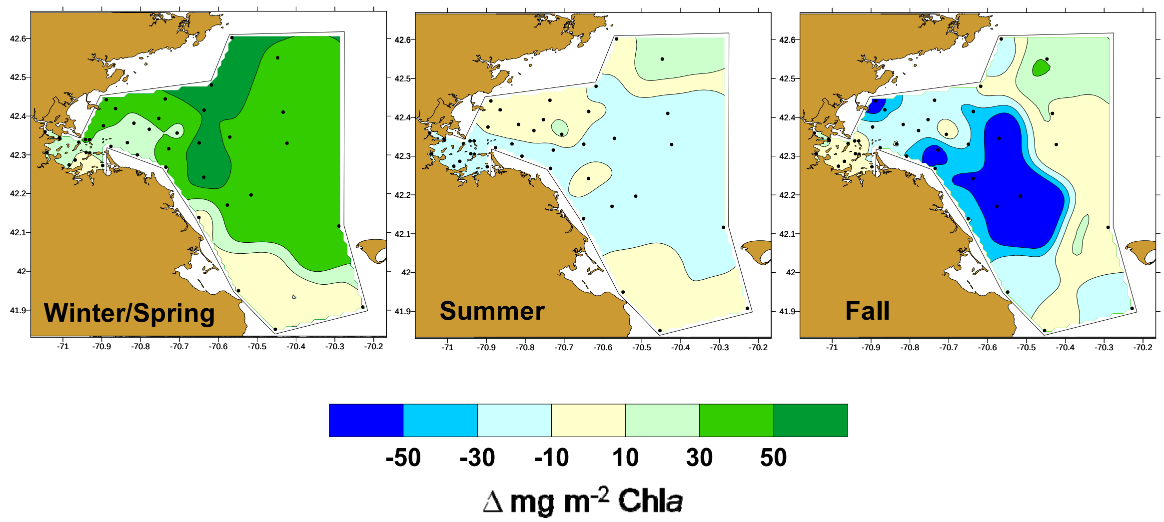


Figure 3-12. Changes in phytoplankton biomass, measured as areal chlorophyll, from the baseline to the post-diversion period. The changes reflect an increase in the *Phaeocystis* blooms in the spring and relative lack of fall blooms. These changes have occurred across the broad region and are not attributed to the relocated discharge.

The possibility that the outfall would cause lower dissolved oxygen levels in bottom waters was one important public concern prior to the diversion. However, measurements of concentrations and percent saturation of dissolved oxygen in bottom waters have shown no response to the outfall (Figure 3-13). There has been no change in levels or the seasonal pattern in any year. Summer and fall bottom water dissolved oxygen levels were somewhat lower in 2009 than in 2008, a result of a lack of the downwelling conditions in 2009.

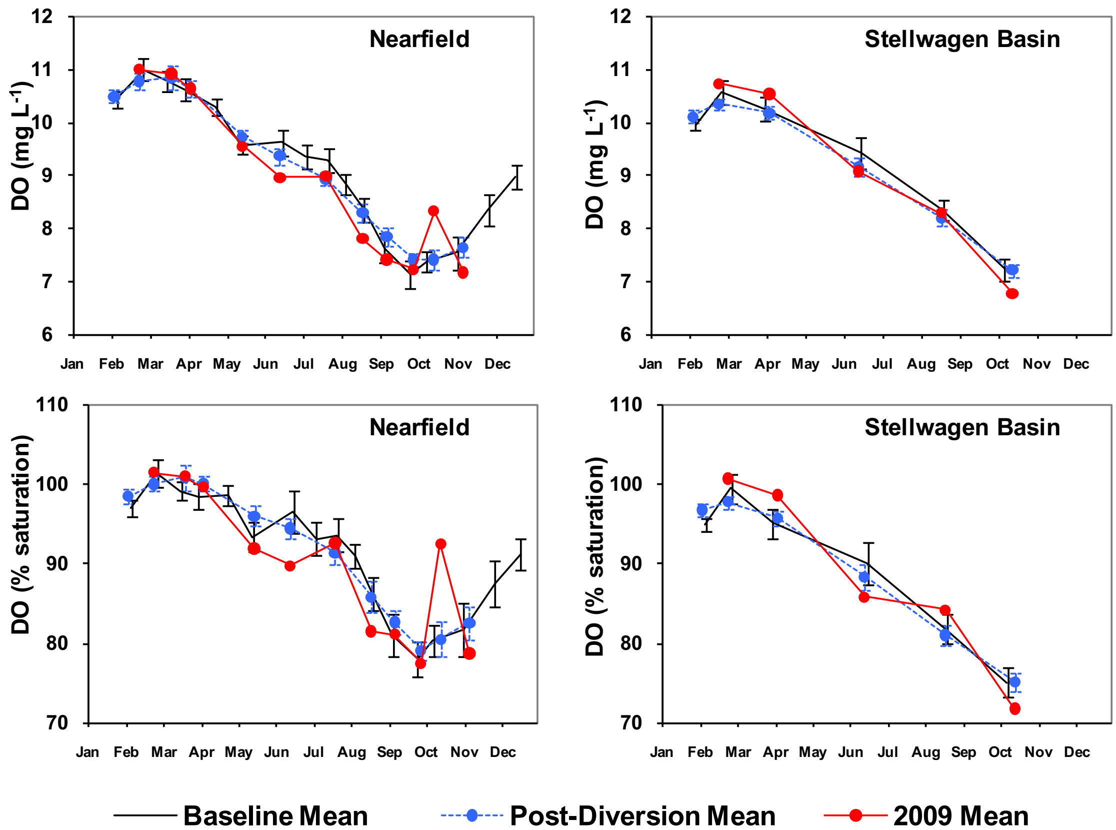


Figure 3-13. Survey-mean dissolved oxygen levels (top graphs) and percent saturation (bottom graphs) in nearfield and Stellwagen Basin bottom waters. There has been no change between the baseline period and the post-diversion years. Data for Stellwagen Basin collected from stations F12, F17, F19, and F22. Error bars represent ± one standard error.

The data from the baseline and post-diversion years have shown that temperature and salinity, rather than effluent inputs, control bottom water dissolved oxygen in the nearfield (Figure 3-14). The observed minimum dissolved oxygen levels in 2009 matched those that were predicted solely from temperature and salinity data.

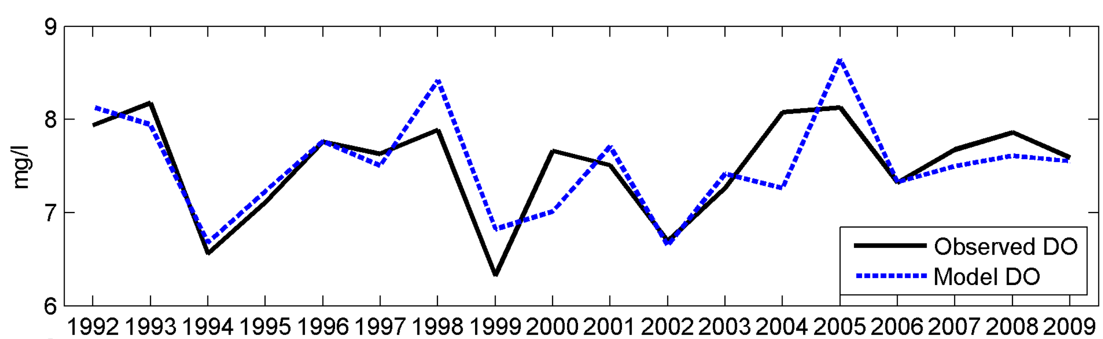


Figure 3-14. A simple model predicting nearfield dissolved oxygen (DO) minima from temperature and salinity variations in the boundary areas matches observations most years.

Phytoplankton Communities

Nearfield abundance of total phytoplankton was within the baseline range throughout 2009 (Figure 3-15), but the regional changes in phytoplankton biomass, measured as chlorophyll concentrations (see Figure 3-13, above) reflect some of the long-term patterns in the phytoplankton populations (Libby et al. 2010). For example, there has been a general decrease in the abundance of diatoms. Except in September, diatoms were rare in the nearfield and throughout the wider region.

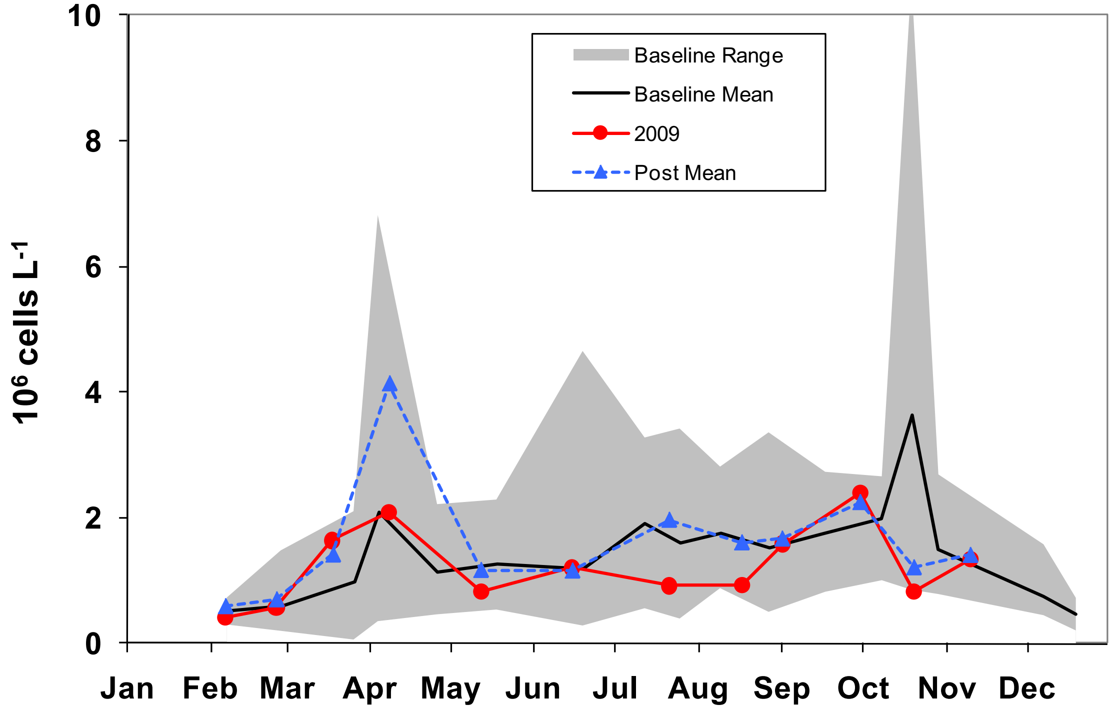


Figure 3-15. Nearfield abundance of total phytoplankton compared to baseline range and mean and post-diversion mean.

The general region-wide increase in phytoplankton biomass during the winter/spring can be attributed to annual blooms of the colonial species *Phaeocystis pouchetii*, which have occurred each year since 2000 (Figure 3-16). *Phaeocystis* is not toxic but is considered a nuisance species, because at high densities it forms gelatinous aggregates that may provide insufficient nutrition for zooplankton egg production (Turner et al. 2002). The timing and geographical extents of the blooms have not suggested any effect of the outfall. Rather, it appears that physical processes, such as water temperature, are the most important factors affecting the timing and duration of *Phaeocystis* blooms.

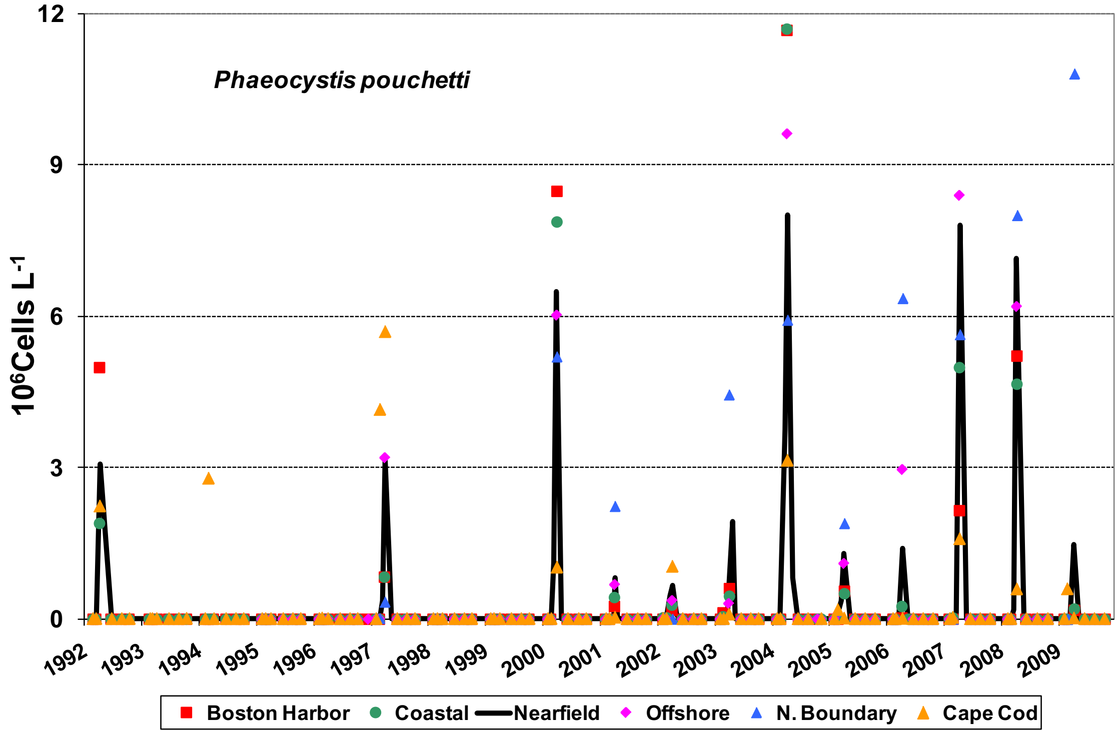


Figure 3-16. Abundance of *Phaeocystis pouchetii* since 1992.

Another general change has been an increase in the frequency of *Alexandrium fundyense* red tide blooms (Figure 3-17), which produce a toxin that causes paralytic shellfish poisoning (PSP). The 2009 *Alexandrium* bloom occurred in April and May, with a maximum abundance of 150 cells per liter at Station N18, located to the south of the outfall, during the May survey. This abundance triggered a series of rapid-response surveys, which showed that the bloom had ended by early June. A small number of cells were detected in November. Frequency of red tides with PSP toxicity has increased throughout the Gulf of Maine since 2006, suggesting that the broad region is entering a period of frequent toxic blooms, similar to conditions during 1970s. More information about red tides and efforts to predict them is presented in Section 6, Special Studies.

A third nuisance species group *Pseudo-nitzschia* has been rare during the post-diversion years (Figure 3-18). The 2009 peak of 12,000 cells/L occurred at the boundary stations in October.

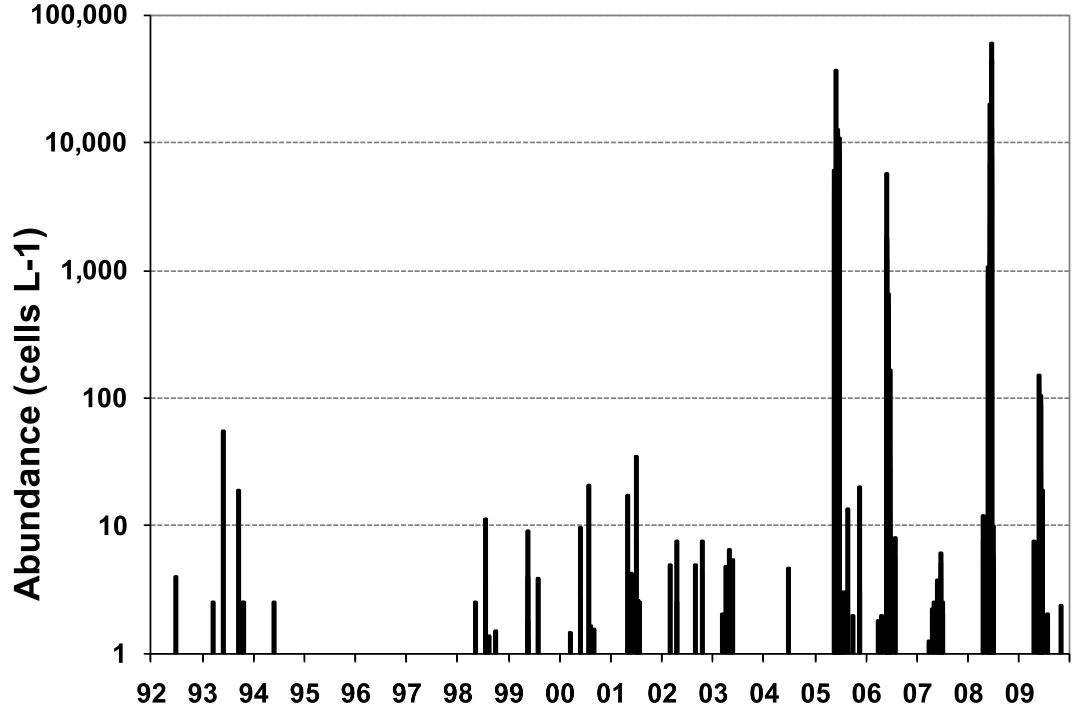


Figure 3-17. Nearfield abundance of *Alexandrium fundyense* since 1992.

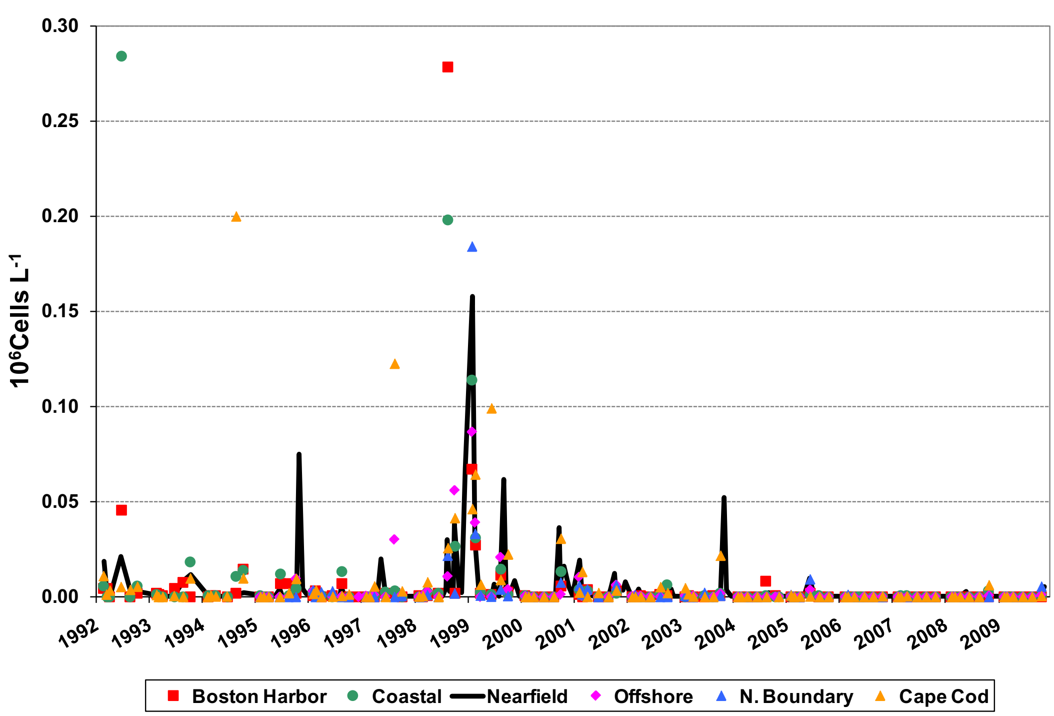


Figure 3-18. Abundance of *Pseudo-nitzschia* spp. since 1992.

Zooplankton Communities

The total abundance of zooplankton in the nearfield and other regions in 2009 was similar to that of many earlier years (Figure 3-19). As is typical, abundance was relatively low during the winter and peaked in the summer. The dominant species group continued to be copepods, and the dominant copepod continued to be the small species *Oithona similis*. A trend in *Oithona similis* abundance continued upward after a decline in 2004–2005. Abundance of the large copepod *Calanus finmarchicus* was also high, with the second highest nearfield abundance of the monitoring program, 14,000 animals per cubic meter, measured in samples from the May 2009 survey. Other taxa, including barnacle nauplii, bivalve and gastropod veligers, and polychaete larvae occurred sporadically. The fluctuations in zooplankton occurrence and abundance appear to be related to large-scale climatic conditions.

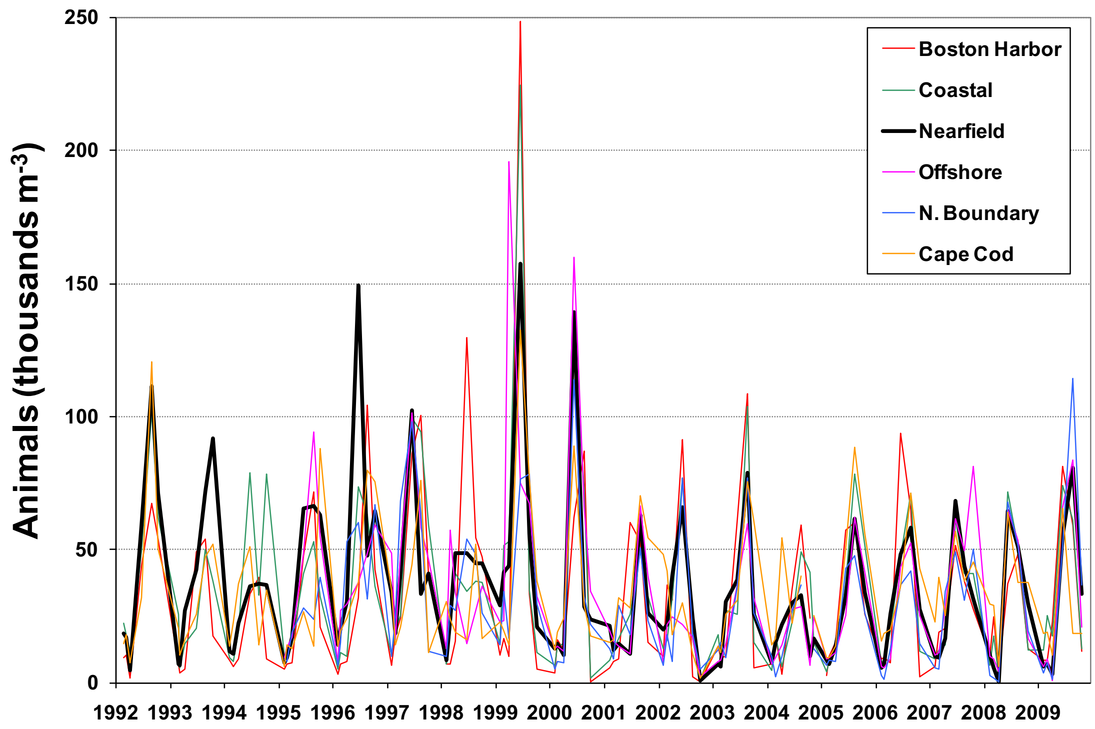


Figure 3-19. Abundance of total zooplankton since 1992.

Contingency Plan Thresholds

Water quality parameters were within normal ranges throughout 2009. There was one exceedance of a nuisance algae threshold, the caution threshold for *Alexandrium fundyense* (Table 3-1). This exceedance had been anticipated, based on information on overwintering *Alexandrium* cysts in the sediments off the coast of Maine (see Section 6, Special Studies) and spring measurements of *Alexandrium* cells in coastal waters of Maine and New Hampshire. As in other years when that level has been exceeded, MWRA, in cooperation with the Woods Hole Oceanographic Institution (WHOI) and the Massachusetts Division of Marine Fisheries, implemented its rapid-response *Alexandrium* survey plan (Libby 2006), which provides for assessment of rapidly developing and potentially large blooms. Results from those surveys indicated that the bloom proceeded in a pattern that was consistent with historic progressions and that the outfall discharge did not affect its intensity, timing, or duration.

Table 3-1. Contingency Plan threshold values and 2009 results for water-column monitoring. (DO=dissolved oxygen)

Location/ Parameter	Specific Parameter	Baseline	Caution Level	Warning Level	2009 Results
Bottom water nearfield	Dissolved oxygen concentration	Background 5th percentile 5.75 mg/L	Lower than 6.5 mg/L for any survey (June-October) unless background conditions are lower	Lower than 6.0 mg/L for any survey (June-October) unless background conditions are lower	Lowest survey mean = 7.23 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 = 77.5%
Bottom water Stellwagen Basin	Dissolved oxygen concentration	Background 5th percentile 6.2 mg/L	6.5 mg/L for any survey (June-October) unless background conditions lower	Lower than 6.0 mg/L for any survey (June-October) unless background conditions are lower	Lowest survey mean = 6.79 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 = 71.8%
Bottom water nearfield	DO depletion rate (June-October)	0.024 mg/L/d	0.037 mg/L/d	0.049 mg/L/d	0.010 mg/L/d
Chlorophyll nearfield	Annual	79 mg/m^2	118 mg/m^2	158 mg/m^2	52 mg/m^2
	Winter/spring	62 mgml^2	238 mg/m^2	None	63 mg/m^2
	Summer	51 mg/m^2	93 mg/m^2	None	43 mg/m^2
	Autumn	97 mg/m^2	212 mg/m^2	None	49 mg/m^2
Nuisance algae nearfield *Phaeocystis pouchetii*	Winter/spring	468,000 cells/L	2,020,000 cells/L	None	402,000 cells/L
	Summer	72 cells/L	357 cells/L	None	Absent
	Autumn	317 cells/L	2,540 cells/L	None	Absent
Nuisance algae nearfield *Pseudo-nitzschia*	Winter/spring	6,200 cells/L	21,000 cells/L	None	Absent
	Summer	14,600 cells/L	43,100 cells/L	None	Absent
	Autumn	9,940 cells/L	24,700 cells/L	None	1,460 cells/L
Nuisance algae nearfield *Alexandrium fundyense*	Any nearfield sample	Baseline maximum = 163 cells/L	100 cells/L	None	**150 cells/L, caution level exceedance**
Farfield	PSP toxin extent	Not applicable	New incidence	None	No new incidence

4. Sea Floor

Sea-floor monitoring in 2009 was conducted at soft-bottom stations in the nearfield (Figure 4-1) and farfield (Figure 4-2) and through a video and photographic survey of rocky habitats in the vicinity of the outfall and at reference locations to the north and south (Figure 4-3).

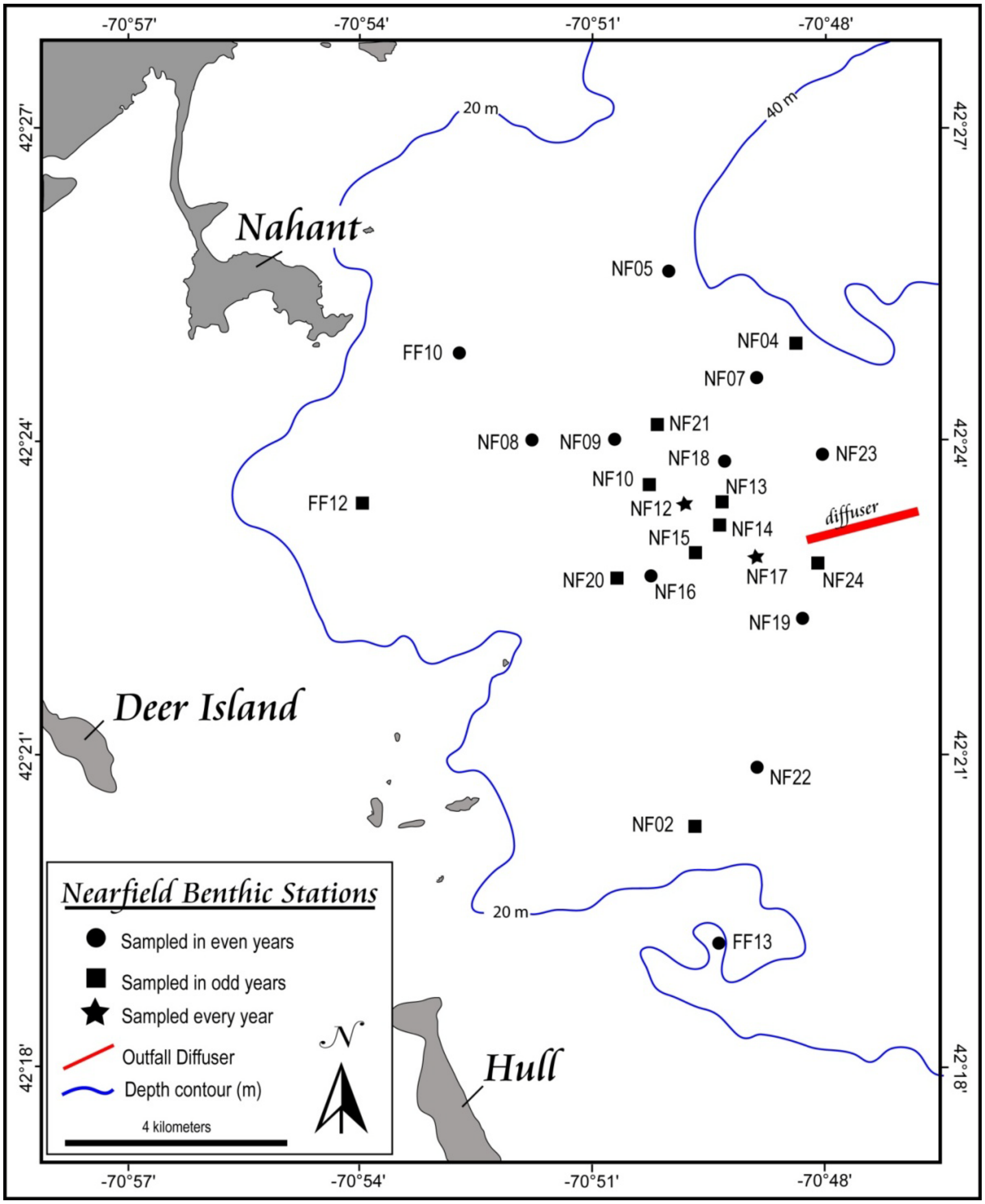


Figure 4-1. Locations of nearfield soft-bottom stations for chemical parameters, sediment-profile imaging (SPI), and community parameters. SPI sampling is performed on all stations every year.

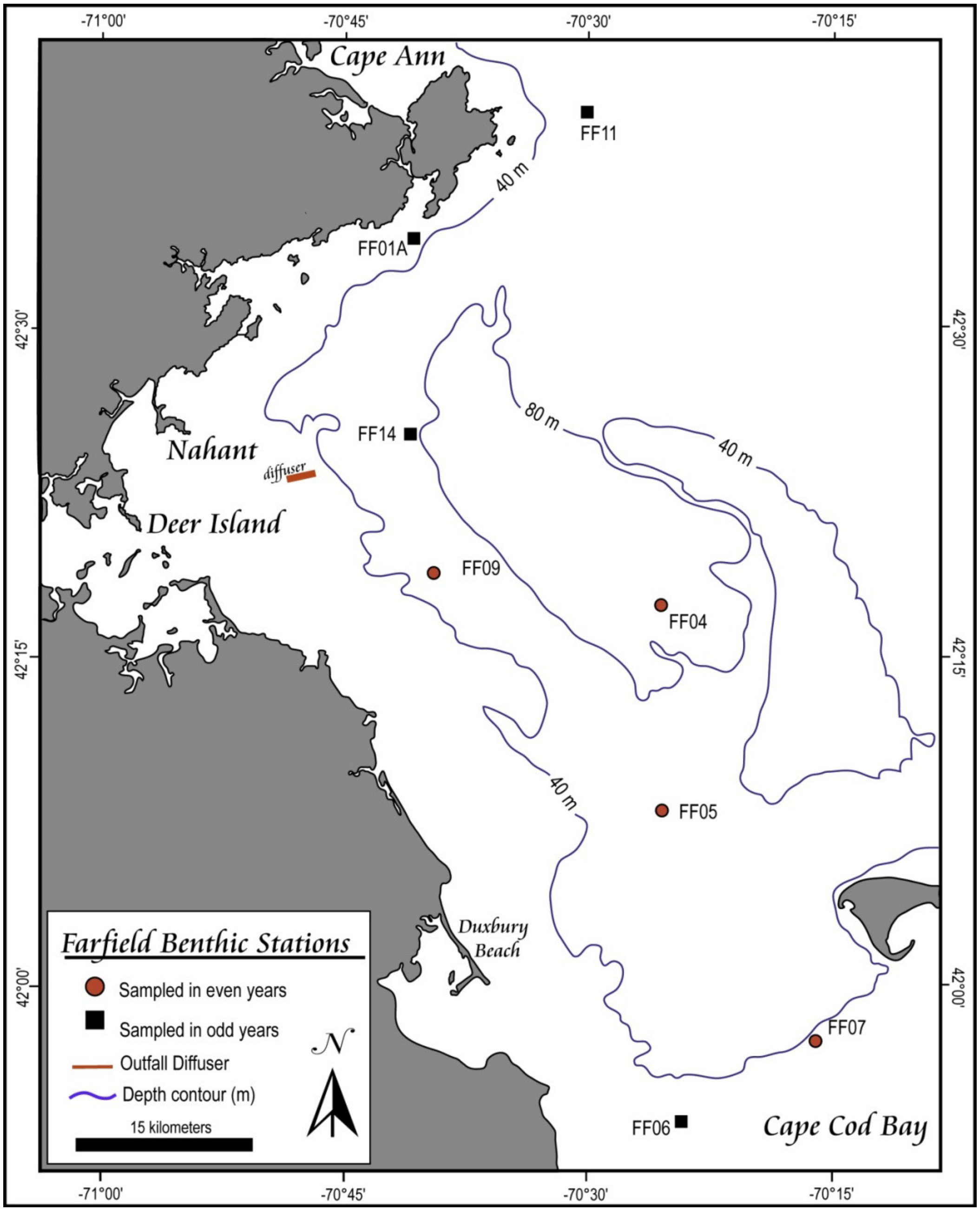


Figure 4-2. Locations of farfield soft-bottom stations for chemical and community parameters.

The soft-bottom studies included measurements of sediment grain-size distribution, total organic carbon, the sewage-bacteria tracer *Clostridium perfringens* spores, chemical contaminants, and community parameters at stations labeled as "sampled in odd years" or "sampled every year." Sediment-profile imaging measurements were made at all nearfield Massachusetts Bay stations shown on Figure 4-1, including those denoted as being sampled in even years.

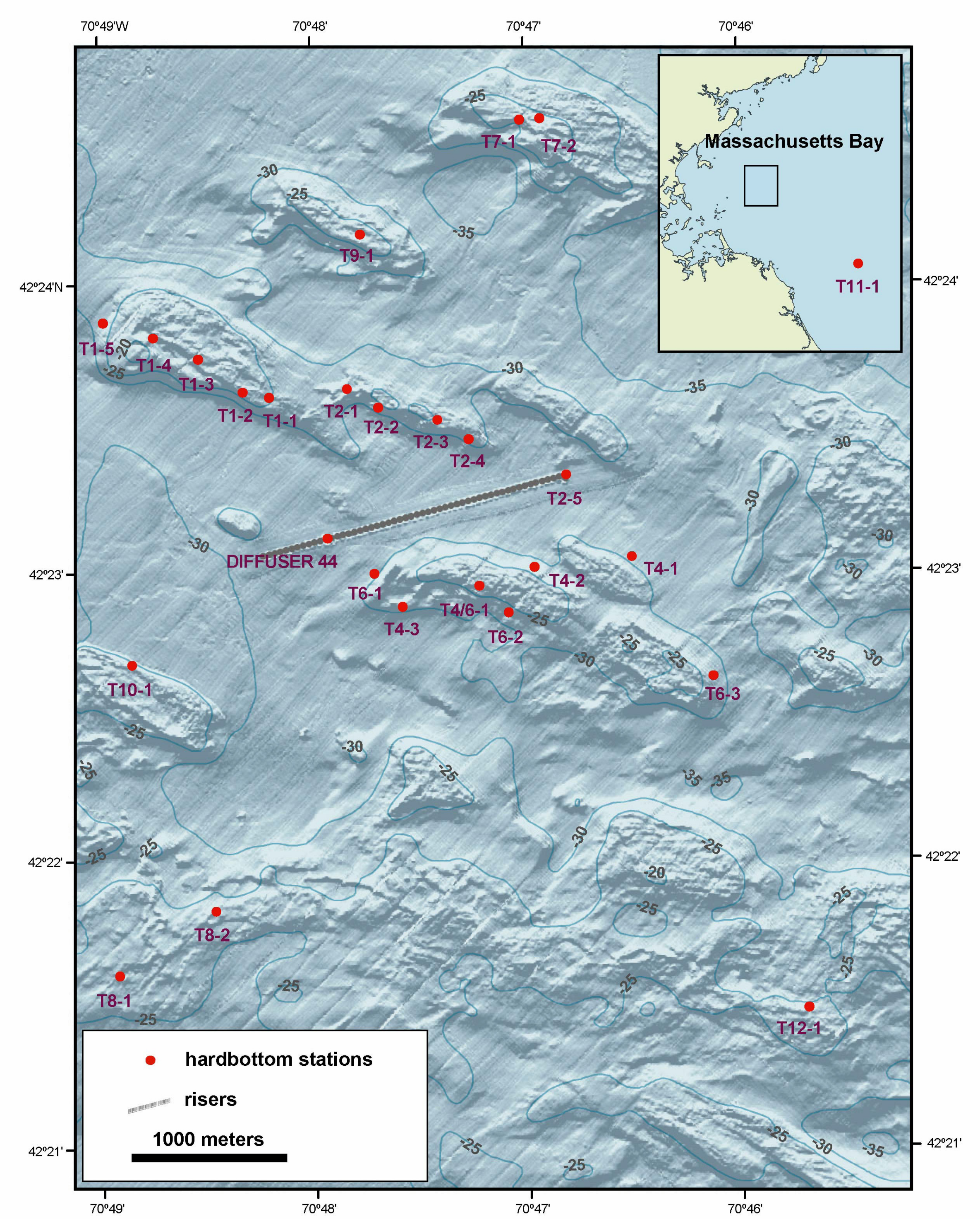


Figure 4-3. Locations of hard-bottom stations. Video and still photographs are collected at 17 stations distributed among six transects and at six additional waypoints, including one active diffuser and one diffuser that has not been opened.

Sediment Characteristics and Tracers

Grain-size distributions at the 16 stations sampled in 2009 remained within the historic ranges of the monitoring program, ranging from coarse to fine sediments (Maciolek et al. 2010). Total organic carbon concentrations were relatively low at most stations, especially in the nearfield. There has been no increase in mean concentrations of total organic carbon at stations located near the outfall since the outfall diversion. Rather, there has been a slight decrease in the nearfield and at stations located between the nearfield and Boston Harbor.

As in other post-diversion years (except 2006), it was possible to detect elevated levels of *Clostridium perfringens* spores in some sediments collected within two kilometers of the outfall. The signal was especially apparent when comparing the data to those from late baseline years, 1999–2000 (Figure 4-4). These findings were consistent with predictions that it would be possible to detect sewage tracers such as *Clostridium* spores in the immediate vicinity of the outfall. There has been a decline in spore counts from stations located in the transition area, located between Boston Harbor and the outfall, where the single station sampled in 2009 had a spore count at the bottom of the baseline range.

There has been no indication of accumulation of toxic compounds in the region surrounding the relocated outfall. Concentrations of chemical contaminants in the sediments were measured at two stations in 2009 (NF12 and NF17) and were generally at the low ends of the ranges measured throughout the monitoring program. Concentrations of PCBs (Figure 4-5) and chlorinated pesticides (not shown) have decreased at both nearfield and farfield stations, probably reflecting the slow declines in those contaminants since they were banned in the 1970s and 1980s. There have also been small decreases in silver, cadmium, and mercury concentrations. No similar region-wide declines in polycyclic aromatic hydrocarbons (PAHs) have been observed.

Concentrations of aluminum have increased in the nearfield and at transition stations since the outfall diversion, but possible reasons for the increase have not been determined. Aluminum in sediments is more typically the result of natural processes than anthropological activities.

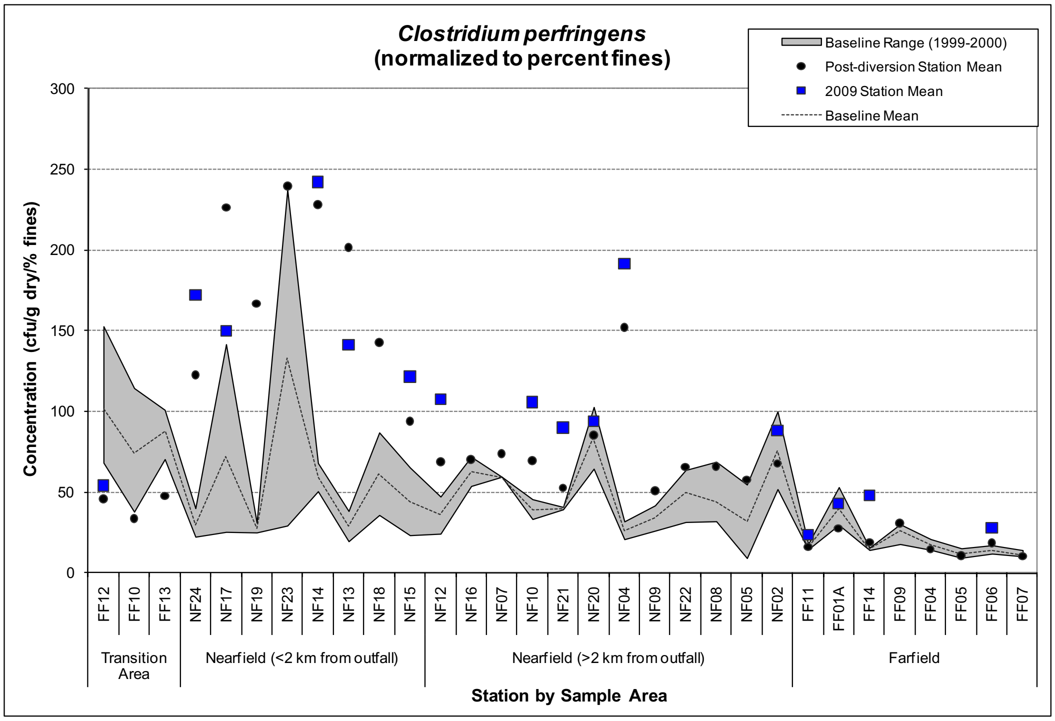


Figure 4-4. *Clostridium perfringens* spores normalized to percent fine fraction in the sediments compared to the late baseline range and post-diversion mean. Transition area" denotes stations located between Boston Harbor and the outfall; "Farfield" denotes stations offshore from the outfall.

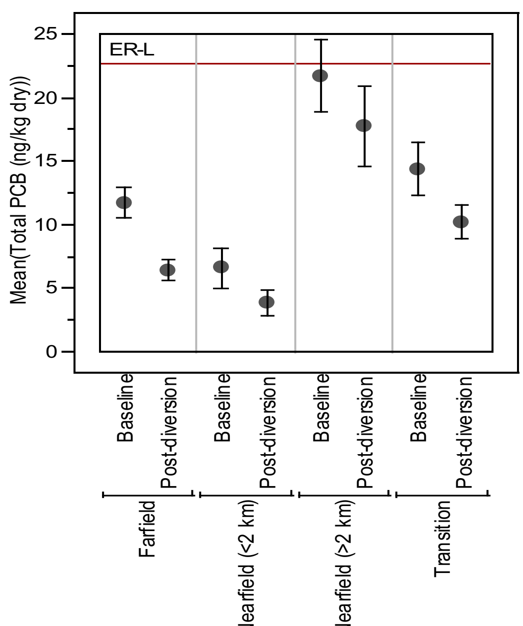


Figure 4-5. Regional trends in PCB concentrations during the baseline and post-diversion periods. Values are mean ± standard error. The horizontal line represents the effects range-low (ER-L), the lower tenth percentile of concentrations of PCBs in sediments that have been determined to be toxic in a broad range of studies. ER-Ls are not thresholds but are useful for comparisons across regions or time.

In Boston Harbor, where monitoring has also been conducted since 1991, data continued to show a decline in concentrations of total organic carbon at some stations, including those closest to the former harbor outfall near DITP. The large harbor-wide decline in concentrations of *Clostridium perfringens* spores also continued in 2009.

Sediment-Profile Imaging

Sediment-profile imaging measurements were made at 23 nearfield stations in 2009 and continued to show no adverse effects of the outfall (Maciolek et al. 2010). The number of animals and burrows recorded in each image has been lower during 2005–2009 since a high in 2004, continuing to suggest that physical rather than biological processes have been the primary forces structuring the sediments in recent years. In 2009, Hurricane Bill passed offshore two days prior to sampling, and storm-related waves and bottom currents may have destroyed surficial biogenic structures, such as feeding mounds and pits. Storms and storm-induced sediment transport and deposition remain the primary stresses on the sea-floor communities in Massachusetts Bay.

Concerns that an increase in the amount of organic matter deposited on the sea floor would result in a shallower apparent redox potential discontinuity (RPD) at stations near the Massachusetts Bay outfall have not been realized (Figure 4-6). The mean RPD was shallower in 2009 than in 2006–2008, but remained deeper than the baseline mean. No other measure, including the organism sediment index (OSI) and accumulation of fine sediments and organic material, have suggested any adverse effects of the outfall diversion.

At Boston Harbor stations, where a separate monitoring program is conducted, the RPD, successional stage, and OSI remained about the same in 2009 as in 2008, and the incidence of biogenic features decreased. The sediment-profile images recorded fewer burrowing amphipods *Leptocheirus pinguis* than in 2008, when there had been a large increase (see Figure 6-10 in Section 6, Special Studies). For the second year, eelgrass was detected near Deer Island Flats. Since 1993, there has been an increase in the number of animals and burrows per image and a functional shift, with animals that burrow deeper into the sediments becoming more prevalent.

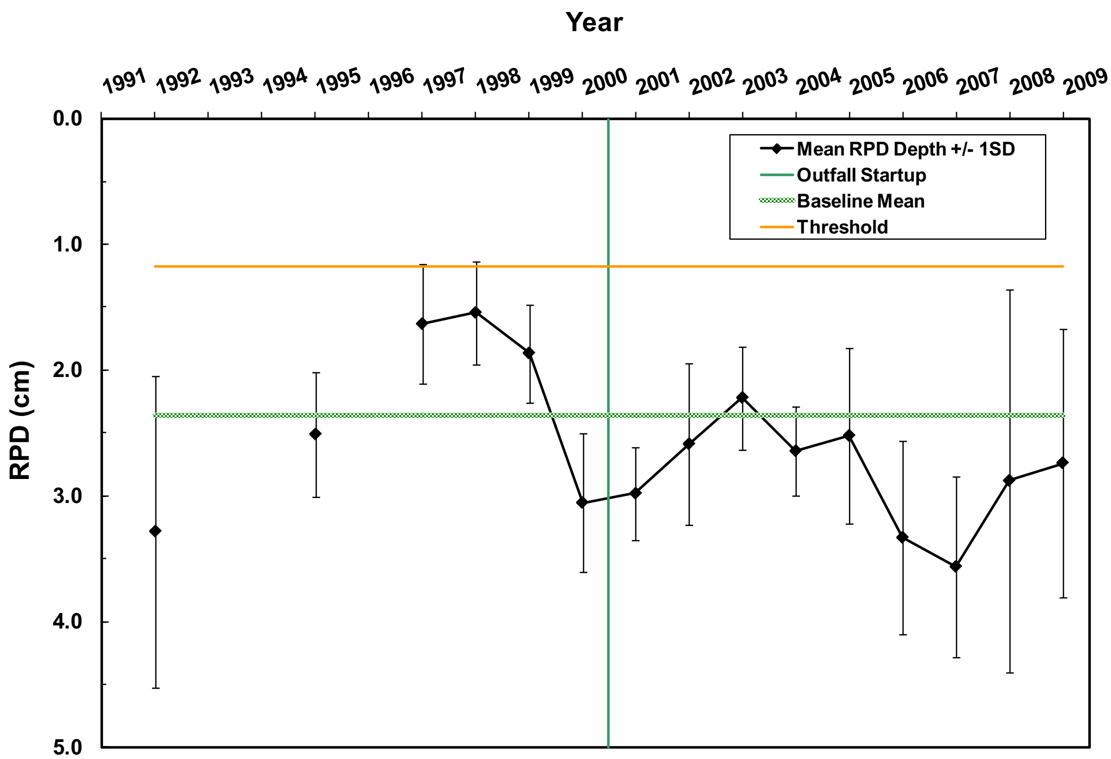


Figure 4-6. Annual apparent color RPD for data from nearfield stations. The average RPD depth in 2009 remained deeper than the baseline mean, continuing to indicate that there has been no adverse effect from the discharge. Data are mean +1 standard error.

Soft-bottom Communities

The soft-bottom communities continued to show no response to the outfall. Rather, post-diversion monitoring has continued to confirm the baseline finding that sediment grain size is the most important influence on the benthic infaunal communities (Maciolek et al. 2010).

Twenty samples from 12 nearfield stations taken in 2009 yielded more than 45,000 animals. Species composition remained consistent with earlier years. Average density of the spionid polychaete *Prionospio steenstrupi*, which has been the numerically dominant species in recent years, was about the same as in 2007, the last year in which the same set of stations was sampled. The tunicate *Molgula* sp. was especially abundant at one station, NF17.

The number of species per sample, total abundance of animals per sample, and other community parameters all remained within the baseline ranges (Figure 4-7).

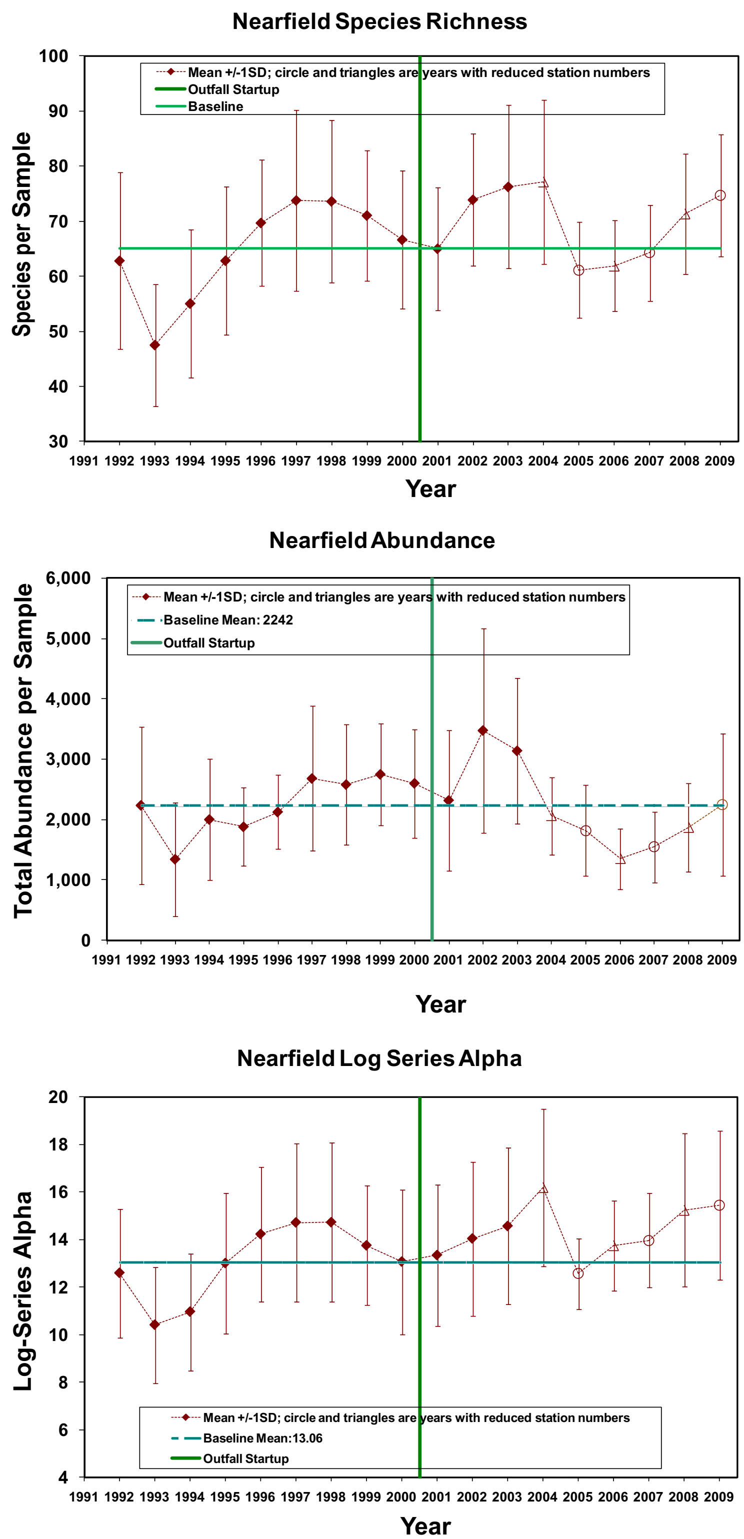


Figure 4-7. Annual community parameters in the nearfield.

The mean values for most community parameters were higher than those measured in 2007 and similar to or higher than the baseline means. The diversity measures were influenced by the abundance of tunicates at Station N17. Over the course of monitoring, some community parameters have fluctuated in sine wave-like patterns. These patterns appear to be driven by annual fluctuations in several dominant species, particularly polychaete worms that inhabit fine-grained sediments. The results have held constant through both even and odd years, when separate sets of stations are sampled.

The farfield stations are more geographically widespread, with mostly finer sediments, and polychaetes dominate at most stations. The species compositions at those stations have always differed from those at nearfield stations. There were no unusual findings in the twelve samples from four farfield stations in 2009. Dominant species in 2009 were generally similar to those found in earlier years. Mean total abundance of animals was lower than the baseline mean but similar to what had been found in the early 1990s. The decline in total numbers could largely be attributed to a decline in the regionally abundant polychaete *Prionospio steenstrupi*.

Hard-bottom Communities

The rocky habitats in the vicinity of the outfall and at reference locations continued to support robust communities of algae, invertebrates, and fish (Maciolek et al. 2010). Baseline and post-diversion monitoring has shown that the hard-bottom communities in the region are spatially diverse but temporally stable. While there have been some shifts in species composition and abundance, those changes have been modest. Lush epifaunal growth, particularly sea anemones, has thrived on the diffuser heads.

Of the fifty taxa recorded during the 2009 survey, there were 37 invertebrate species, nine fishes, and four algal species (Figure 4-8). Some modest changes have been noted over time, including decreases in the number of upright algae at some stations. There have also been increases in the amount of “sediment drape,” a visual assessment of the detritus deposited on hard surfaces, with a concurrent decrease in coralline algae at some stations, including northern reference sites. Some changes at the northern stations may be attributed to disturbance of the sea floor by anchors. Sightings of cod and lobster have increased greatly since the baseline period, but these increases may be the result of quieter sampling equipment.

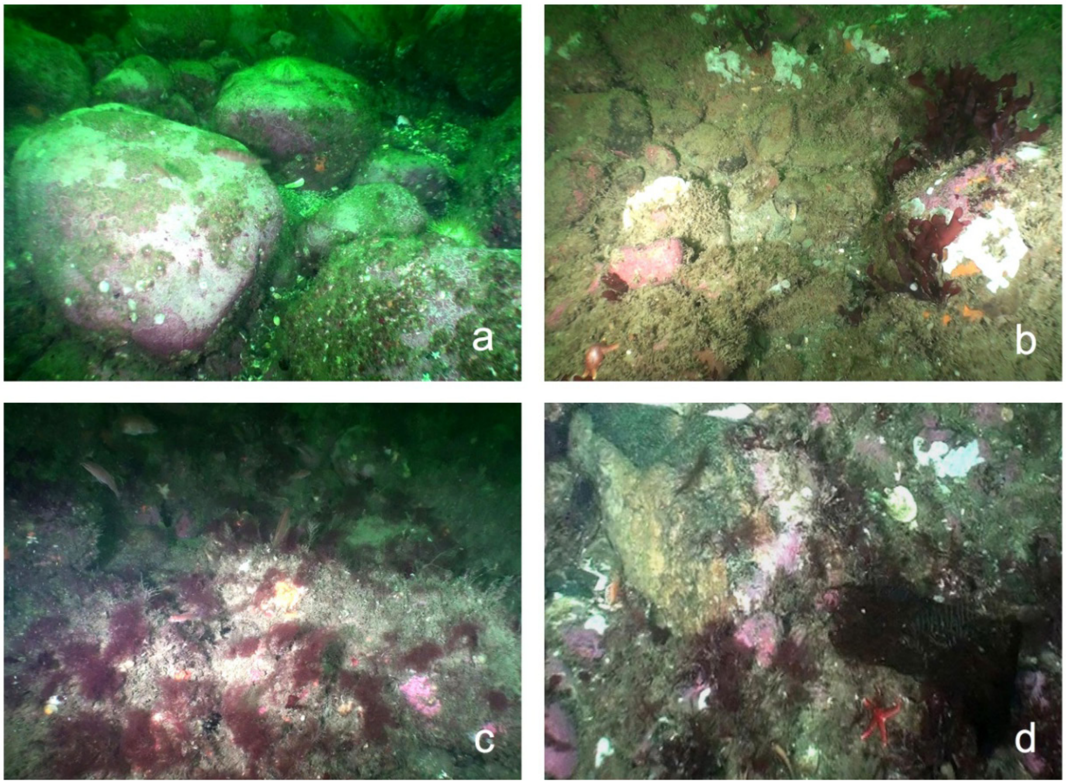


Figure 4-8. Screen captures of the four algal species observed during the 2009 hard-bottom survey. (a) coralline algae encrusting rock surfaces at waypoint T1-3; (b) dulse *Palmaria palmata* on a boulder at southern reference site T8-1; (c) red filamentous algae *Ptilota serrata* at northern reference site T9-1; (d) shotgun kelp *Agarum cribrosum* on a boulder at northern reference site T7-1.

Contingency Plan Thresholds

No Contingency Plan thresholds for sea-floor monitoring were exceeded in 2009 (Table 4-1). There have been no threshold exceedances for any sea-floor parameter during the course of the monitoring program. RPD depth continued to be deeper than the baseline mean, and the soft-bottom community parameters were within normal ranges. The percent of the soft-bottom community composed of opportunistic species remained low, about two orders of magnitude below the warning threshold.

Table 4-1. Contingency Plan threshold values and 2009 results for sea-floor monitoring.

Location/ Parameter Type	Parameter	Caution Level	Warning Level	2009 Results
Nearfield	RPD depth	1.18 cm	None	2.74 cm
Odd years, benthic diversity, nearfield	Species per sample	<46.52 or >79.95	None	71.9
	Fisher's log-series alpha	<9.95 or >15.17	None	14.8
	Shannon diversity	<3.30 or >3.91	None	3.84
	Pielou's evenness	<0.56 or >0.66	None	0.622
Benthic opportunists	% opportunists	>10%	>25%	0.275 %

5. Fish and Shellfish

Each year MWRA monitors the health of winter flounder in Boston Harbor, Massachusetts Bay, and Cape Cod Bay. Every three years, including 2009, monitoring also includes chemical analyses of flounder fillets and liver, lobster meat and hepatopancreas, and blue mussel tissue. Flounder and lobster were sampled from Deer Island Flats, near the outfall site, and Cape Cod Bay (Figure 5-1). Flounder were also taken near Nantasket Beach. Mussels were collected from a reference site at Stover's Point, Maine and deployed in cages at two outfall site locations (the edge of the mixing zone and one kilometer south of the diffuser line), at Deer Island Light, and in the Inner Harbor for 60 days.

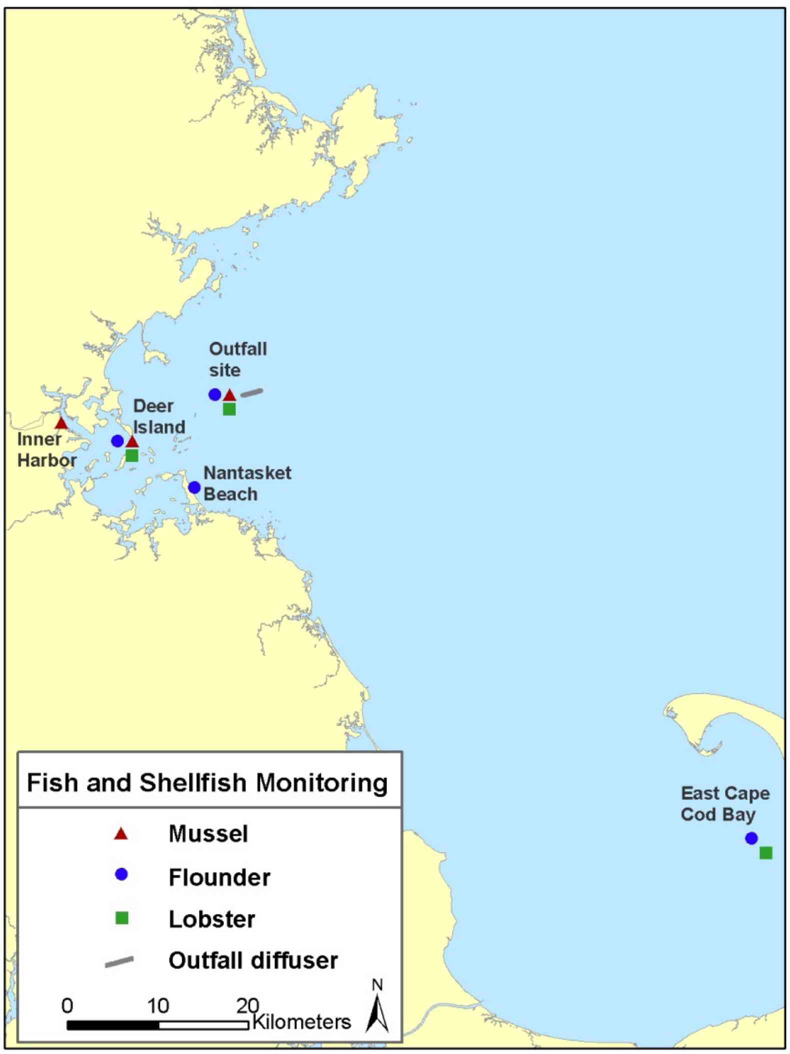


Figure 5-1. Fish and shellfish monitoring sites.

Flounder Health

Fifty sexually mature winter flounder were taken from each of the four sampling sites during April and May 2009 for assessment of external condition and examination of liver histology (Moore et al. 2009, Hall et al. 2010). Catch per unit effort was greater than in 2006–2008 for all sites except Nantasket Beach (Figure 5-2). In Cape Cod Bay, the catch per unit effort was the highest measured over the course of the monitoring program.

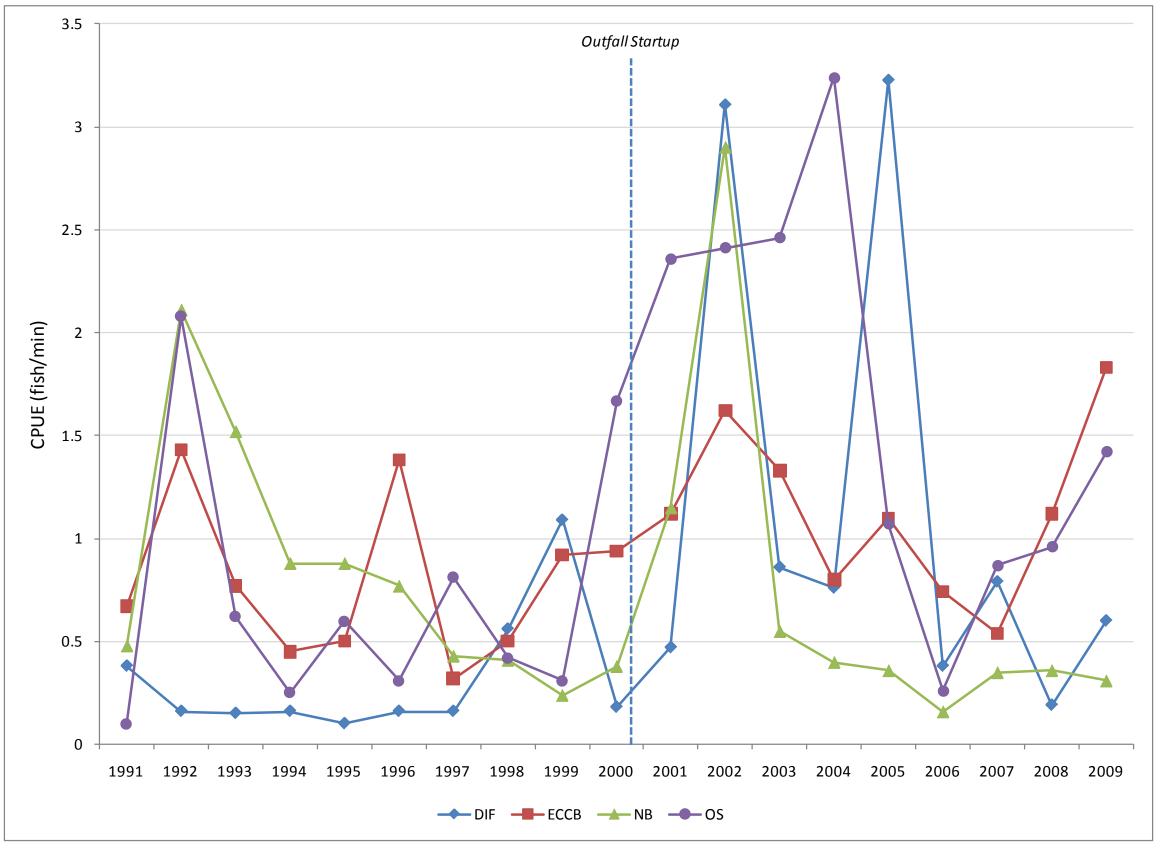


Figure 5-2. Annual catch per unit effort. (DIF = Deer Island Flats, ECCB = Eastern Cape Cod Bay, NB = Nantasket Beach, OS = Outfall Site)

Average ages, lengths, and weights of the winter flounder collected in 2009 were within the historic ranges. The catches continued to be dominated by females, as they have been throughout most of the monitoring program (Figure 5-3).

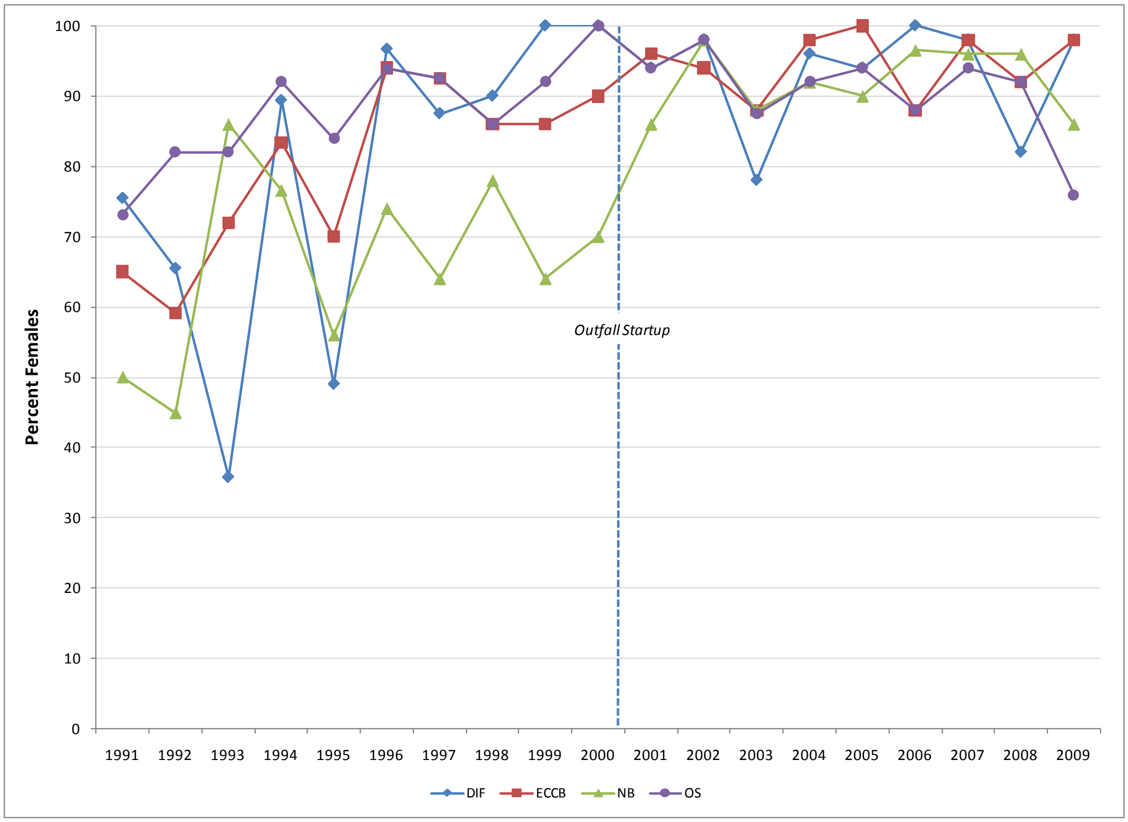


Figure 5-3. Annual percent females in winter flounder samples. (DIF = Deer Island Flats, ECCB = Eastern Cape Cod Bay, NB = Nantasket Beach, OS = Outfall Site)

Prevalence of fin erosion, a condition that can be indicative of elevated concentrations of ammonium and other pollutants, was within the historic range of the monitoring program and lower than had been observed in the late 1970s and early 1980s. Blind-side ulcers were present in low numbers on fish from Deer Island Flats and Nantasket Beach. Ulcers were first detected in 2003, when they were found on 36% of the fish collected near the outfall. That year proved to be the peak for the infection, and in 2009, no fish taken from near the outfall had ulcers. The cause of the ulcers has not been determined.

No neoplasms were observed in any fish from any site. Incidence of neoplasia has been rare throughout the area since routine monitoring started in 1991, although levels were as high as 12% in flounder taken from Boston Harbor for other monitoring programs during the 1980s. Neoplasia has never been observed in fish taken from the outfall site.

The incidence of centrotubular hydropic vacuolation (CHV), a mild condition associated with exposure to contaminants, remained lower than the baseline observations (Figure 5-4). Incidence of CHV at Deer Island Flats was slightly greater in 2009 than in 2008 but less than baseline levels. Average severity of CHV also remained lower than baseline levels.

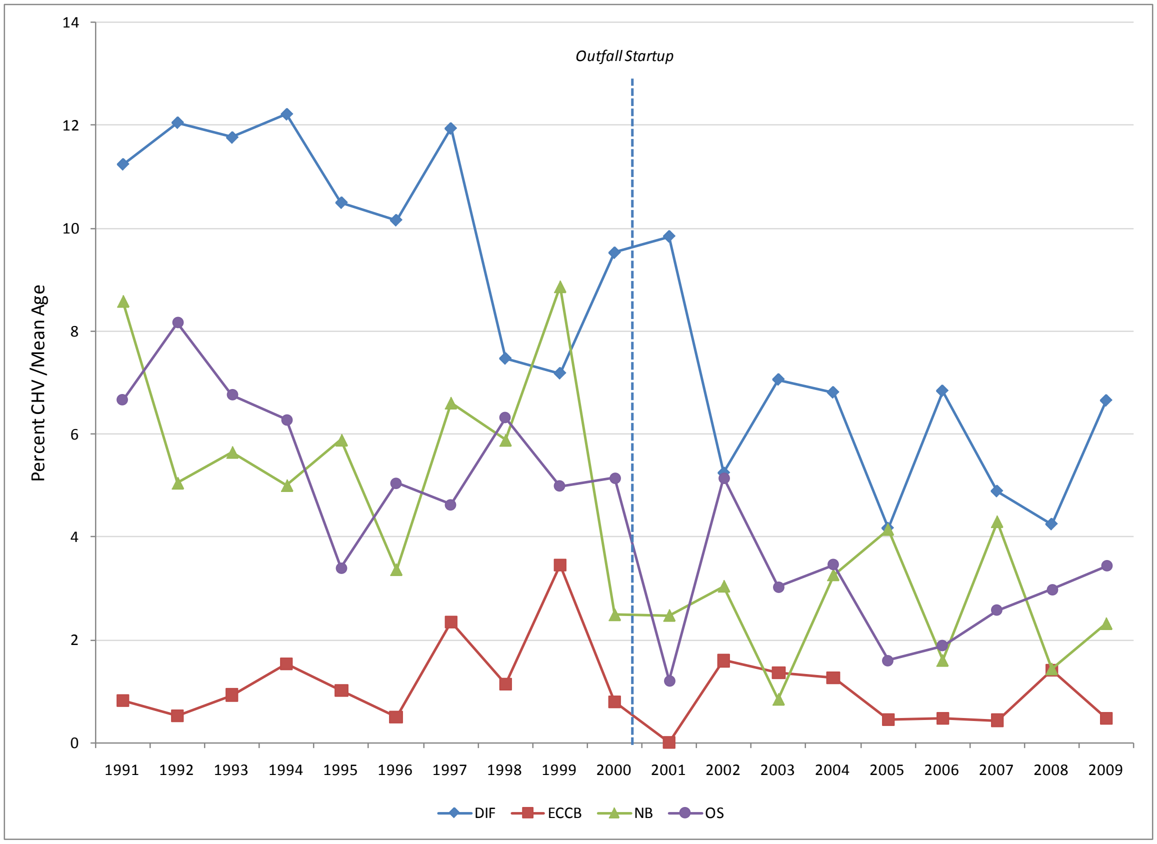


Figure 5-4. Annual prevalence of centrotubular hydropic vacuolation (CHV), corrected for age. (DIF = Deer Island Flats, ECCB = Eastern Cape Cod Bay, NB = Nantasket Beach, OS = Outfall Site)

Levels of one marker of substandard liver health, biliary proliferation, were elevated in 2009, particularly in fish from Cape Cod Bay. Three fish from Cape Cod Bay had single-celled parasites in bile duct cells (Figure 5-5), and it is possible that the elevated levels of biliary proliferation are associated with this parasite.

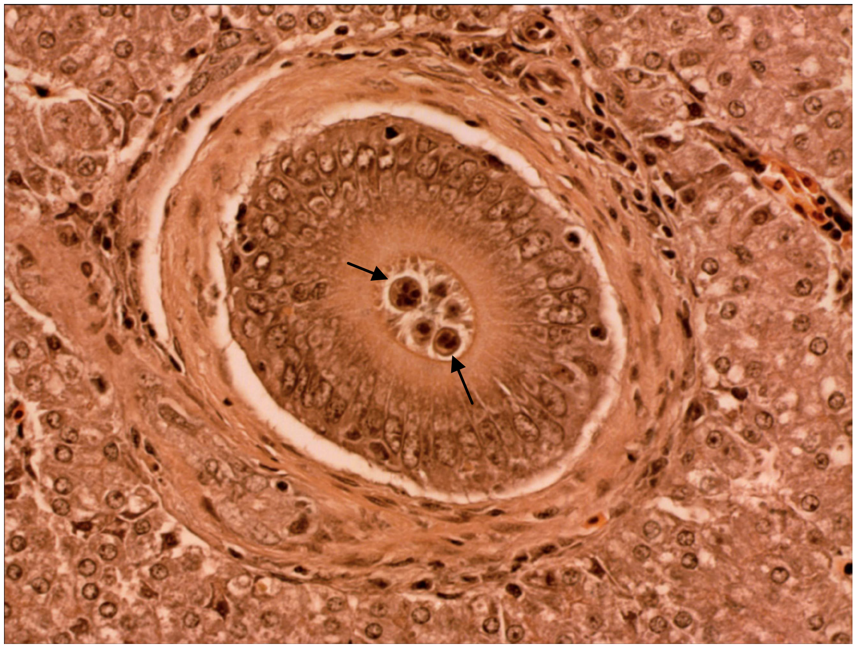


Figure 5-5. Stained section of a winter flounder liver showing protozoan parasites in a bile duct. (Arrows indicate the parasites.)

Fish and Shellfish Chemistry

Samples for chemical analyses of winter flounder tissues were taken from the same collections as were used to assess health (Hall et al. 2010). Three replicates of winter flounder fillets and livers, each composed of tissue from five fish, were analyzed for PCBs, pesticides, and mercury. Liver samples were also analyzed for selected metals. Similarly, three replicates of lobster meat and hepatopancreas were composed of tissues from seven lobsters and were analyzed for PCBs, pesticides, and mercury. Hepatopancreas samples were also analyzed for metals. Mussel tissues were analyzed for PCBs, pesticides, PAHs, mercury, and lead.

Before-After Control-Impact (BACI) analyses of flounder chemistry data have detected no changes related to the outfall diversion. There have been slow declines in contaminant levels of products that have been banned, such as PCBs, DDTs, and chlordanes. For example, total chlordane levels have decreased in flounder fillets, particularly in those from Deer Island Flats (Figure 5-6), and levels of total PCBs in flounder livers have declined at all sites (Figure 5-7). These declines may reflect region-wide conditions as the ecosystem slowly cleanses itself, or they may result from changes in fish distribution. The winter flounder in the more recent collections may have spent more time in more northern or deeper waters, which may also be expected to be cleaner.

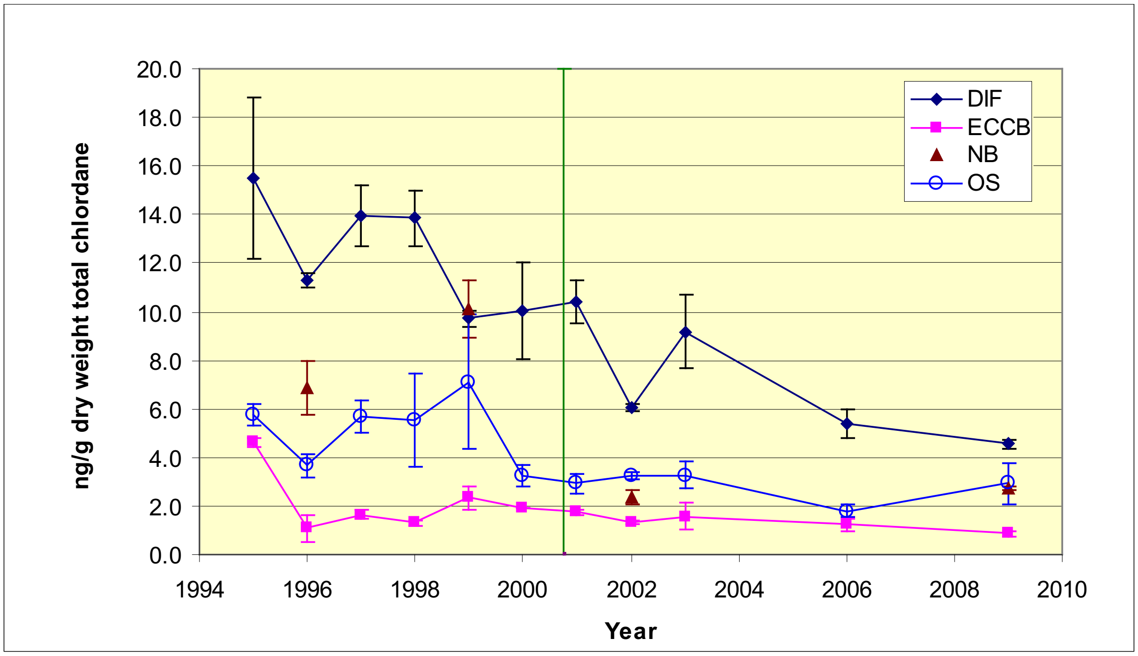


Figure 5-6. Chlordane levels in flounder fillets, 1994–2009. (DIF=Deer Island Flats, ECCB=Eastern Cape Cod Bay, NB=Nantasket Beach, OS=Outfall Site)

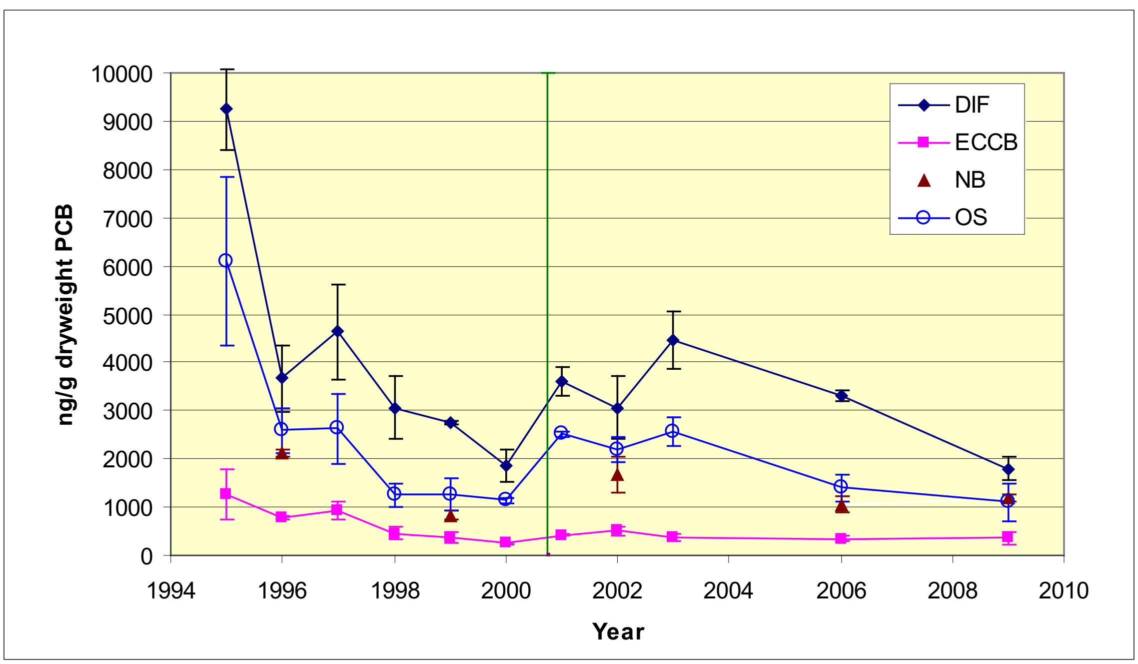


Figure 5-7. PCB levels in flounder livers, 1994–2009. (DIF=Deer Island Flats, ECCB=Eastern Cape Cod Bay, NB=Nantasket Beach, OS=Outfall Site)

Chemistry data for lobster meat and hepatopancreas are quite variable, sometimes the result of one of the seven lobsters making up a replicate having widely different concentrations than the others. The reason for such anomalies is not known.

A 2007 BACI analysis of mussel data, using Cape Cod Bay as a control, shows that there has been a decrease in concentrations of high molecular weight PAHs in mussels deployed at Deer Island Light and an increase in levels deployed at the edge of the outfall mixing zone, particularly in the years immediately after the diversion (Figure 5-8, Kane-Driscoll et al. 2008). These higher levels were still well below those that are harmful to mussels or humans. The lower levels in 2006 and 2009 are the result of the cleaner effluent that has been achieved since 2005.

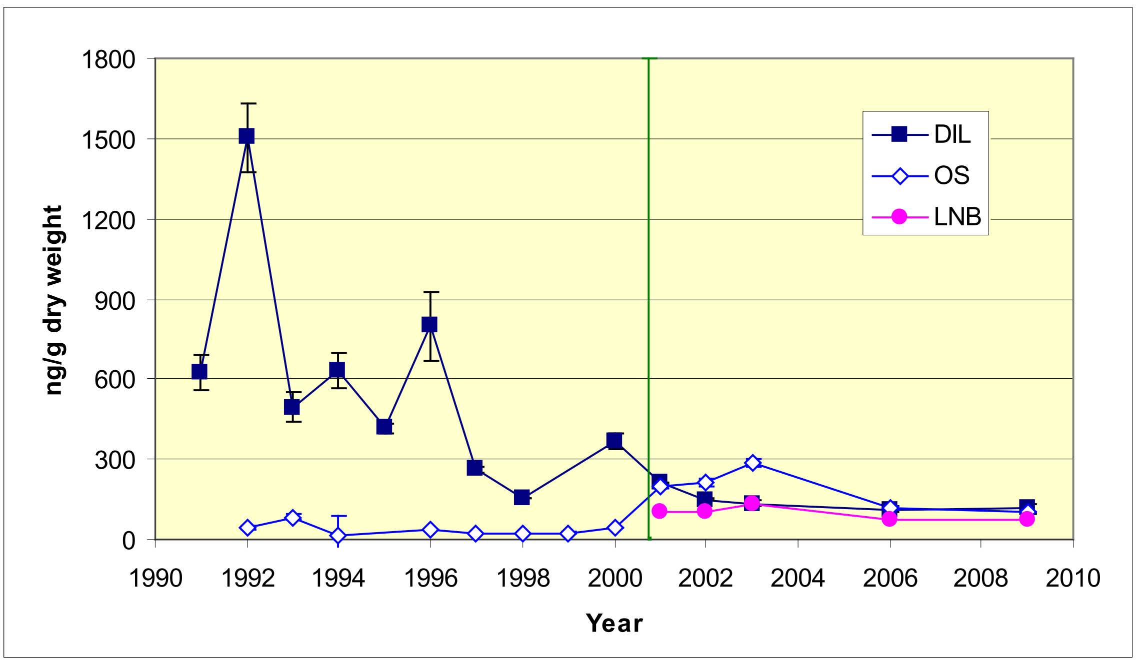


Figure 5-8. High molecular weight PAH levels in mussels deployed at and near the outfall site and at Deer Island Light. (DIL=Deer Island Light, OS=Outfall Site, LNB=Outfall Site B Buoy)

Contingency Plan Thresholds

There were no exceedances of threshold parameters for fish and shellfish in 2009 (Table 5-1). Incidence of CHV, the most common indicator of liver disease in the winter flounder of the region, was 15% in fish taken from the vicinity of the outfall site, lower than the baseline average (the threshold) of 24.4%.

Table 5-1. Contingency Plan threshold values and 2009 results for fish and shellfish monitoring.

Parameter Type/ Location	Parameter	Baseline	Caution Level	Warning Level	2009 Results
Flounder nearfield	Liver disease (CHV)	24.4%	44.9%	None	15%
Flounder tissue nearfield	PCB	0.033 ppm	1 ppm wet weight	1.6 ppm wet weight	0.028 ppm
	Mercury	0.074 ppm	0.5 ppm wet weight	0.8 ppm wet weight	0.09 ppm
Flounder tissue, lipid normalized, nearfield	Chlordane	242 ppb	484 ppb	None	74 ppb
	Dieldrin	63.7 ppb	127 ppb	None	0 ppb
	DDT	775.9 ppb	1552 ppb	None	255 ppb
Lobster tissue nearfield	PCB	0.015 ppm	1 ppm wet weight	1.6 ppm wet weight	0.022 ppm
	Mercury	0.148 ppm	0.5 ppm wet weight	0.8 ppm wet weight	0.09 ppm
Lobster tissue, lipid normalized, nearfield	Chlordane	75 ppb	150 ppb	None	12 ppb
	Dieldrin	161 ppb	322 ppb	None	13 ppb
	DDT	341.3 ppb	683 ppb	None	63 ppb
Mussel tissue nearfield	PCB	0.011 ppm	1 ppm wet weight	1.6 ppm wet weight	0.003 ppm
	Lead	0.415 ppm	2 ppm wet weight	3 ppm wet weight	0.11 ppm
	Mercury	0.019 ppm	0.5 ppm wet weight	0.8 ppm wet weight	0.01 ppm
Mussel tissue, lipid normalized, nearfield	Chlordane	102.3 ppb	205 ppb	None	62 ppb
	Dieldrin	25 ppb	50 ppb	None	0 ppb
	DDT	241.7 ppb	483 ppb	None	87 ppb
	PAH	1080 ppb	2160 ppb	None	1820 ppb

6. Special Studies

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 2009, MWRA continued several special studies. This section updates information on modeling in Massachusetts Bay, water quality monitoring in Boston Harbor, tracking and predicting red tides, marine mammal observations, and nutrient flux at the sediment-water interface.

Model Upgrade

For many years, MWRA has used the numerical Bays Eutrophication Model (BEM) to simulate and predict the physical and biological conditions in Massachusetts Bay. BEM was developed as a combination of the hydrodynamic model ECOMsi (Signell et al. 1996) and the water quality model RCA (HydroQual 2000).

In December 2008, OMSAP agreed to MWRA's recommendation that, subject to testing and evaluation, the hydrodynamic part of BEM be upgraded to the Finite Volume Coastal Ocean Model (FVCOM). FVCOM has several advantages, including being nested within a larger-scale version, which provides suitable outer boundary conditions for Massachusetts Bay (Figure 6-1). Each change in the model configuration was tested to ensure that the results were consistent with past model results (Chen et al. 2009, Chen et al. 2010).

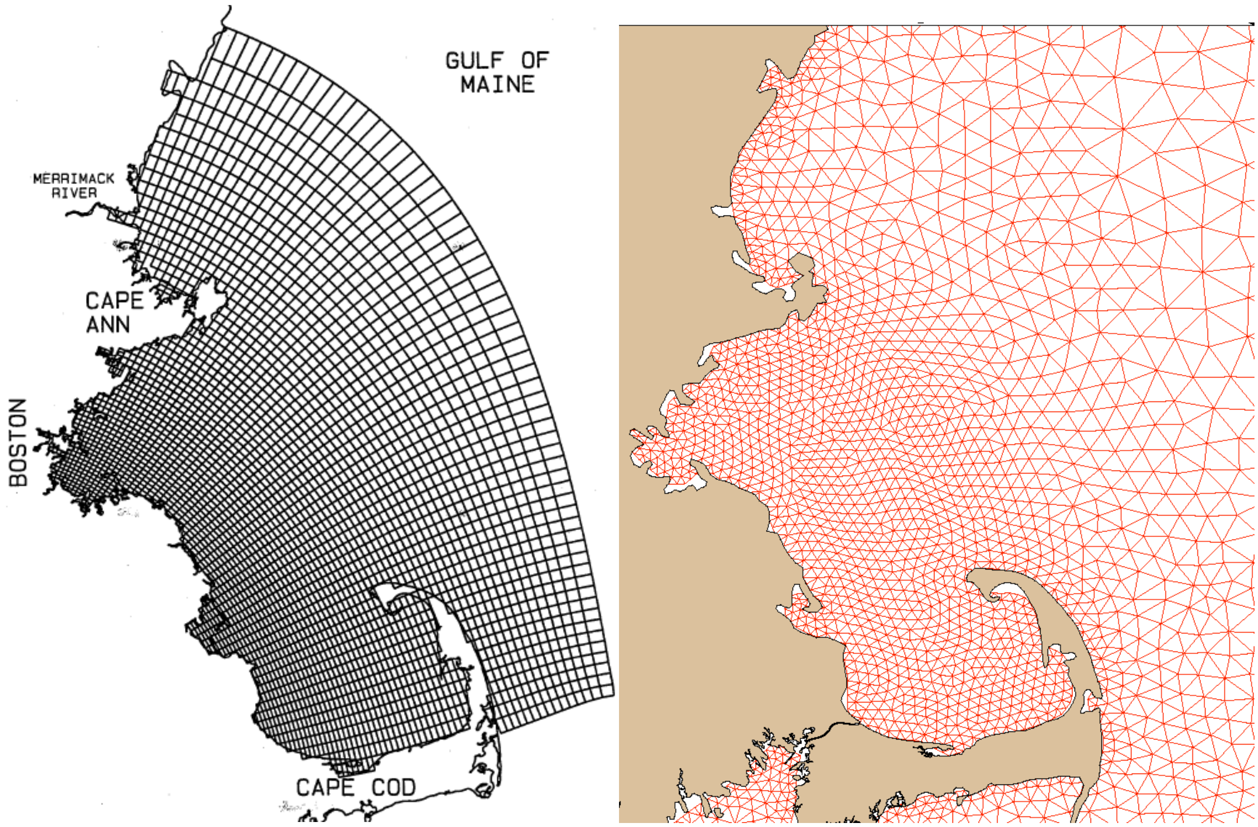


Figure 6-1. The BEM was initially based on a structured grid (left), but has been replaced by an unstructured grid, finite volume model (right), which provides a more accurate fit to the irregular geometry of the coast.

The BEM reproduces the observed seasonal cycles of physical, water quality, and biological variables, including the spring and fall phytoplankton blooms. Using the model, the effects of the MWRA outfall can be isolated by comparing model runs with and without the outfall nutrients included. These sensitivity analyses indicate that the MWRA outfall has very little effect on Massachusetts Bay ecosystem function. Consistent with field observations before and after outfall relocation, effects of the discharge are limited to small, localized increases in dissolved inorganic nitrogen concentrations in the bottom layer (Tian et al. 2009, Chen et al. 2010). Water quality in Massachusetts Bay appears from the modeling studies to be sensitive to the strength and direction of the wind, the timing of upwelling and storm events, and the availability of light and nutrients.

Another sensitivity analysis was conducted (Chen et al. 2010) to determine whether proposed changes to MWRA's monitoring program would compromise the model simulations by reducing the amount of data available to construct boundary conditions. There are only small differences in model predictions when the model input data set has fewer nearfield surveys and fewer farfield stations.

Boston Harbor Water Column Monitoring

Water quality monitoring in Boston Harbor continues to demonstrate improvements in response to decreased loadings of nutrients, total suspended solids, and organic material (Taylor et al. 2010). Nitrogen concentrations, weighted across four regions of the harbor, have declined substantially. Chlorophyll concentrations, measured as chlorophyll-a and phaeophytin, have also declined, particularly in response to the outfall diversion (Figure 6-2). Levels of total suspended solids increased in 2009, although the organic component decreased.

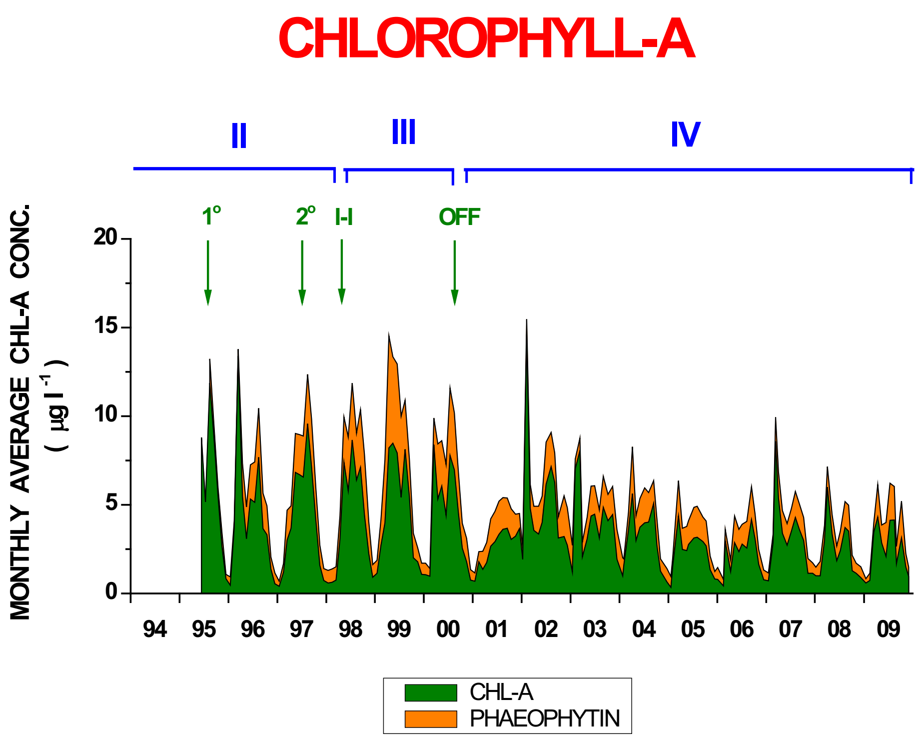


Figure 6-2. Monthly chlorophyll concentrations since 1995, showing decreases, particularly since the outfall relocation to Massachusetts Bay. II=January 1992–April 1998, the period after biosolids discharge to the harbor and ended, upgrades to primary treatment were completed, and secondary treatment was implement. III=April 1998–September 2000, the period beginning with the onset of the inter-island diversion, bringing all sewage influent to DITP. IV=September 2000–December 2009, the period beginning with the diversion of effluent discharge from Boston Harbor to Massachusetts Bay. 1°=upgrade of primary treatment plant, 2°=implementation of secondary treatment, I-I=ending of discharge to the southern harbor with construction of the inter-island tunnel, OFF=ending of effluent discharge to the harbor with the commissioning of the new outfall.

The data suggest that Boston Harbor may be shifting from a system that was regulated by the rate that water was flushed from the system to one that is regulated by the remaining nutrient inputs.

Predicting Red Tides

Since 2005, MWRA has conducted targeted research aimed at understanding and predicting blooms of the red tide dinoflagellate *Alexandrium fundyense*. The studies have been conducted in coordination with the WHOI Gulf of Maine Toxicity (GOMTOX) program, a cooperative observation and modeling effort focused on the Gulf of Maine and the adjacent southern New England coastal region. The GOMTOX studies have identified the abundance of cysts in seed beds off the coast of Maine, coupled with a population-dynamics model, as the best predictor of the magnitude of blooms in the following year.

In 2009, these studies predicted a moderate red tide in Massachusetts Bay. Data from fall 2008 surveys of the seed beds (Figure 6-3, top) were used in a model simulating weather and oceanographic conditions of past years to predict cell abundance for 2009 (Figure 6-3, bottom). Those predictions were realized, with shellfish beds being closed to fishing in May. The bloom ended in early June.

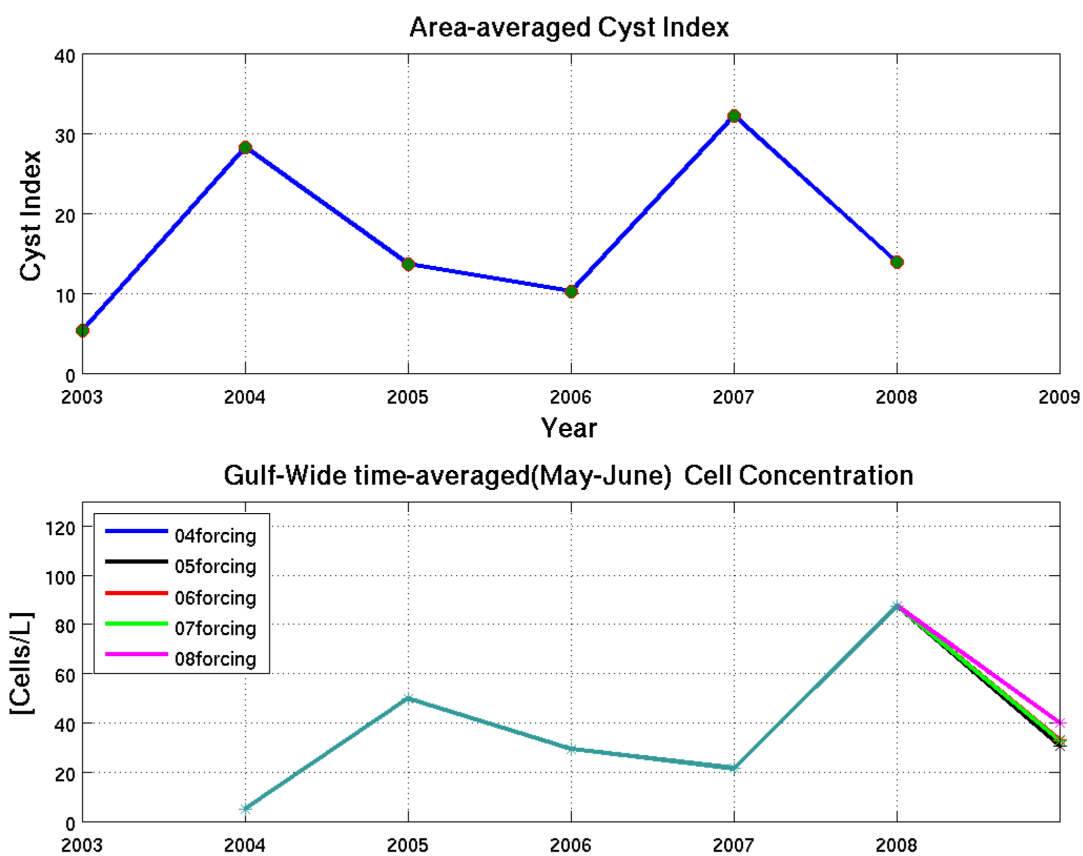


Figure 6-3. Top: Annual abundance of *Alexandrium* cysts in Maine seed beds. Bottom: Annual modeled concentrations of *Alexandrium* cells. Values for 2009 were predicted from 2008 cyst abundance and weather forcing conditions from 2004–2008.

There was a much larger and more sustained red tide in Maine, where persistent winds from the east and northeast resulted in a resurgence in toxicity in late June and early July. The fall cyst count was high, and the cyst seed bed extended farther south than had been previously measured (Figure 6-4).

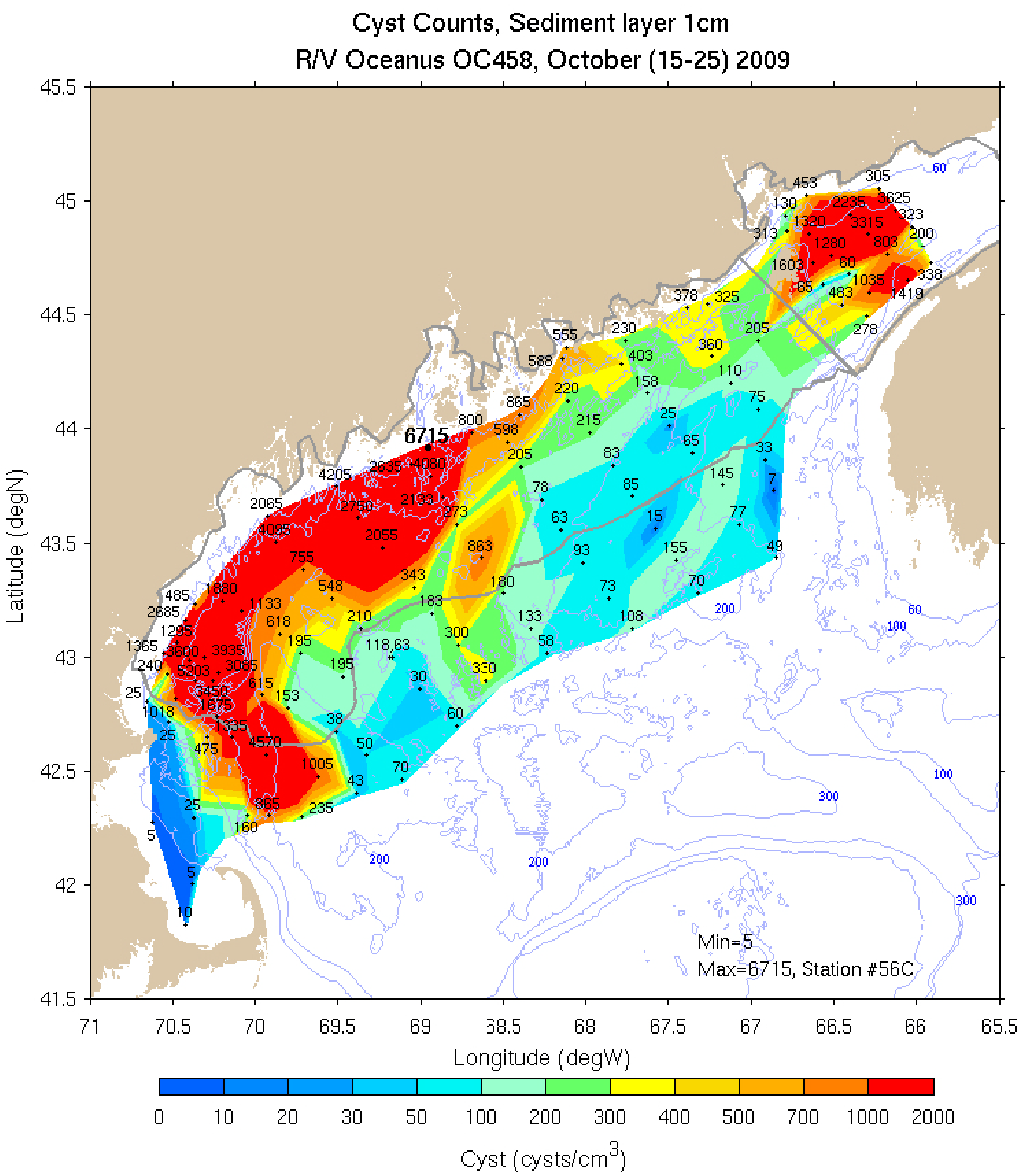


Figure 6-4. Abundance of *Alexandrium* cells in 2009, showing the new extent of cysts into the south.

The research and modeling continues to suggest that the western Gulf of Maine has entered an era of frequent and high-intensity red tides. Prior to 1972, it appears that *Alexandrium* cysts were abundant in the Bay of Fundy but not in the western Gulf of Maine. From 1972, when a large red tide occurred, through the early 1990s, cysts began to accumulate in the western Gulf of Maine, but abundance then waned. During the early years of the MWRA monitoring program, there were few cysts in the western Gulf of Maine, and PSP toxicity resulting from blooms was rare. Since the mid 2000s, cysts have again become abundant in the Gulf of Maine, and significant red tides have occurred.

The timing and geographic progression of the blooms has not been associated with any stimulating effect from the nutrients in the Massachusetts Bay discharge. Additional field and modeling studies are continuing.

Marine Mammal Observations

Several species of endangered or threatened whales and turtles visit Massachusetts and Cape Cod bays, including right, humpback, finback, sei, and, rarely, blue whales. Also seen are the protected, but not endangered, 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 2009, observers were included on all nearfield and farfield water quality surveys (Wu 2010). Besides providing observational data, the presence of trained marine mammal observers addresses a request by the National Marine Fisheries Service that MWRA take active steps to minimize the chances of a collision of one of its survey vessels with a right whale.

During the 2009 surveys, the trained observers and other members of the monitoring team counted 38–39 individual whales, 6–7 Atlantic white-sided dolphin, two unidentified dolphins, and nine harbor porpoises (Figure 6-5). Observers also noted 153 pinniped sightings, including 130 harbor seals and one grey seal. The whales included one right whale, ten humpback whales, and ten minke whales. The 17–18 unidentified species included 11–12 baleen whales. Whale sightings were concentrated in the Stellwagen Bank National Marine Sanctuary. Six whales were counted in the nearfield.

In an independent study, the Provincetown Center for Coastal Studies found that in 2009 right whales were resident in Cape Cod Bay and adjacent waters for 92 days during the winter and spring (Leeney et al.

2009). That project made 354 sightings and counted 196 individual right whales. They matched 187 unique individual whales to photographs of known right whales, comprising 49% of the total known population. Of the 192 individually identified whales that had visited Cape Cod Bay in 2008, 61% were sighted in 2009. Of 29 right whale calves known to have been born in 2009, five were seen with their mothers. Surface-feeding behaviors were observed in March and April.

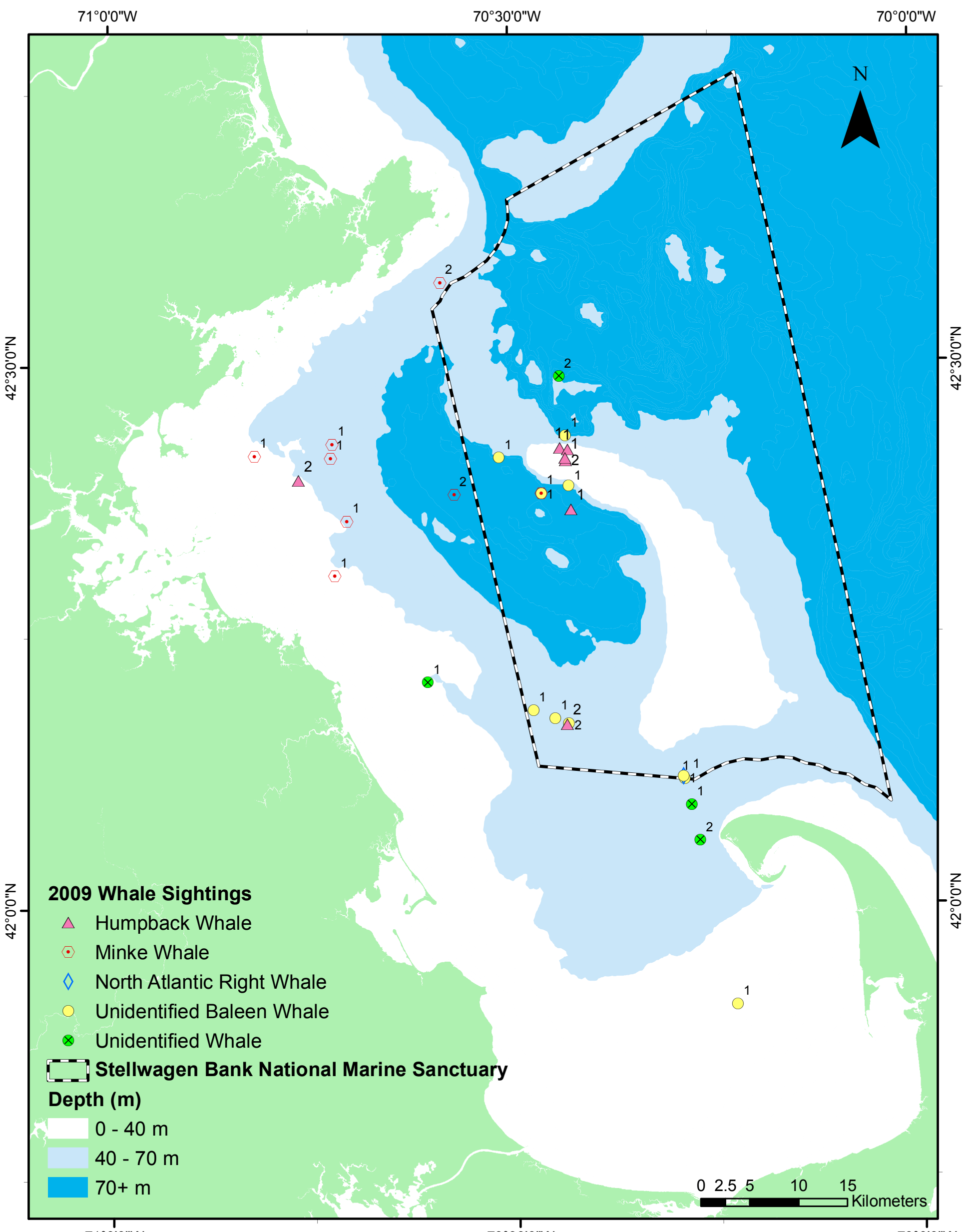


Figure 6-5. Approximate locations of whale sightings during 2009 nearfield and farfield water quality surveys.

Benthic Flux

One concern about the outfall diversion was that increased loads of organic matter might enhance benthic respiration and increase fluxes of nutrients between the sediments and the water column. The resulting higher rates of benthic respiration or sediment oxygen demand might lead in turn to lower levels of oxygen in both the sediments and the water column. In response to these concerns, MWRA has conducted studies of the sediment-water interface in Massachusetts Bay and in Boston Harbor since 1993 (Figure 6-6).

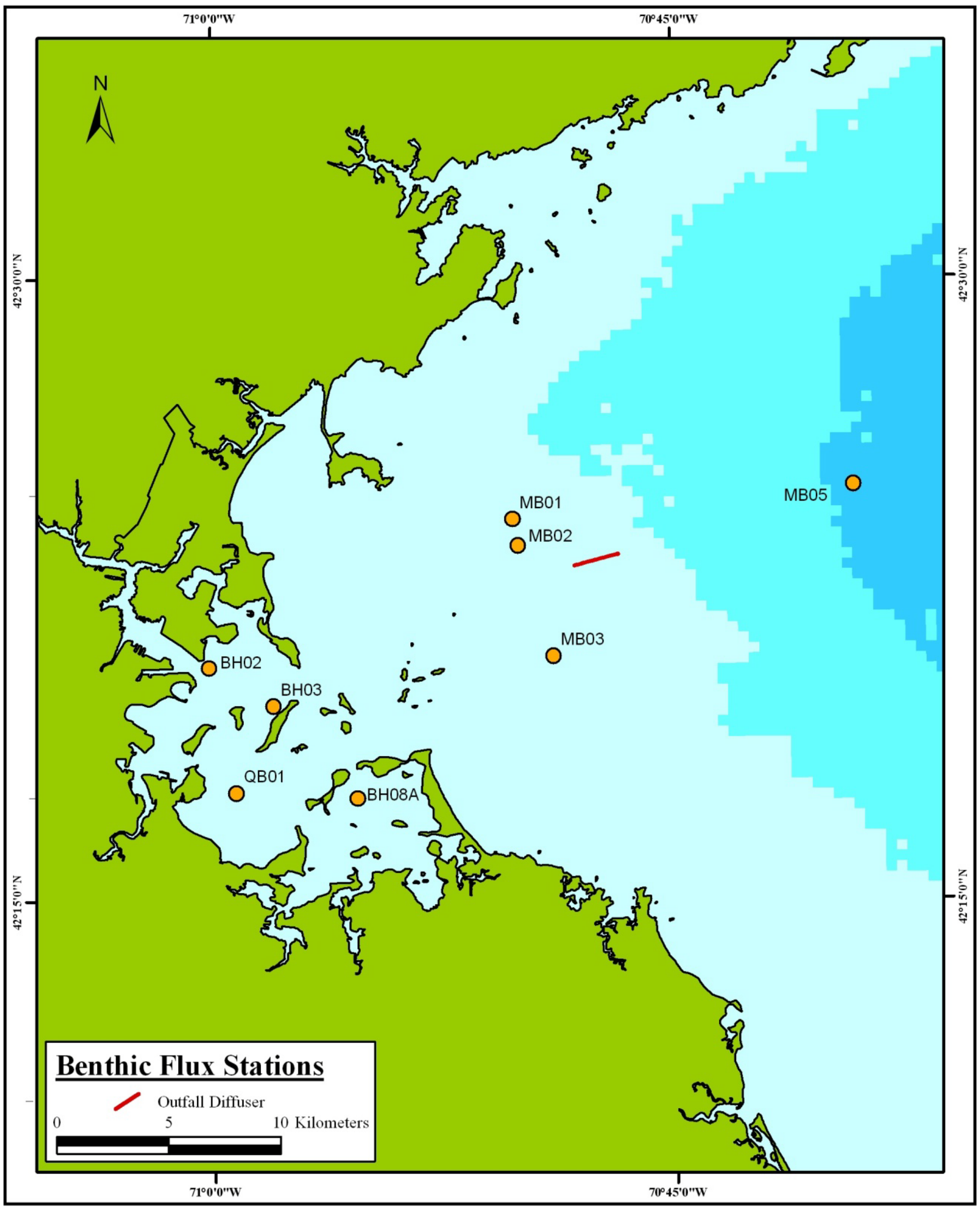


Figure 6-6. Benthic flux stations in Massachusetts Bay and Boston Harbor.

The Massachusetts Bay studies have shown no significant changes from baseline conditions (Tucker et al. 2010). There has been little or no indication of increased deposition of organic matter to the sea floor and no change in the oxidation of the bottom waters or sediments. There have been no increases in sediment oxygen demand and no changes in nutrient fluxes at the Massachusetts Bay stations (Figures 6-7, 6-8). In fact, the overall average nearfield sediment oxygen demand is slightly lower in the post-diversion period. In 2009, the rate of oxygen consumption by the sediments in the nearfield was among the lowest in the monitoring program, possibly because there had been two successive years of relatively little phytoplankton deposition. Dissolved inorganic nitrogen fluxes have also declined and were particularly low in 2008 and 2009. The decline appears to be in the ammonium component of the measurement. Average ammonium flux was 0.6 mmol per m^2 per day during the baseline period and has averaged only 0.2 mmol per m^2 per day during the post-diversion period.

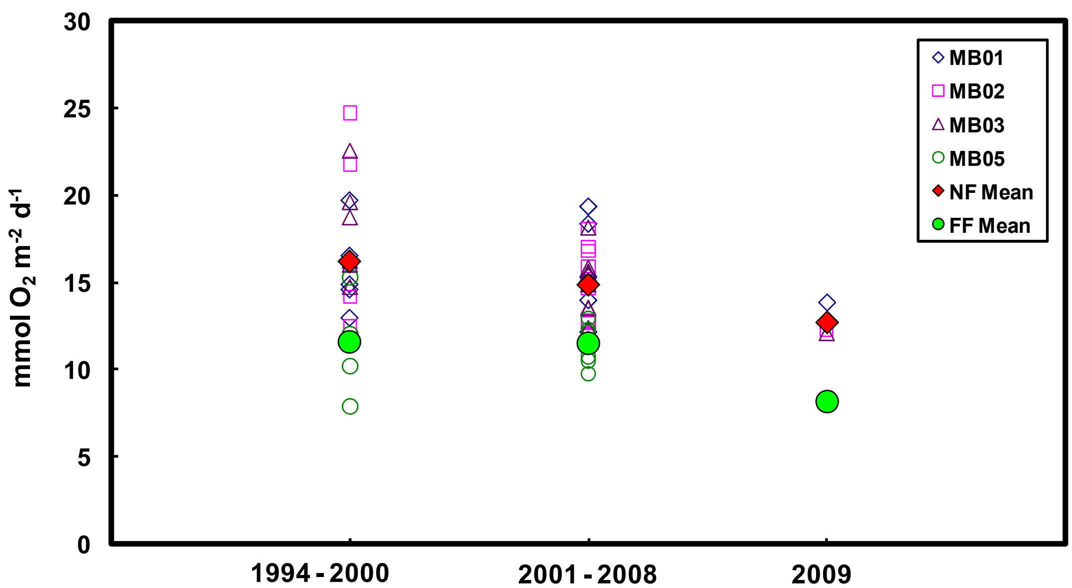


Figure 6-7. Sediment oxygen demand in surface sediments in 2009, compared with baseline (1994–2000) and other post-diversion (2001–2008) years. (NF=nearfield, FF=farfield)

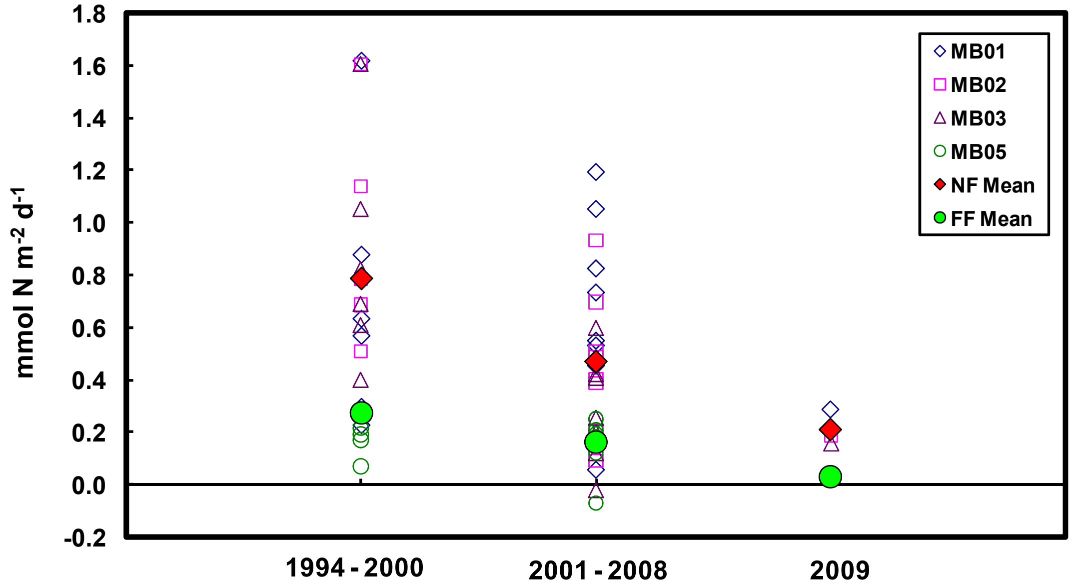


Figure 6-8. Dissolved inorganic nitrogen flux in surface sediments in 2009, compared with baseline (1994–2000) and other post-diversion (2001–2008) years. (NF=nearfield, FF=farfield)

Meanwhile, there have been decreases in fluxes at the four stations in Boston Harbor, reflecting improvements to the benthic environment during those same time periods that are considered important in the evaluation of nutrient loading (see above section on Boston Harbor Water Quality Monitoring). In 2007 and 2008, there were some increases in the processes, with subsequent declines in 2009.

For example, during the first stages of the Boston Harbor Project, sediment oxygen demand measurements at some stations were among the highest reported in the literature. Sediment oxygen demand began to decrease during the baseline period, as sewage biosolids were no longer discharged into the harbor. Declines continued during 2001–2006, increased in 2007 and 2008, and then declined in 2009 (Figure 6-9). The increases in 2007 and 2008 coincided with increased colonization by an amphipod *Leptocheirus pinguis*, which then declined in abundance in 2009 (Figure 6-10). Similar episodes are likely as the harbor continues to recover.

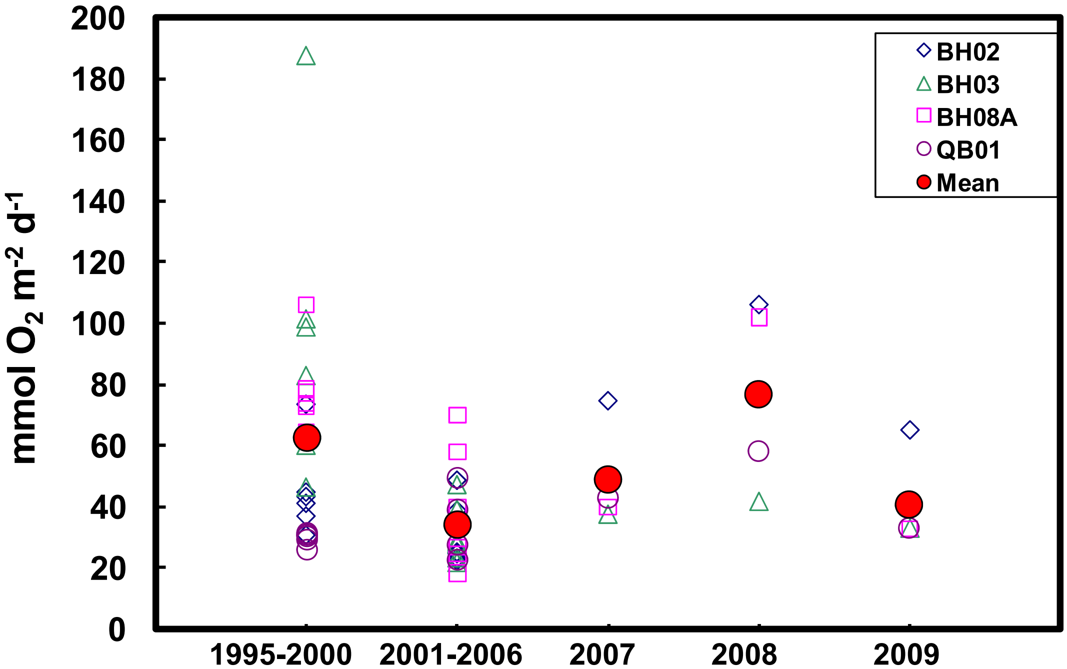


Figure 6-9. Sediment oxygen demand in surface sediments from Boston Harbor in 2009, compared to baseline (1995–2000), early post-diversion (2001–2006), 2007, and 2008. Sediment oxygen demand had already begun to fall during the baseline period.

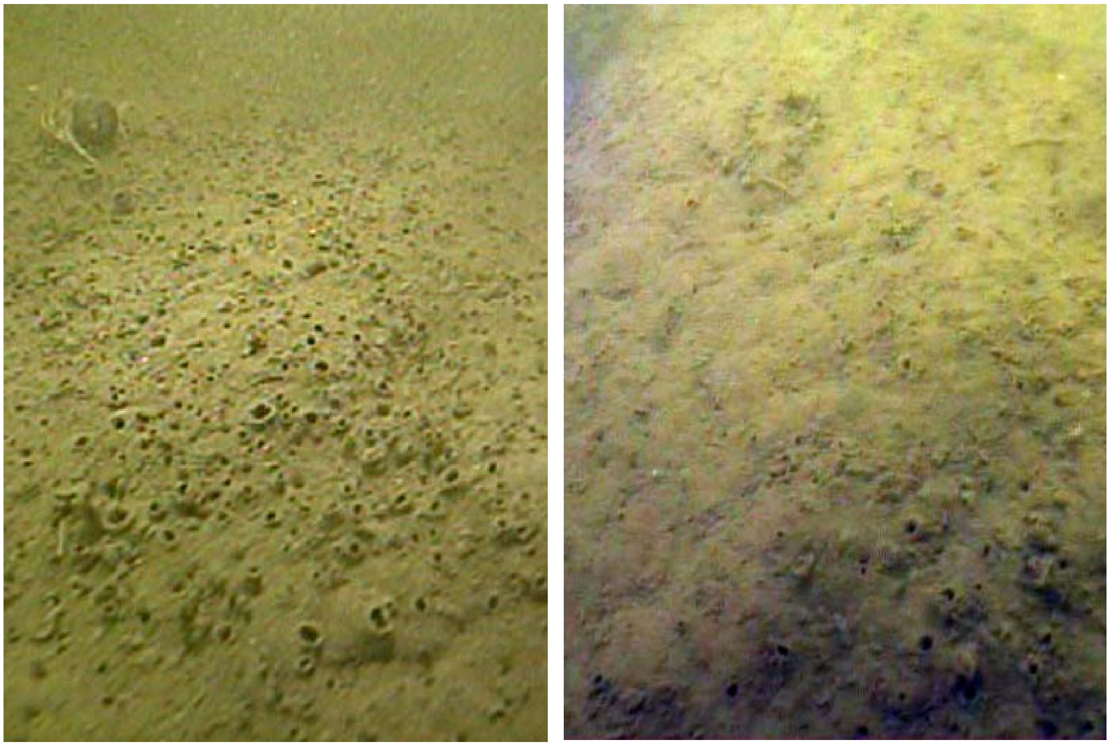
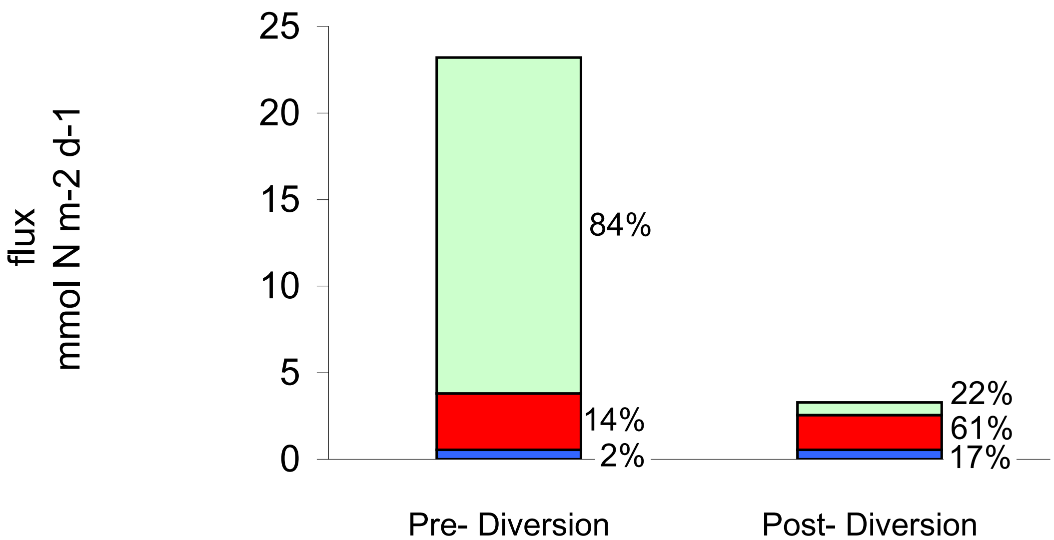


Figure 6-10. Bottom photographs showing heavy colonization of *Leptocheirus pinguis* in 2008 (left) and subsequent decline in 2009 (right). Photographs taken during sediment profile imaging surveys.

The total nitrogen budget for Boston Harbor has changed considerably between the pre-diversion and post-diversion periods (Figure 6-11). During the early years of monitoring, 1991–1994, Kelly (1997) found that about 14% of the total nitrogen load to the harbor was lost to denitrification, and 2% was lost to burial, leaving the bulk of the nitrogen to be lost through export to Massachusetts Bay. During the post-diversion years, total loads have decreased to about 14% of the earlier estimate. Denitrification now removes about 60% of the loads, and losses through export have been greatly reduced.



	Pre- Diversion	Post- Diversion
export	19.41	0.72
denitrification	3.25	2.01
burial	0.55	0.55

Figure 6-11. Pre-diversion and post-diversion nitrogen budgets for Boston Harbor. (Values expressed in mmol nitrogen per m^2 per day.)

7. Stellwagen Bank National Marine Sanctuary

The Gerry E. Studds Stellwagen Bank National Marine Sanctuary protects 842 square miles of open water at the boundary between Massachusetts Bay and the rest of the Gulf of Maine. It includes a part of Stellwagen Basin, which is the deepest part of Massachusetts Bay and a long-term sediment sink. Stellwagen Bank rises to the east of Stellwagen Basin and provides a rich habitat for marine life.

The management plan for the sanctuary (U.S. Department of Commerce 2010) focuses on issues including alteration of ecosystems by cables, pipelines, and fishing gear; introduction of pollutants from sea- and shore-based sources; and disturbance of marine mammals by ship vessels, aircraft, noise, and fishing gear. The NPDES permit to discharge effluent into Massachusetts Bay requires an annual report on possible effects of the discharge on the sanctuary. This section of the outfall monitoring overview meets that requirement.

Water Column

The MWRA outfall is located about nine miles from the sanctuary border, a greater distance than any effects of the discharge have been recorded. Other wastewater treatment plants discharge to the north and south of the sanctuary, and the area receives pollutant inputs from aerial deposition, discharges from commercial and private vessels, dredged material disposal at the Massachusetts Bay Disposal Site, and other sources. However, the overall water quality in the sanctuary remains good. The 2009 MWRA water-quality monitoring measurements at the stations in and near the sanctuary (Figure 7-1) continued to find that dissolved oxygen, nutrient concentrations, and plankton abundances and community measures were within the expected ranges for this region of Massachusetts Bay.

Concentrations of dissolved oxygen and percent saturation have remained unchanged in Stellwagen Basin, as they have in the nearfield (Figure 7-2; see also Figure 3-13 in Section 3, Water Column). Potential decreases in dissolved oxygen concentrations or percent saturation had been a concern before the outfall diversion, but those concerns have not been realized. The 2009 bottom water oxygen concentrations were in the middle of the baseline range.

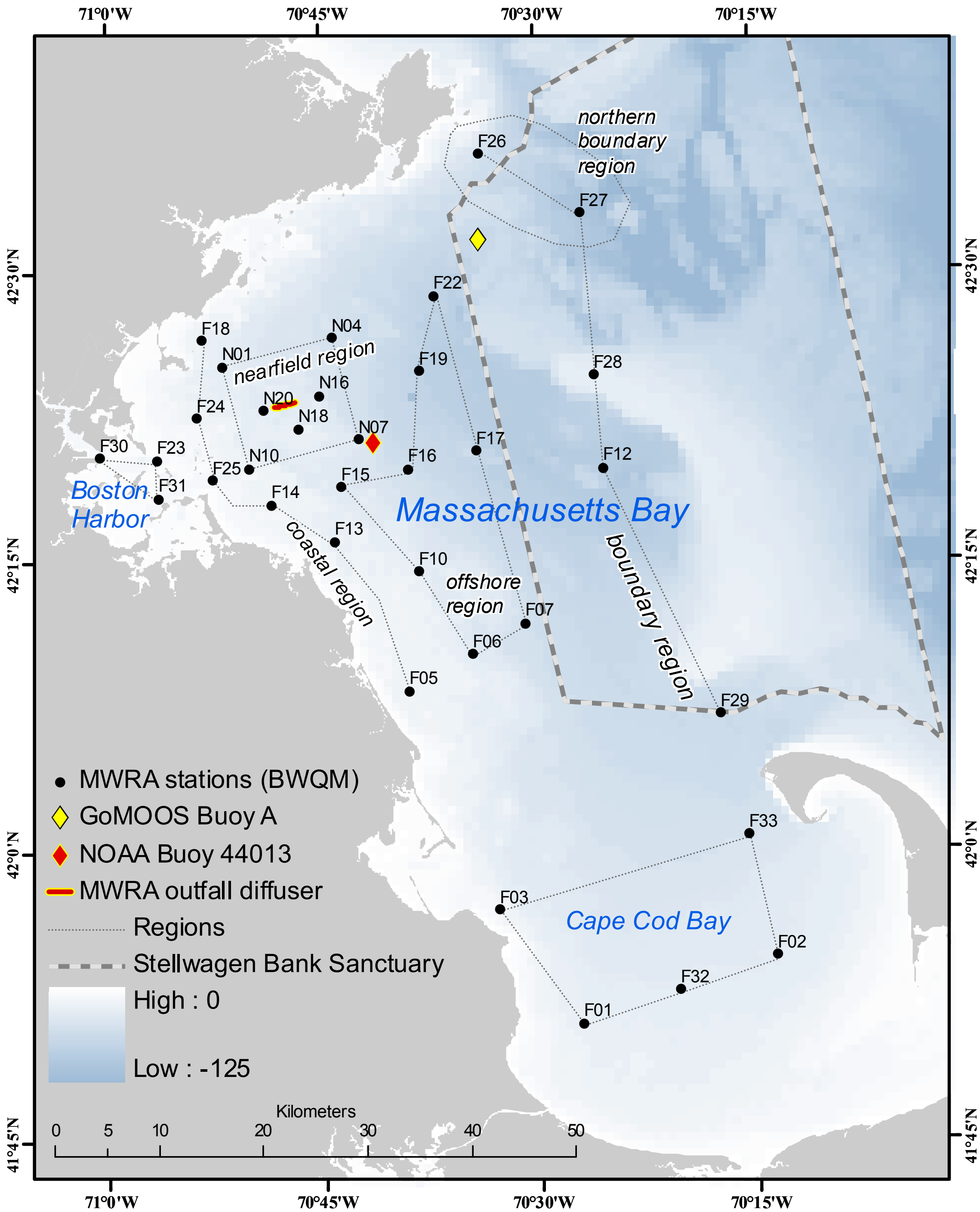


Figure 7-1. Water column stations, including those in and near the Stellwagen Bank National Marine Sanctuary (F27, F28, F12).

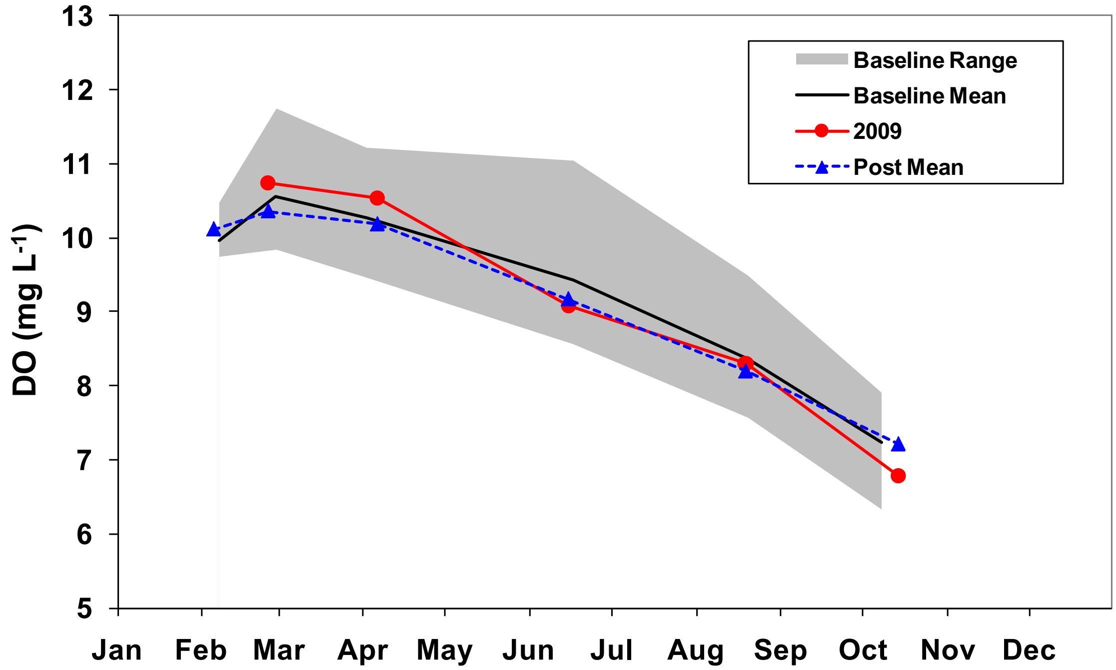


Figure 7-2. 2009 bottom water dissolved oxygen (DO) concentrations in Stellwagen Basin compared to baseline range, baseline mean, and post-diversion mean. There has been no change in patterns of dissolved oxygen concentrations (or saturation) since the outfall diversion.

Annual mean concentrations of nutrients in water samples have varied somewhat over the years, but the changes have not been substantial, and no changes at stations in and near the sanctuary have been attributed to the outfall diversion. Similar patterns have been observed in and near the sanctuary, in the nearfield, and in Cape Cod Bay. Annual mean concentrations of total nitrogen have varied across the study area from year to year, but the pattern is similar among areas (Figure 7-3). Although ammonium levels (Figure 7-4) rose in the nearfield when the outfall first went on line, ammonium concentrations in and near the sanctuary were not similarly affected. Background ammonium levels vary from year to year; the nearfield ammonium levels are elevated above background by about 1µM.

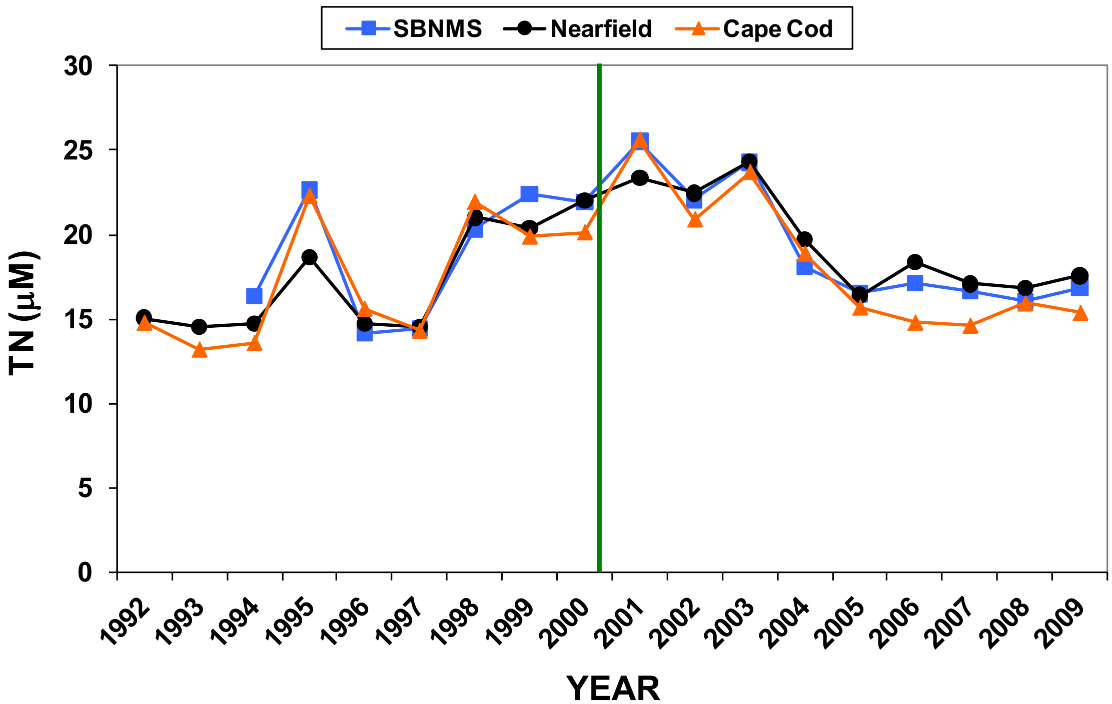


Figure 7-3. Annual mean total nitrogen (TN) at the Stellwagen Bank National Marine Sanctuary (SBNMS), the outfall nearfield, and Cape Cod Bay. Concentrations have varied by year but have been similar across regions. Vertical line indicates when outfall came on-line.

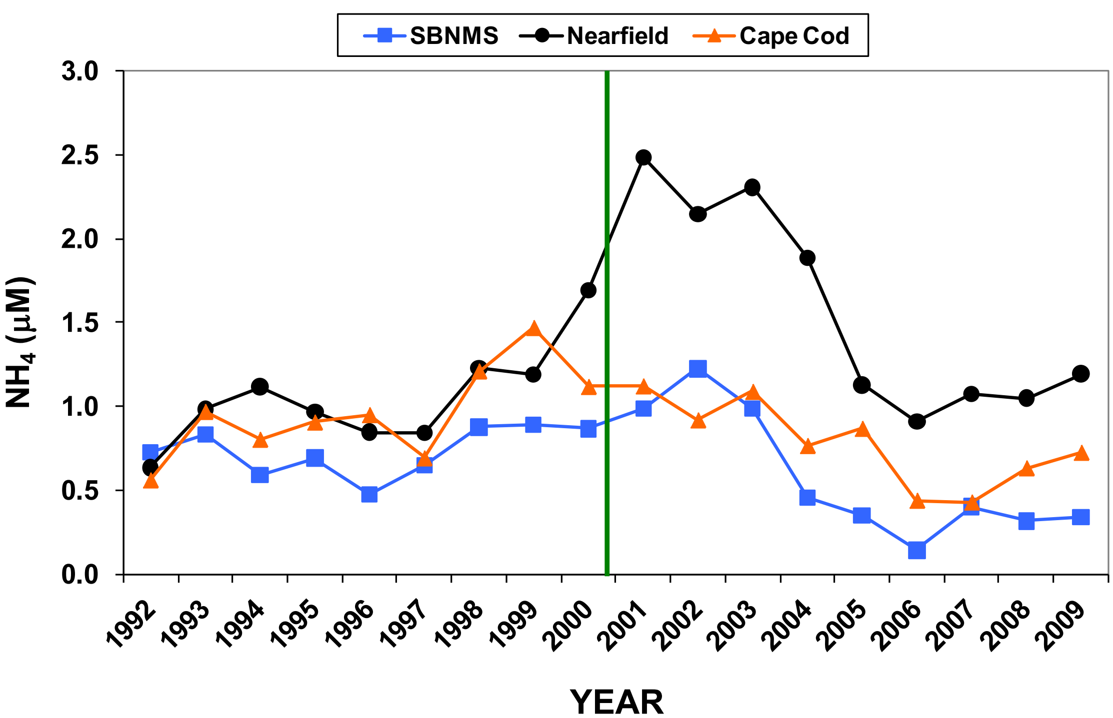


Figure 7-4. Annual mean ammonium at the Stellwagen Bank National Marine Sanctuary (SBNMS), the outfall nearfield, and Cape Cod Bay. Vertical line indicates when outfall came on-line.

Nitrate concentrations (Figure 7-5) continue to be quite variable across all regions. Concentrations of nitrate, as well as silicate and phosphate (not shown), have been consistently higher at stations in and near the sanctuary than at stations in the nearfield or Cape Cod Bay. These higher levels are associated with deeper offshore waters. It is these nutrient-rich bottom waters that feed plankton and small fishes and make Stellwagen Bank a thriving habitat for commercial fishes and whales. There has been a long-term, slight, upward trend in nitrate levels across the regions.

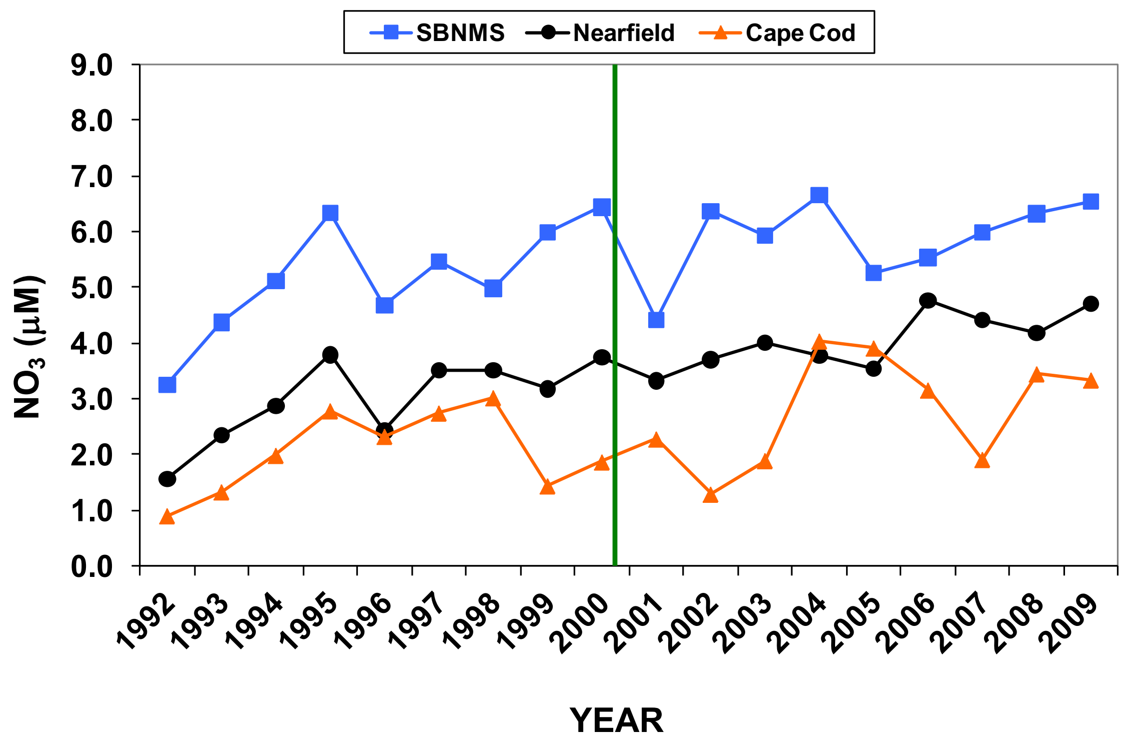


Figure 7-5. Annual mean nitrate at the Stellwagen Bank National Marine Sanctuary (SBNMS), the outfall nearfield, and Cape Cod Bay. Nitrate concentrations are variable, but there have been no changes that can be attributed to the outfall. Vertical line indicates when outfall came on-line.

The annual mean areal chlorophyll levels have varied at the sanctuary stations, the nearfield, and in Cape Cod Bay throughout the monitoring program, but post-diversion levels are not significantly different from the baseline (Figure 7-6). Chlorophyll levels do not correlate with nitrogen and have not changed in response to changes in nutrient inputs.

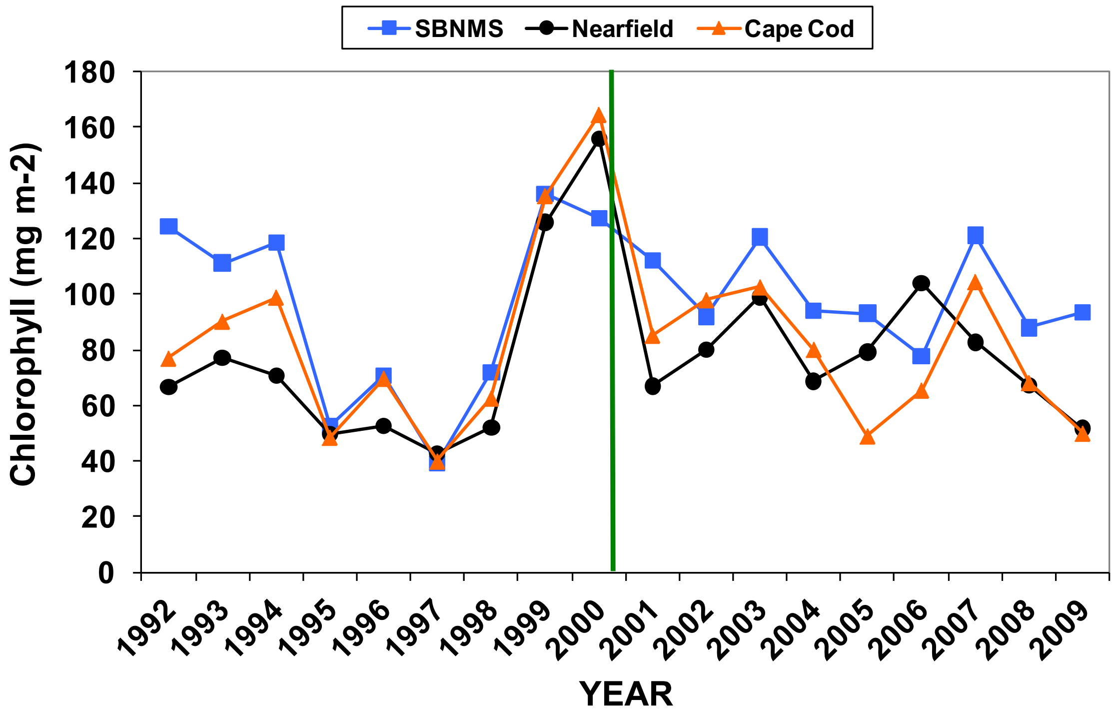


Figure 7-6. Annual chlorophyll at the Stellwagen Bank National Marine Sanctuary (SBNMS), the outfall nearfield, and Cape Cod Bay. Over the course of monitoring, annual chlorophyll levels have varied, but similar patterns have been seen in samples from every region. Vertical line indicates when outfall came on-line.

Sea Floor

No changes in bottom community parameters have been measured within or near the sanctuary since the outfall diversion. Stations FF11 and FF14 were sampled in 2009 (Figure 7-7, Maciolek et al. 2010).

Those deep-water stations continued to support a distinct infaunal community, with recognizable differences from communities in the nearfield and Cape Cod Bay. Benthic community parameters at individual stations showed no pattern of change following the outfall diversion in 2000. The total number of individual organisms per sample has varied widely, but remained within the baseline range for stations in or near the sanctuary in 2009. The numbers of species per sample and the diversity of organisms within the samples were also within the baseline ranges (Figure 7-8). A general increase in number of species, which began during the baseline period and peaked in 2003, is considered to be a result of normal cycling. No patterns that relate to the outfall diversion have been found.

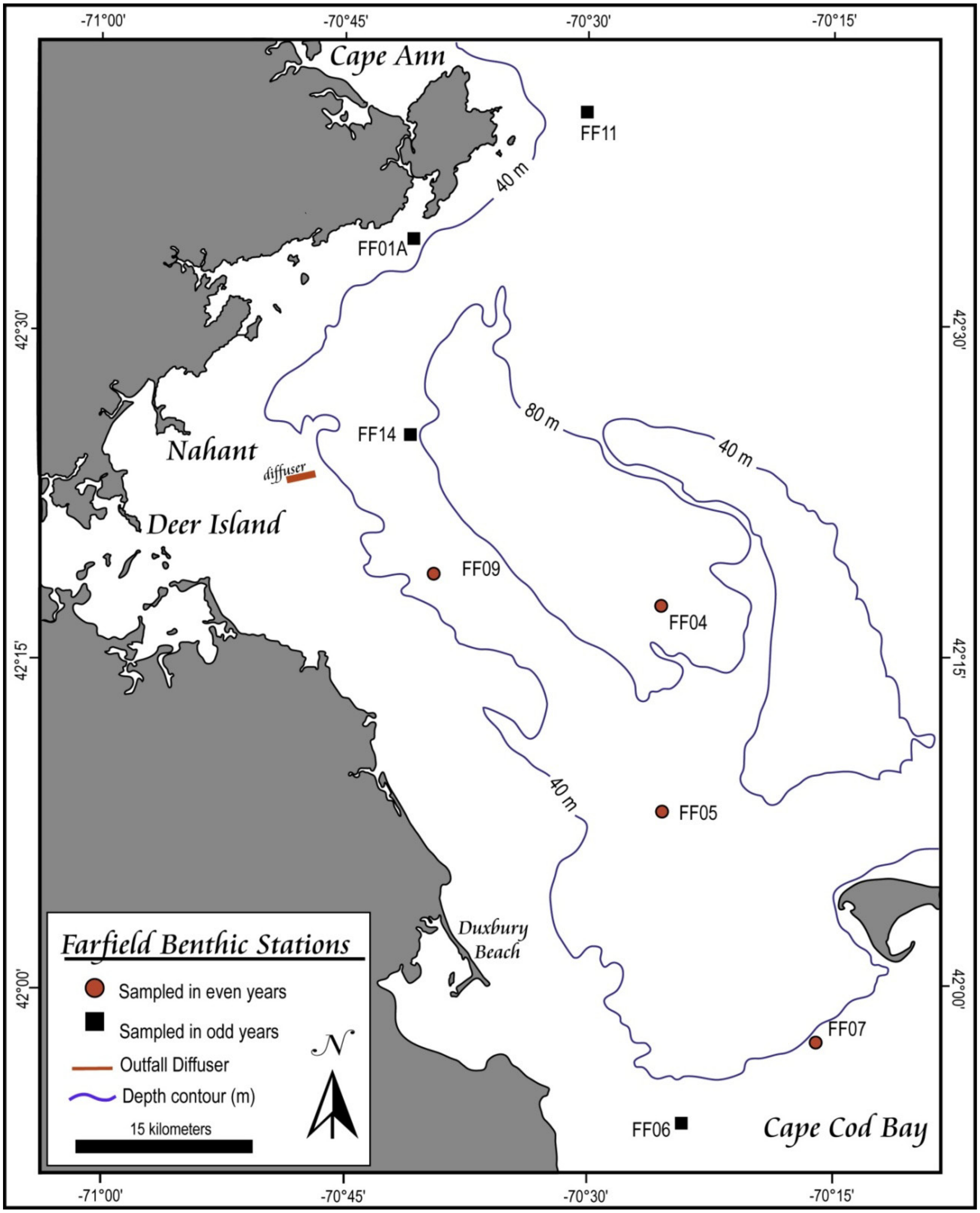
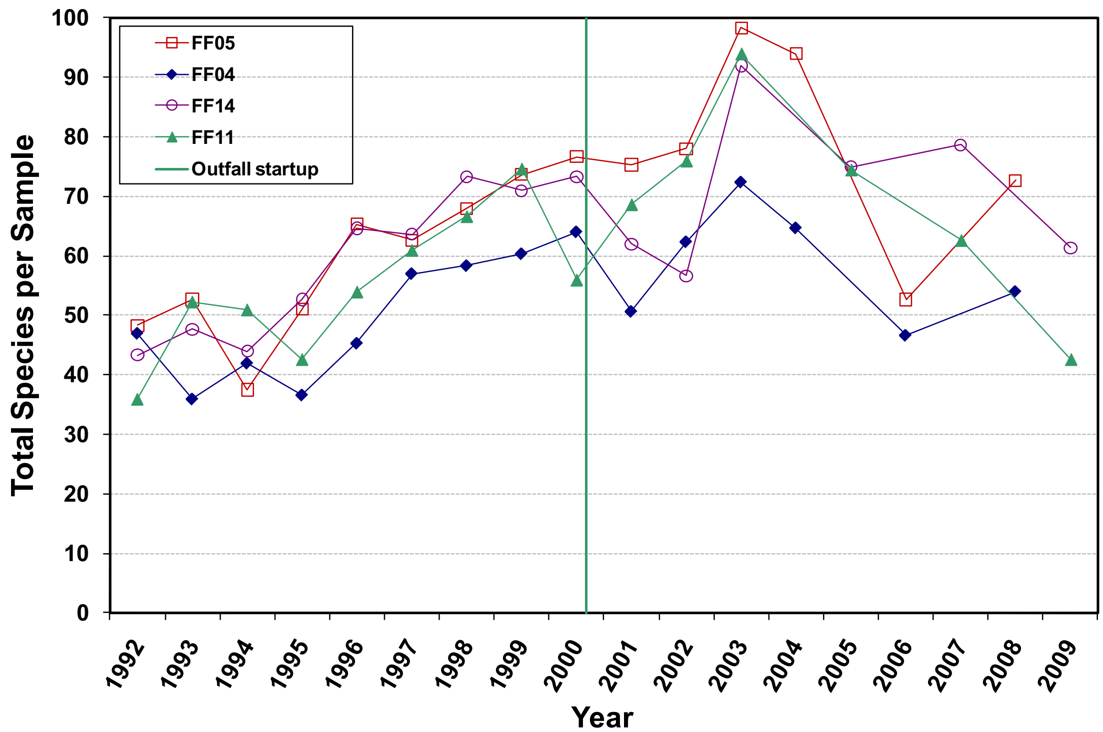


Figure 7-7. Farfield benthic stations. Stations FF04, FF05, FF11, and FF14 are in or near the Stellwagen Bank National Marine Sanctuary. FF11 and FF14 were sampled in 2009.



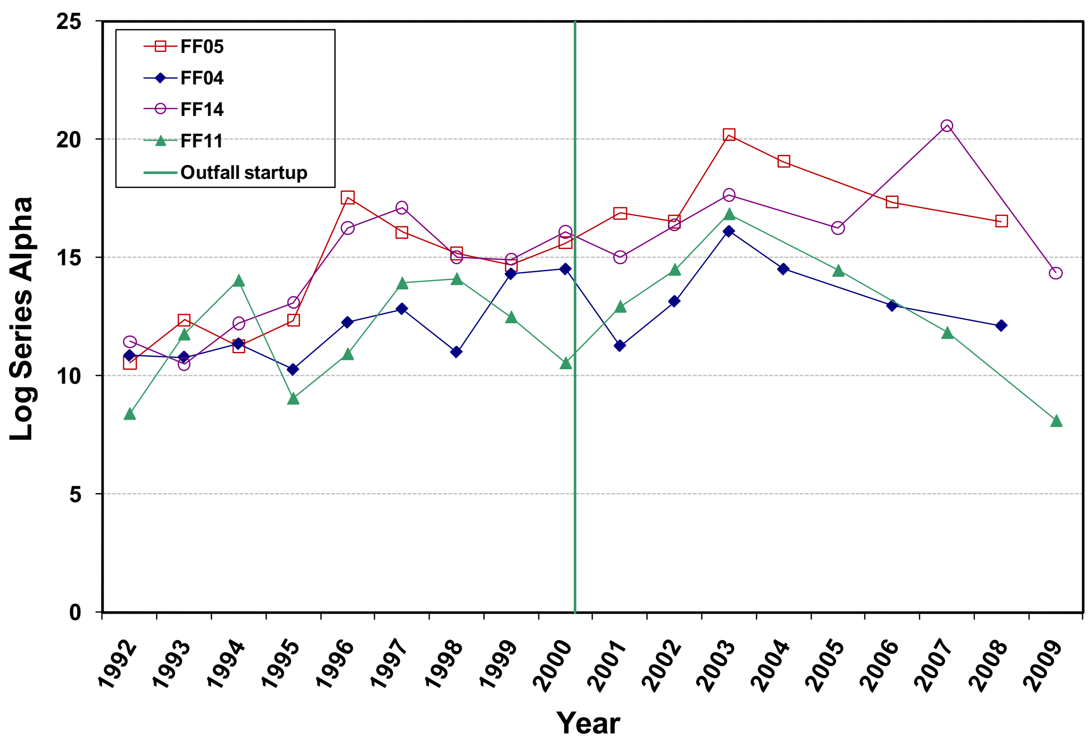


Figure 7-8. Community parameters at stations in or near the Stellwagen Bank National Marine Sanctuary. Top: species richness or number of species per sample; Bottom: Log-series alpha, a measure of diversity.

8. Monitoring Questions and Answers

The monitoring program is based on a series of questions that focused on plausible unanticipated consequences of the diverted effluent discharge on the Massachusetts Bay and Cape Cod Bay ecosystems. Those questions have now been answered (Table 8-1).

Monitoring has confirmed that any effects of the discharge are small and localized. Compliance with effluent permit limits has proven to be the key to ensuring that there are no unanticipated effects. Out of the tens of thousands of measurements that have been made since the Massachusetts Bay outfall began to discharge, there have been only eleven violations of permit limits for effluent (Contingency Plan thresholds exceedances). The exceedances have included failures of four toxicity tests, none of which were attributed to toxic constituents of the effluent; an exceedance of the total suspended solids limits after an industrial discharge caused a disruption of the secondary treatment process; and exceedances of fecal coliform limits during storms.

Water-column monitoring has confirmed that it is possible to detect sewage tracers at stations in the immediate vicinity of the outfall, but there have been no unexpected changes resulting from the relocated discharge. Late summer and fall levels of dissolved oxygen in bottom waters have not been affected by the outfall. Incidence of nuisance algal blooms has increased for some species, but those changes have been regional and not attributed to any nutrient stimulation from the discharge.

Similarly, there have been no unanticipated changes on the sea floor. Elevated concentrations of the sewage tracer *Clostridium perfringens* spores are detected at stations within the immediate vicinity of the outfall, but there are no elevated concentrations of toxic contaminants. The soft- and hard-bottom communities of Massachusetts and Cape Cod bays remain healthy.

There have been no effects on fish or shellfish. Some contaminant levels have been elevated in mussels deployed in the immediate vicinity of the outfall, within the mixing zone. There have been no increases in contaminant levels or disease in the flounder and lobsters included in the monitoring program or in mussels deployed outside the immediate mixing zone.

Table 8-1. Answers to the monitoring questions at the end of 2009.

Monitoring Question	Answer
Do effluent pathogens exceed the permit limits?	No. Secondary treatment and disinfection effectively remove pathogens. In thousands of tests, daily fecal coliform limits have been exceeded twice, both times during storms.
Does acute or chronic toxicity of effluent exceed the permit limit?	No. In more than 500 tests, there have been four exceedances of permit limits.
Do effluent contaminant concentrations exceed permit limits?	No. Discharges of priority pollutants are well below SEIS predictions and in most cases meet receiving water quality criteria even before dilution.
Do conventional pollutants in the effluent exceed permit limits?	No. Discharges of solids and BOD have decreased by 80% compared to the old treatment plant. In more than 500 tests, there have been three exceedances of suspended solids limits, which occurred during an upset of the secondary treatment process by an industrial discharge.
What are the concentrations of contaminants in the influent and effluent and their associated variability?	There has been great success in reducing contaminants in the influent and a high degree of removal of contaminants by the treatment system, with consistently low concentrations since secondary treatment was implemented.
Do levels of contaminants in water outside the mixing zone exceed water quality standards?	No. Water quality standards are not exceeded. The projected degree of mixing was confirmed by plume studies conducted in 2001. Ongoing effluent monitoring assures that standards are not violated.
Are pathogens transported to shellfish beds at levels that might affect shellfish consumer health?	No. Dilution is sufficient for pathogens to reach background concentrations before reaching shellfish beds. Dilution rates were confirmed by plume studies conducted in 2001.
Are pathogens transported to beaches at levels that might affect swimmer health?	No. Dilution is sufficient for pathogens to reach background concentrations before reaching beaches. Dilution rates were confirmed by plume studies conducted in 2001.
Has the clarity and/or color of the water around the outfall changed?	No. Although clarity and color have not changed, there are occasional observations of tiny bits of grease, similar to samples collected at the treatment plant.
Has the amount of floatable debris around the outfall changed?	Floatable debris of concern is rare in the effluent. Signs of effluent can occasionally be detected in the field.
Are the model estimates of short-term (less than one day) effluent dilution and transport accurate?	Yes. Model estimates were confirmed by plume studies conducted in 2001.
What are the nearfield and farfield water circulation patterns?	Flow is controlled by general circulation in the Gulf of Maine and influenced by tides and local wind. Bottom currents around the outfall can flow in any direction with no mean flow direction.

Monitoring Question	Answer
What is the farfield fate of dissolved, conservative, or long-lived effluent constituents?	There have been no detectable changes in the farfield. Changes in salinity and dissolved components of the effluent are not detected within tens of meters of outfall and not observed in farfield water or sediments.
Have nutrient concentrations changed in the water near the outfall; have they changed at farfield stations in Massachusetts Bay or Cape Cod Bay, and, if so, are they correlated with changes in the nearfield?	Changes have been consistent with model predictions. The effluent signature is observed in the vicinity of the outfall but is quickly diluted.
Do the concentrations (or percent saturation) of dissolved oxygen in the water column meet the state water quality standards?	Yes. Conditions are unchanged from the baseline.
Have the concentrations (or percent saturation) of dissolved oxygen in the vicinity of the outfall or at selected farfield stations in Massachusetts Bay or Cape Cod Bay changed relative to pre-discharge baseline or a reference area? If so, can changes be correlated with effluent or ambient water nutrient concentrations, or can farfield changes be correlated with nearfield changes?	No. Conditions have not changed from the baseline.
Has the phytoplankton biomass changed in the vicinity of the outfall or at selected farfield stations in Massachusetts Bay or Cape Cod Bay, and, if so, can these changes be correlated with effluent or ambient water nutrient concentrations, or can farfield changes be correlated with nearfield changes?	No. No substantial change 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?	Productivity patterns in Boston Harbor may be changing, as the area transitions from eutrophic conditions to a more typical coastal regime. There has been no concurrent increase in productivity in Massachusetts Bay.
Has the abundance of nuisance or noxious phytoplankton changed in the vicinity of the outfall?	The frequency of *Phaeocystis* blooms has increased, but the phenomenon is regional in nature. *Alexandrium* blooms, which have occurred since 2005, are regional and have not been attributed to the outfall.
Has the species composition of phytoplankton or zooplankton changed in the vicinity of the outfall or at selected farfield stations in Massachusetts Bay or Cape Cod Bay? If so, can these changes be correlated with effluent of ambient water nutrient concentrations, or can farfield changes be correlated with nearfield changes?	The increase in frequency of *Phaeocystis* blooms is the most marked change in the phytoplankton community, and the region appears to be entering a period of frequent red tides. Those changes have not been attributed to the outfall. There have been no marked changes in the zooplankton community.
What is the level of sewage contamination and its spatial distribution in Massachusetts and Cape Cod bays sediments before discharge through the new outfall?	The effects of historic inputs from Boston Harbor and other sources can be detected, particularly in coastal stations.

Monitoring Question	Answer
Has the level of sewage contamination or its spatial distribution in Massachusetts and Cape Cod bays sediments changed after discharge through the new outfall?	An effluent signal can be detected only in *Clostridium perfringens* spores, the most sensitive sewage tracer, and is only detectable within a few kilometers of the outfall.
Has the concentration of contaminants in sediments changed?	There has been no general increase in contaminants. An effluent signal can be detected as *Clostridium perfringens* spores within 2 km of the diffuser.
Has the soft-bottom community changed?	Changes have occurred but are the result of natural variation. The changes are not significant and are not attributed to the outfall.
Have the sediments become more anoxic; that is, has the thickness of the sediment oxic layer decreased?	No. The sediment RPD has been deeper during post-diversion years rather than shallower; that is, the sediments are more rather than less oxic.
Are any benthic community changes correlated with changes in levels of toxic contaminants (or sewage tracers) in sediments?	There have been no changes detected, even within 2 km of the outfall.
Has the hard-bottom community changed?	There have been no changes that can be attributed to the outfall. There have been decreases in coralline algae at some stations, but the geographic pattern does not suggest an outfall effect.
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?	These conditions were described by baseline monitoring.
Have the rates of these processes changed?	Conditions have improved in Boston Harbor and have not changed in Massachusetts Bay.
Has the level of contaminants in the tissues of fish and shellfish around the outfall changed since discharge began?	There has been no substantial change in flounder or lobster contaminant body burdens, with concentrations remaining very low. There have been detectable increases in concentrations of some contaminants in mussel arrays deployed within the mixing zone at the outfall.
Do the levels of contaminants in the edible tissue of fish and shellfish around the outfall represent a risk to human health?	There have been no changes that would pose a threat to human health. Regional patterns have persisted since the baseline period, and there appears to be a general long-term downward trend for most contaminant levels.
Are the contaminant levels in fish and shellfish different between the outfall, Boston Harbor, and a reference site?	Differences were documented during baseline monitoring. Regional patterns have persisted since the diversion, with concentrations being highest in Boston Harbor and lowest in Cape Cod Bay.
Has the incidence of disease and/or abnormalities in fish or shellfish changed?	There have been no increases in disease or abnormalities in response to the outfall; there has been a long-term downward trend in liver disease in fish from near Deer Island and near the outfall.

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List of Acronyms

BACI	Before-After, Control-Impact analysis
BEM	Bays Eutrophication Model
BOD	Biochemical oxygen demand
cBOD	Carbonaceous biochemical oxygen demand
BWQM	Bay Water Quality Monitoring
CHV	Centrotubular hydropic vacuolation
DDE	Dichlorodiphenylethylene
DDT	Dichlorodiphenyltrichloroethane
DEP	Massachusetts Department of Environmental Protection
DIF	Deer Island Flats
DIL	Deer Island Light
DITP	Deer Island Treatment Plant
DO	Dissolved oxygen
ECCB	Eastern Cape Cod Bay
EPA	U.S. Environmental Protection Agency
ER-L	Effects range-low
FF	Farfield
FVCOM	Finite Volume Coastal Ocean Model
GoMOOS	Gulf of Maine Ocean Observation System
GOMTOX	Gulf of Maine Toxicity
HMW	High molecular weight
IAAC	Inter-Agency Advisory Committee
LC50	50% mortality concentration
LMW	Low molecular weight
LNB	Outfall site B Buoy
MB	Massachusetts Bay
MGD	Million gallons per day
MWRA	Massachusetts Water Resources Authority
NA	Not analyzed/not applicable
NERACOOS	Northeastern Regional Association of Coastal Ocean Observing Systems
NB	Nantasket Beach
NDBC	National Data Buoy Center
NF	Nearfield
NOAA	National Oceanic and Atmospheric Administration
NOEC	No observed effects concentration
NPDES	National Pollutant Discharge Elimination System
OMSAP	Outfall Monitoring Science Advisory Panel
OS	Outfall site
OSI	Organism sediment index
OSM	Outfall site
PAH	Polycyclic aromatic hydrocarbon
PCB	Polychlorinated biphenyl
PIAC	Public Interest Advisory Committee
PSP	Paralytic shellfish poisoning
RPD	Redox potential discontinuity
SBNMS	Stellwagen Bank National Marine Sanctuary
SEIS	Supplemental Environmental Impact Statement
SPI	Sediment profile imagery
TKN	Total Kjeldahl nitrogen
WHOI	Woods Hole Oceanographic Institution

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