2007 outfall monitoring overview
RESULTS

Massachusetts Water Resources Authority

Environmental Quality Department

Report 2008-17

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2007
Outfall Monitoring Overview
RESULTS

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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 sewage effluent outfall. The report includes data collected through effluent, water-column, sea-floor, and fish-and-shellfish monitoring. It presents information relevant to the MWRA Contingency Plan, including threshold exceedances, responses, and corrective actions.

This year's outfall monitoring overview presents monitoring program results for effluent and field data from 2007, marking seven full years since discharge was diverted from the shallower, more confined waters of Boston Harbor to the deeper waters of Massachusetts Bay (post-diversion monitoring). It compares all results to Contingency Plan thresholds. The overview also includes sections on special studies and the Stellwagen Bank National Marine Sanctuary.

Concentrations of most contaminants in the effluent continued to fall in 2007. Solids, biological oxygen demand, and total metals loads reached new lows. Once used as a sewage-effluent tracer, silver is now only rarely detected in the effluent. Total nitrogen loads, which are not as effectively removed from effluent as organic matter, and toxic contaminants, have remained about the same as the past few years.

There was one Contingency Plan caution level threshold exceedance during the year (Table 1). It came in water-column monitoring, when the nearfield mean winter/spring concentration of the nuisance algal species *Phaeocystis pouchetii* reached 2.15 million cells per liter, exceeding the caution level of 2.02 million cells per liter. The wide geographical extent of the *Phaeocystis* blooms that have occurred each year since 2000 suggests that regional processes, rather than the outfall, have been responsible for the increasing frequency and duration of *Phaeocystis* blooms. There were no exceedances of effluent, sea-floor, or fish-and-shellfish thresholds. There have been no exceedances of threshold parameters for the sea floor throughout the duration of the monitoring program, and no threshold exceedances have been attributed to unexpected adverse effects of the outfall discharge.

Special studies in 2007 included assessments of floatable debris in the effluent and ambient waters near the outfall; ongoing study of nutrient flux at the sediment-water interface; marine mammal observations; evaluation of the fish-and-shellfish monitoring program; assessment of the effects of combined sewer overflows on Boston Harbor sediments; and compilation of results from bacteria monitoring in the harbor and its tributary rivers.

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.

Table 1. Summary of Contingency Plan thresholds and exceedances as of 2007*. (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
Effluent									
	pH	**W**	✔	✔	✔	✔	✔	✔	✔
	Fecal coliform bacteria, monthly	✔	✔	✔	✔	✔	✔	✔	✔
	Fecal coliform bacteria, weekly	✔	✔	✔	✔	✔	✔	✔	✔
	Fecal coliform bacteria, daily	✔	**W**	✔	✔	**W**	✔	✔	✔
	Fecal coliform bacteria, 3 consecutive days	✔	✔	✔	✔	✔	✔	✔	✔
	Chlorine residual, daily	**W**	✔	✔	✔	✔	✔	✔	✔
	Chlorine residual, monthly	✔	✔	✔	✔	✔	✔	✔	✔
	Total suspended solids, weekly	✔	✔	**W**	✔	✔	✔	✔	✔
	Total suspended solids, monthly	✔	✔	**W**	✔	✔	✔	✔	✔
	cBOD, weekly	✔	✔	✔	✔	✔	✔	✔	✔
	cBOD, monthly	✔	✔	✔	✔	✔	✔	✔	✔
	Acute toxicity, mysid shrimp	✔	✔	✔	✔	✔	✔	✔	✔
	Acute toxicity, fish	✔	✔	✔	✔	✔	✔	✔	✔
	Chronic toxicity, fish	✔	**W**	✔	✔	✔	✔	**W**	✔
	Chronic toxicity, sea urchin	✔	**W**	✔	✔	✔	**W**	✔	✔
	PCBs	✔	✔	✔	✔	✔	✔	✔	✔
	Plant performance	✔	✔	✔	✔	✔	✔	✔	✔
	Flow	NA	✔	✔	✔	✔	✔	✔	✔
	Total nitrogen load	NA	✔	✔	✔	✔	✔	✔	✔
	Floatables	NA	NA	NA	NA	NA	NA	NA	NA
	Oil and grease	✔	✔	✔	✔	✔	✔	✔	✔

Table 1, (continued)

Location/ Parameter Type	Parameter	2000	2001	2002	2003	2004	2005	2006	2007
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 *Pseudonitzchia*	Winter/spring	NA	✓	✓	✓	✓	✓	✓	✓
	Summer	NA	✓	✓	✓	✓	✓	✓	✓
	Autumn	✓	✓	✓	✓	✓	✓	✓	✓
Nearfield nuisance algae *Alexandrium*	Any sample	✓	✓	✓	✓	✓	C	C	✓
Farfield shellfish	PSP toxin extent	✓	✓	✓	✓	✓	✓	✓	✓
Plume	Initial dilution	NA	✓	Complete					

Table 1, (continued)

Location/ Parameter Type	Parameter	2000	2001	2002	2003	2004	2005	2006	2007
Sea Floor									
Nearfield sediment contaminants	Acenaphthene	NA	✓	✓	NA	NA	✓	NA	NA
	Acenaphylene	NA	✓	✓	NA	NA	✓	NA	NA
	Anthracene	NA	✓	✓	NA	NA	✓	NA	NA
	Benzo(a)anthracene	NA	✓	✓	NA	NA	✓	NA	NA
	Benzo(a)pyrene	NA	✓	✓	NA	NA	✓	NA	NA
	Cadmium	NA	✓	✓	NA	NA	✓	NA	NA
	Chromium	NA	✓	✓	NA	NA	✓	NA	NA
	Chrysene	NA	✓	✓	NA	NA	✓	NA	NA
	Copper	NA	✓	✓	NA	NA	✓	NA	NA
	Dibenzo(a,h)anthracene	NA	✓	✓	NA	NA	✓	NA	NA
	Fluoranthene	NA	✓	✓	NA	NA	✓	NA	NA
	Fluorene	NA	✓	✓	NA	NA	✓	NA	NA
	Lead	NA	✓	✓	NA	NA	✓	NA	NA
	Mercury	NA	✓	✓	NA	NA	✓	NA	NA
	Naphthalene	NA	✓	✓	NA	NA	✓	NA	NA
	Nickel	NA	✓	✓	NA	NA	✓	NA	NA
	p,p'-DDE	NA	✓	✓	NA	NA	✓	NA	NA
	Phenanthrene	NA	✓	✓	NA	NA	✓	NA	NA
	Pyrene	NA	✓	✓	NA	NA	✓	NA	NA
	Silver	NA	✓	✓	NA	NA	✓	NA	NA
	Total DDTs	NA	✓	✓	NA	NA	✓	NA	NA
	Total HMW PAH	NA	✓	✓	NA	NA	✓	NA	NA
	Total LMW PAH	NA	✓	✓	NA	NA	✓	NA	NA
	Total PAHs	NA	✓	✓	NA	NA	✓	NA	NA
	Total PCBs	NA	✓	✓	NA	NA	✓	NA	NA
	Zinc	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)

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

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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. For most of those years, the efforts have included a monitoring program in Massachusetts Bay. Results from most of the baseline-monitoring years and each post-diversion year (those years since MWRA ended discharges into Boston Harbor and began to discharge treated effluent into Massachusetts Bay), have been documented in annual reports such as this one, the **outfall monitoring overview**. Overviews for 1994 through 1999 included only baseline information. With the outfall operational as of September 2000, subsequent reports have included information relevant to the outfall permit, such as Contingency Plan threshold exceedances, responses, and corrective actions.

After nine years of baseline monitoring and seven years of post-diversion monitoring, MWRA has answered the questions that had been posed before the start-up of the Massachusetts Bay outfall. As had been anticipated during the outfall-siting process, monitoring has been able to detect minimal effects in the immediate vicinity of the outfall, but there has been no indication of unexpected or broad-range changes.

Having answered the initial questions, MWRA has entered a new phase of monitoring. While continuing to focus on verifying that the treatment plant is working as designed, MWRA is also striving to anticipate potential new challenges. A part of this new phase has been to streamline the annual outfall monitoring overview. While past overviews included background information and a full description of the monitoring program, that information has now been put into a separate document (Werme and Hunt 2008). That document and the monitoring plans (MWRA 1991, 1997a, 2004), the Contingency Plan (MWRA 1997b, 2001), 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 .

This year's outfall monitoring overview focuses on results and compares relevant data to Contingency Plan thresholds. The overview presents 2007 monitoring results for effluent, water column, sea floor, and winter flounder. It also includes sections on special studies and the Stellwagen Bank National Marine Sanctuary. A final section lists the monitoring questions that were posed at the beginning of the program and their answers to date.

2. Effluent

2007 Characterization

Average daily flow to the Deer Island Treatment Plant (DITP) in 2007 was the lowest it has been throughout the monitoring program (Figure 2-1), partially because it was a dry year, but possibly also because ongoing maintenance has prevented intrusion of groundwater into sewage pipes and because the people in MWRA's service area have responded to water-conservation initiatives. Almost all of the DITP flow received primary and secondary treatment. A small amount of primary-only-treated effluent flow, which was blended with secondary-treated flow, occurred during March and April storms (Figure 2-2).

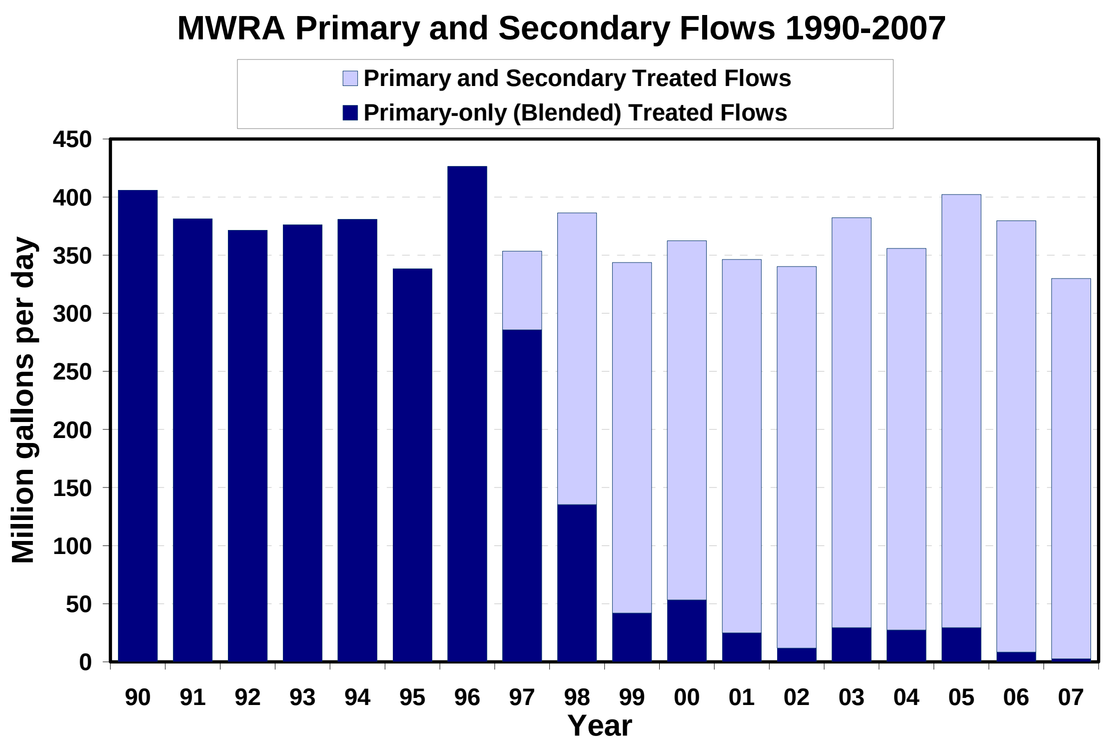


Figure 2-1. Annual effluent flows. *Average daily flow reached a record low in 2007. (Primary-only flows are blended with secondary flows, and the blended flows meet permit limits.)*

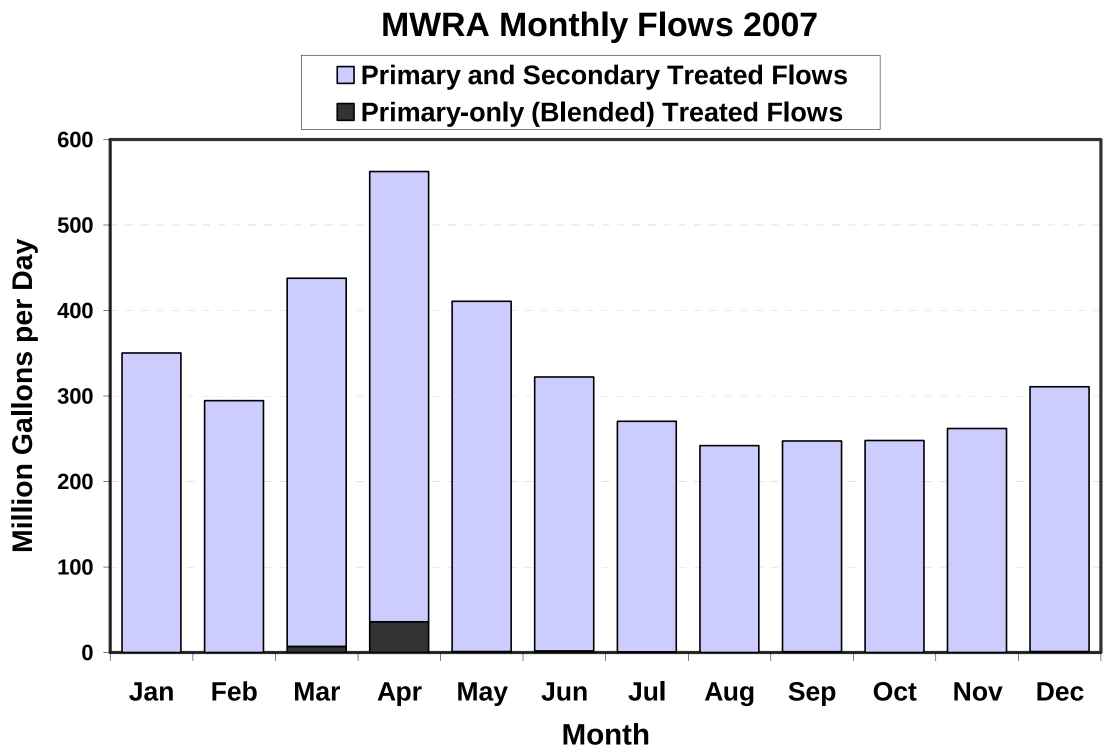


Figure 2-2. Monthly primary and secondary flows in 2007. *A small amount of primary-only treated effluent was blended with secondary flows and released during spring storms. (Blended flows meet all permit limitations.)*

Solids discharges continued to decrease in 2007 to the lowest annual load measured (Figure 2-3). Biological oxygen demand (BOD), measured as carbonaceous BOD (cBOD) also continued to decrease to a record low (Figure 2-4). At the same time, the nitrogenous BOD has increased, particularly since 2005. Nitrogenous BOD is a direct result of the microbiological breakdown that occurs during secondary treatment, which is designed to remove cBOD. BOD in the effluent has not adversely affected the receiving waters—ambient monitoring data show that the discharge has had no effect on dissolved oxygen in the environment (see Section 3, Water Column).

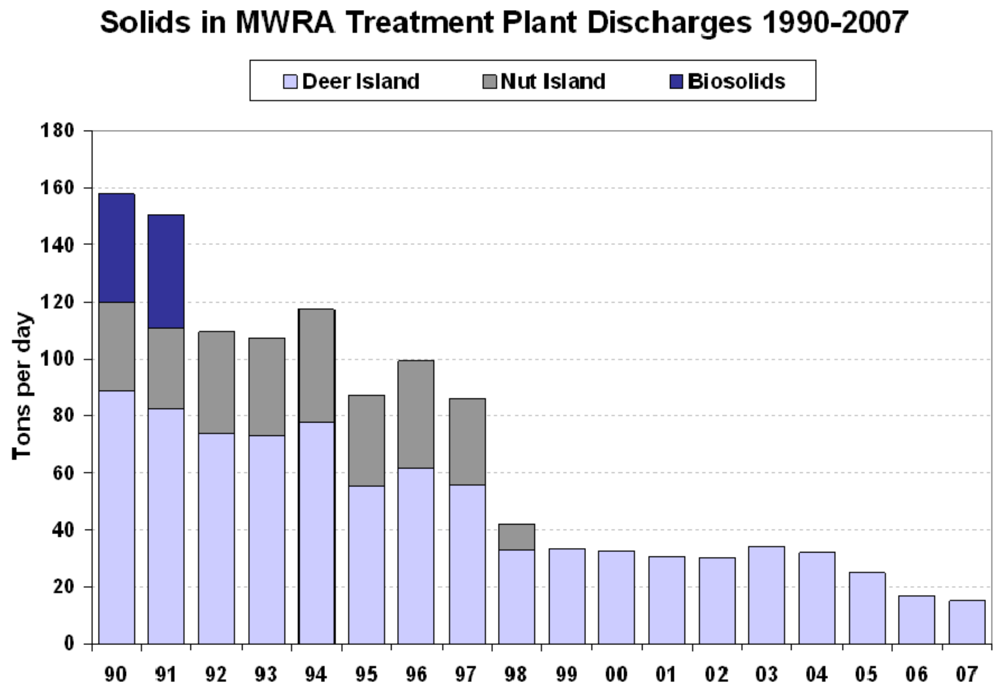


Figure 2-3. Annual solids discharges*. Solids discharges reached a record low in 2007.*

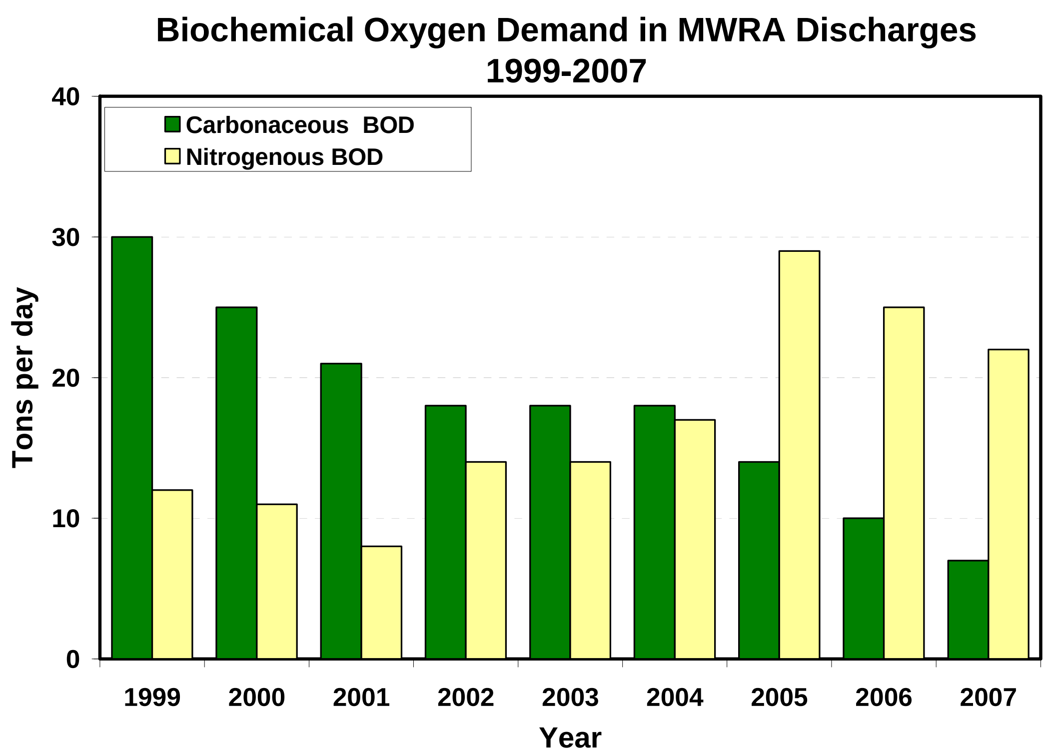


Figure 2-4. Average biochemical oxygen demand in tons/day for the past nine years. *MWRA's permit limits carbonaceous BOD, which reached a record low in 2007. Nitrogenous BOD is the result of microbiological breakdown that occurs during secondary treatment. Ambient monitoring data show that the discharge has had no effect on dissolved oxygen in the environment.*

Total nitrogen loads have remained about the same for several years, while the portion of the total load made up of ammonium has slightly increased to the highest level measured in the monitoring program (Figure 2-5). The secondary treatment biological process changes nitrate/nitrite and other forms of nitrogen to ammonium.

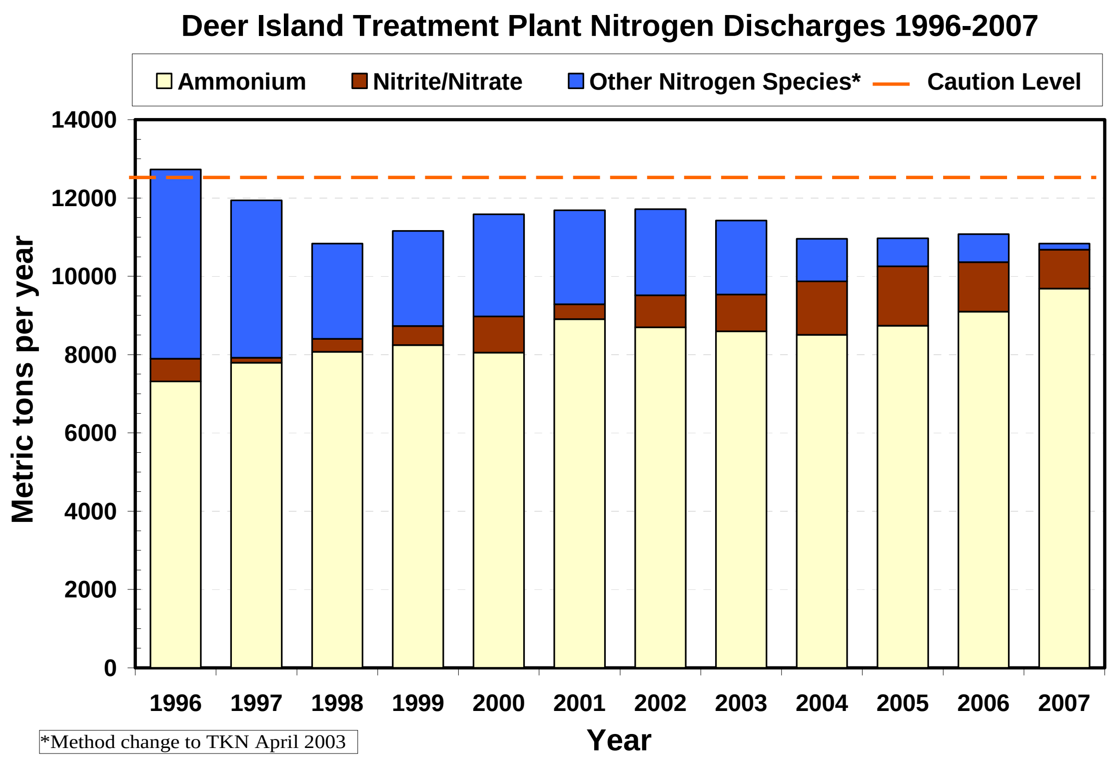


Figure 2-5. Annual nitrogen discharges. *Total nitrogen discharges reached a record low in 2007, but discharges of ammonium were higher, a result of the secondary treatment process. (TKN = total Kjeldahl nitrogen, a measure of total nitrogen in the effluent)*

Metals loads also reached new lows (Figure 2-6), with only copper and zinc remaining in significant quantities. Once used as a sewage-effluent tracer, silver is now only rarely detected in MWRA's effluent. The treatment plant is currently removing approximately 95% of the mercury and lead, about 85% of the cadmium and copper, 80% of the chromium and zinc, and 45% of the nickel from the influent. Organic contaminants are also removed: about 95% of the polycyclic aromatic hydrocarbons (PAHs) and 85% of the polychlorinated biphenyls (PCBs) are removed during treatment. A review of contaminant monitoring at the Deer Island Treatment Plant during 2000–2005 was completed in 2007 (Delaney and Rex 2007).

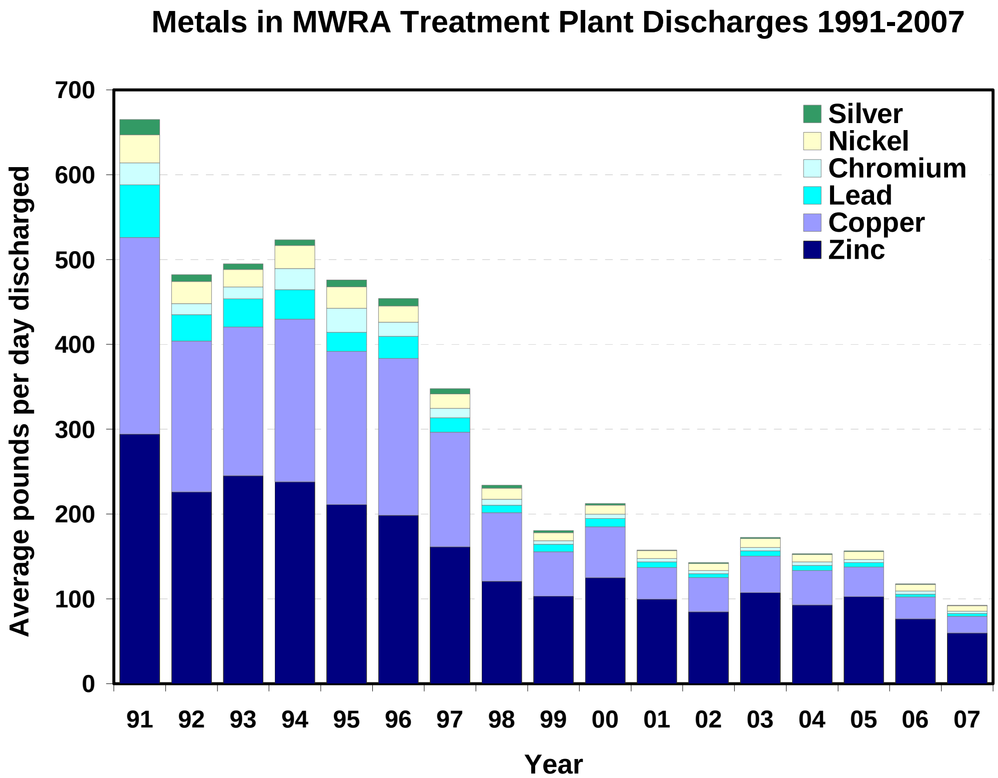


Figure 2-6. Annual metals discharges*. Total metals discharges reached a record low in 2007.*

Reducing mercury in the environment has been a top priority not only for MWRA, but for policy makers throughout New England and Canada. Mercury accumulation in fish is a major source to humans, and most water bodies in Massachusetts are subject to fish consumption advisories due to mercury. Through MWRA's source-reduction program, approximately 75% of dentists in the region installed amalgam separators to reduce mercury inputs to the sewer system, and hospitals are reducing mercury discharges. Loads in the influent, effluent, and fertilizer pellets made from biosolids show large declines (Figure 2-7). Influent loads have been cut in half since 1999. Mercury discharges in the effluent have decreased from an average of 0.14 pounds per day in 1999 to 0.02 pounds per day in 2007. Concentrations as well as loads have also declined—the concentration of mercury in the fertilizer pellets made from biosolids decreased from 3.8 mg/kg to 1.8 mg/kg during 2004–June 2008, the period in which the dental amalgam separator program was implemented. Now, most of the mercury entering Massachusetts water bodies originates from power plants in the Midwest and Southeast.

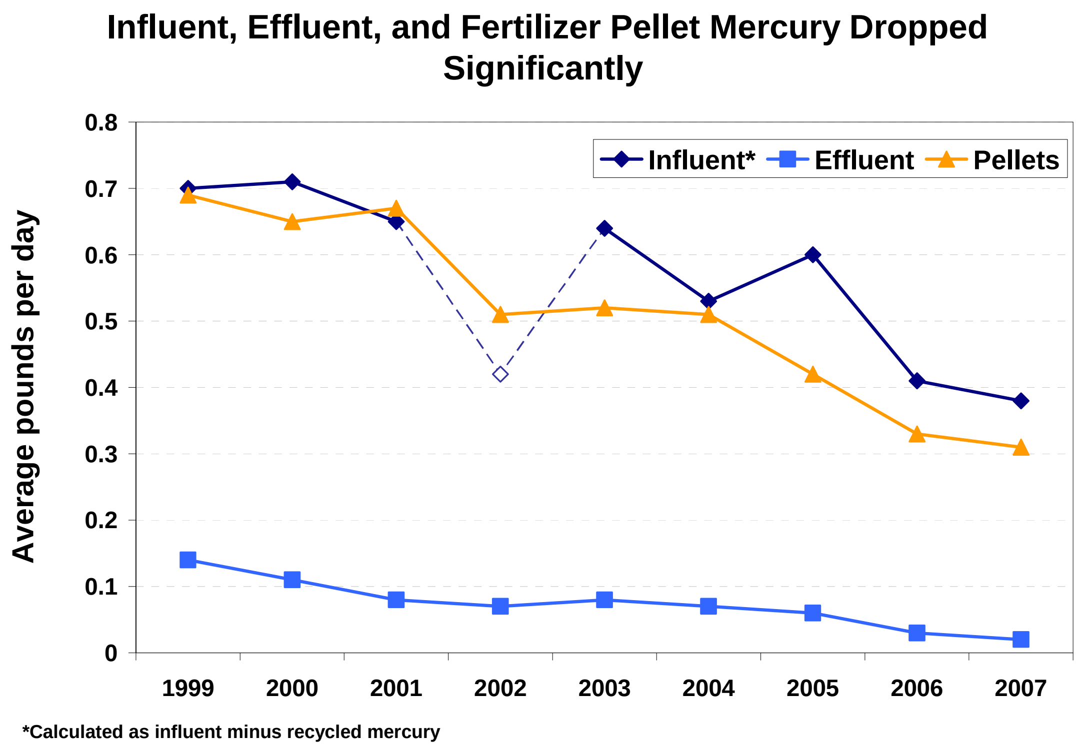


Figure 2-7. Annual mercury loadings in influent, effluent, and biosolids fertilizer pellets have dropped significantly. *"Influent" is calculated as total mercury minus the amount that is recycled. The influent loading for 2002, indicated by an open symbol, is probably underestimated, due to sampling error. (Note: The MWRA industrial pretreatment program prohibits mercury from industries permitted to discharge to the sewer system. Operationally, this prohibition is enforced at concentrations of 1µg/L or 1 part per billion. Monitoring of industries measures levels to 10 ng/L or 10 parts per trillion, and monitoring of the effluent is to the level of 0.1 ng/L or 100 parts per quadrillion.)*

Contingency Plan Thresholds

The Deer Island Treatment Plant had no permit violations and no exceedances of the Contingency Plan thresholds in 2007 (Table 2-1).

Table 2-1. Contingency Plan threshold values and 2007 results for effluent monitoring.

Parameter	Caution Level	Warning Level	2007 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

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. In 2007, the overall physical, water quality, and biological conditions were about average for the monitoring period and followed typical seasonal patterns. Total annual flows from the Merrimack and Charles rivers were lower than average, but flows during April through June were relatively high (Figures 3-1, 3-2). From July through the end of the year, the flows were relatively low.

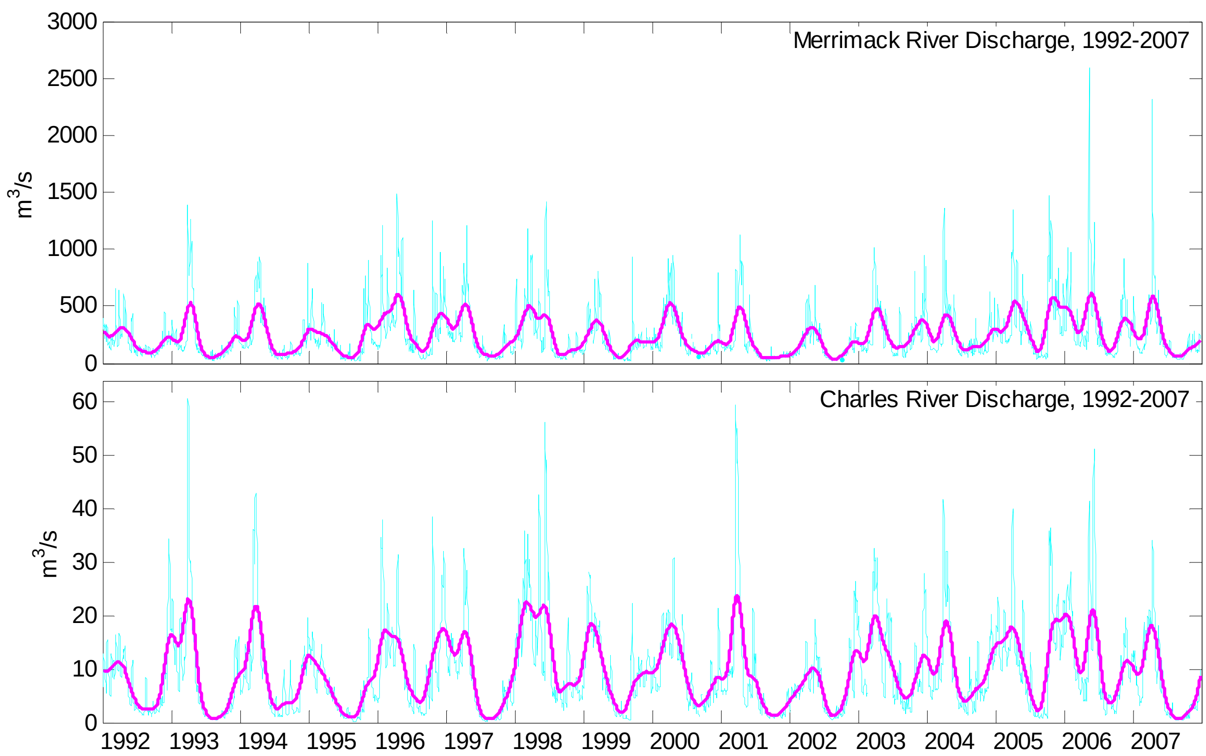


Figure 3-1. Merrimack River (top) and Charles River (bottom) discharges to the ocean. *(Data are from gauges at Lowell and Waltham, Massachusetts; smooth lines are 3-month moving averages; note the differences in scale.)*

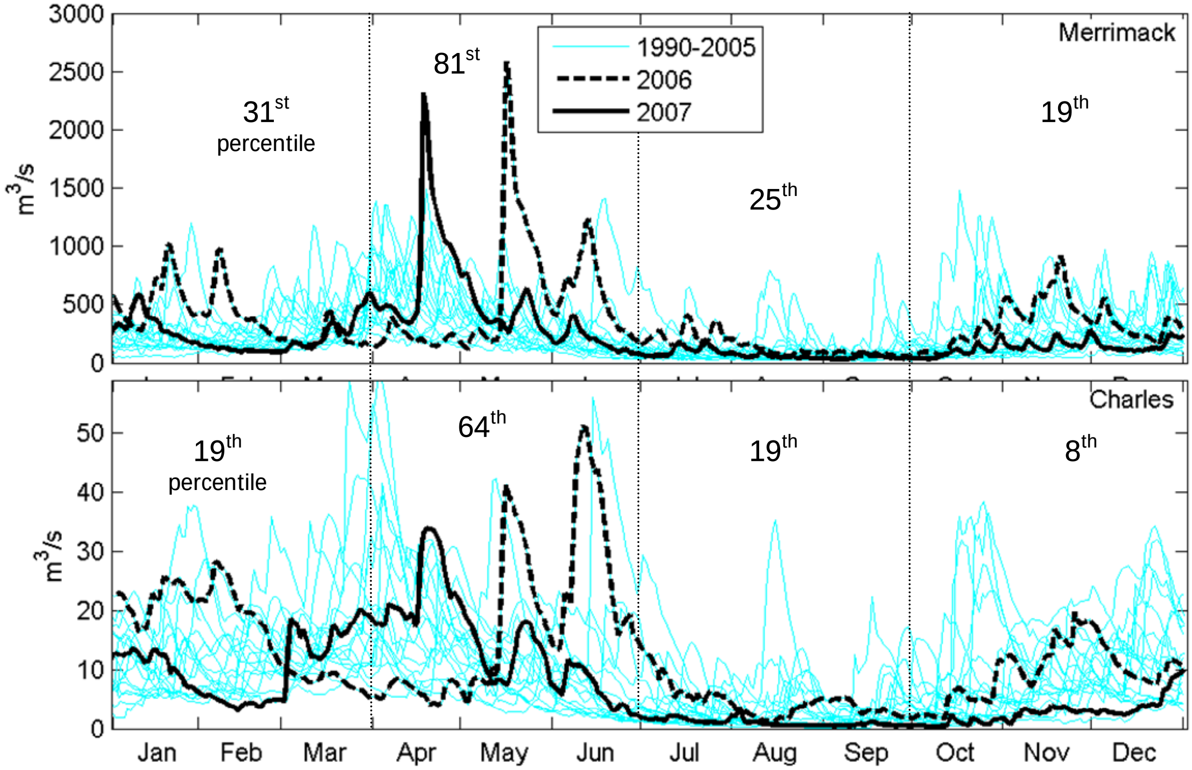


Figure 3-2. Flows of the Merrimack (top) and Charles (bottom) rivers during 2007 were relatively high in the spring quarter and low during other seasons. *For example, the average April–June 2007 flow of the Merrimack River ranked 15th out of 18 years of data, which translates to the 81st percentile. The year 2006, shown for contrast, had high flow in every season.*

Overall, the wind-forcing conditions in 2007 were typical for the monitoring period. In most years, spring is a transitional period between winter downwelling and spring upwelling conditions. Downwelling, the condition in which winds from the north or east move waters toward the coast, was slightly stronger than average during April, May, and June 2007. Those spring downwelling conditions were not as strong as the downwelling conditions during May and October 2005 (Figure 3-3), which resulted from large storms with winds from the northeast.

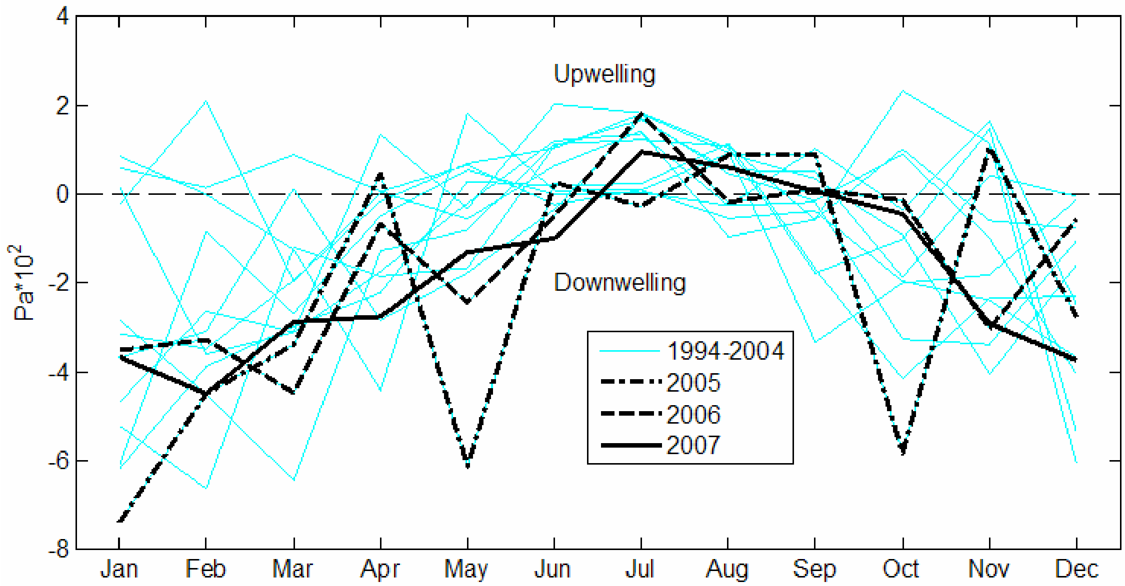


Figure 3-3. 2005–2007 monthly average wind stress at the Boston Buoy compared with observations from the previous 11 years. *(Positive values indicate winds from the south or west, which result in upwelling-favorable wind stress; negative values indicate winds from the north or east, which favor downwelling.)*

The annual progression of air temperatures and water temperatures (Figure 3-4) in 2007 was about typical. The winter of 2006–2007 was slightly warmer than average, and June 2007 was slightly colder than average. It is not easy to see in Figure 3-4, but surface and bottom water temperatures were warmer than average in June, probably because of the downwelling conditions that occurred at that time. Surface waters seemed cooler than average in August and September, but a separate analysis of buoy data showed that the ship surveys happened by chance to occur on days that were a couple of degrees cooler than was typical for those months.

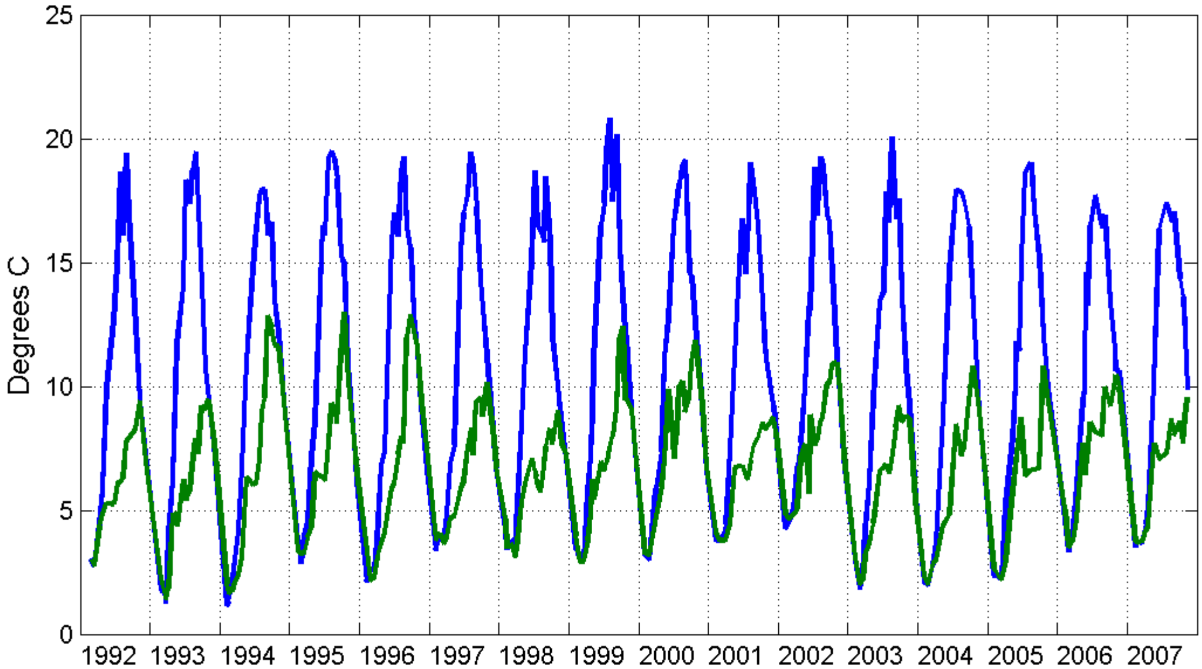


Figure 3-4. Nearfield surface and bottom water temperature. *Surface measurements are the upper line.*

Each year, salinities in the bay are affected by spring runoff. During spring 2007, as in the previous two springs, the salinities fell to relatively low levels following strong storms. Salinities in the bottom waters were relatively high at the beginning of the year but were at normal levels by the end of the year (Figure 3-5).

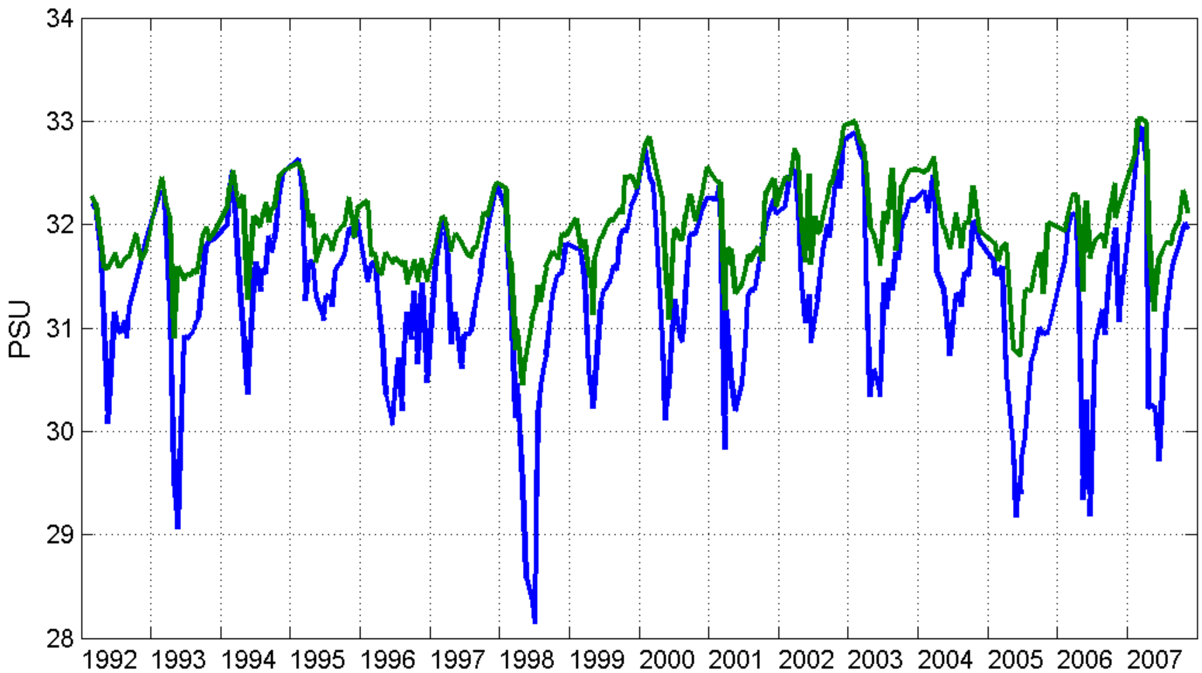


Figure 3-5. Nearfield surface and bottom water salinity. *Surface measurements are the lower line.*

Water Quality

The monitoring program measures water quality (and plankton, which are discussed in the next two subsection sections below) at stations in Massachusetts Bay, Cape Cod Bay, and Boston Harbor (Figures 3-6, 3-7, and 3-8). The sampling stations located within seven kilometers of the outfall diffuser are called nearfield stations; those beyond are grouped into regions, which together are called farfield stations. Results for 2007 continued to confirm predictions that the effects of the discharge would be local for certain parameters and not detectable for others (Libby *et al.* 2008). As in other post-diversion years, trends in water quality parameters were similar to baseline observations with some differences in the timing and magnitude of events.

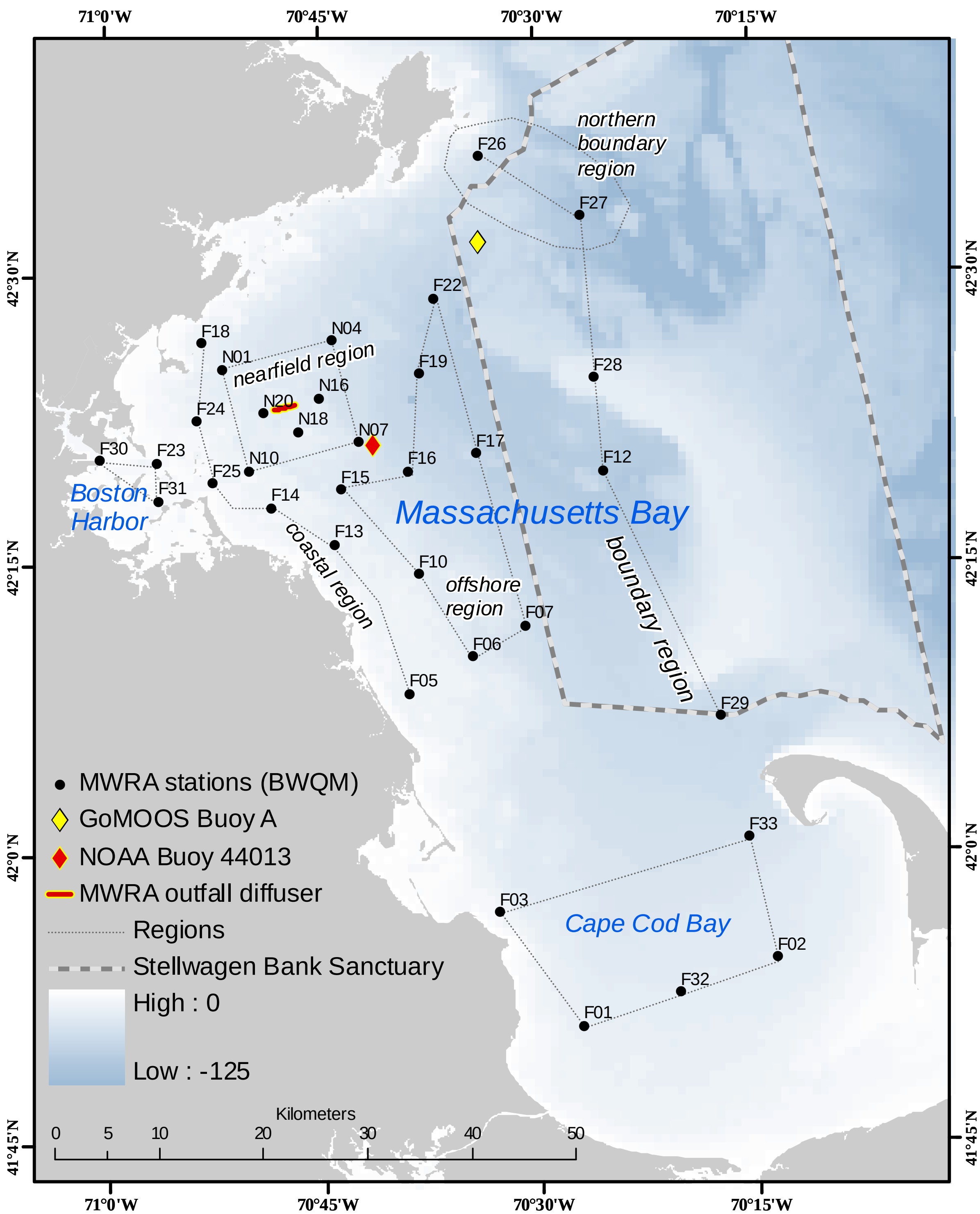


Figure 3-6. MWRA Bay Water Quality Monitoring (BWQM) stations and regional groupings included in the program. *"Farfield" stations include all stations in Boston Harbor; the coastal, offshore, and northern boundary regions; and Cape Cod Bay. Also shown are the MWRA outfall; two instrumented buoys, one 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.*

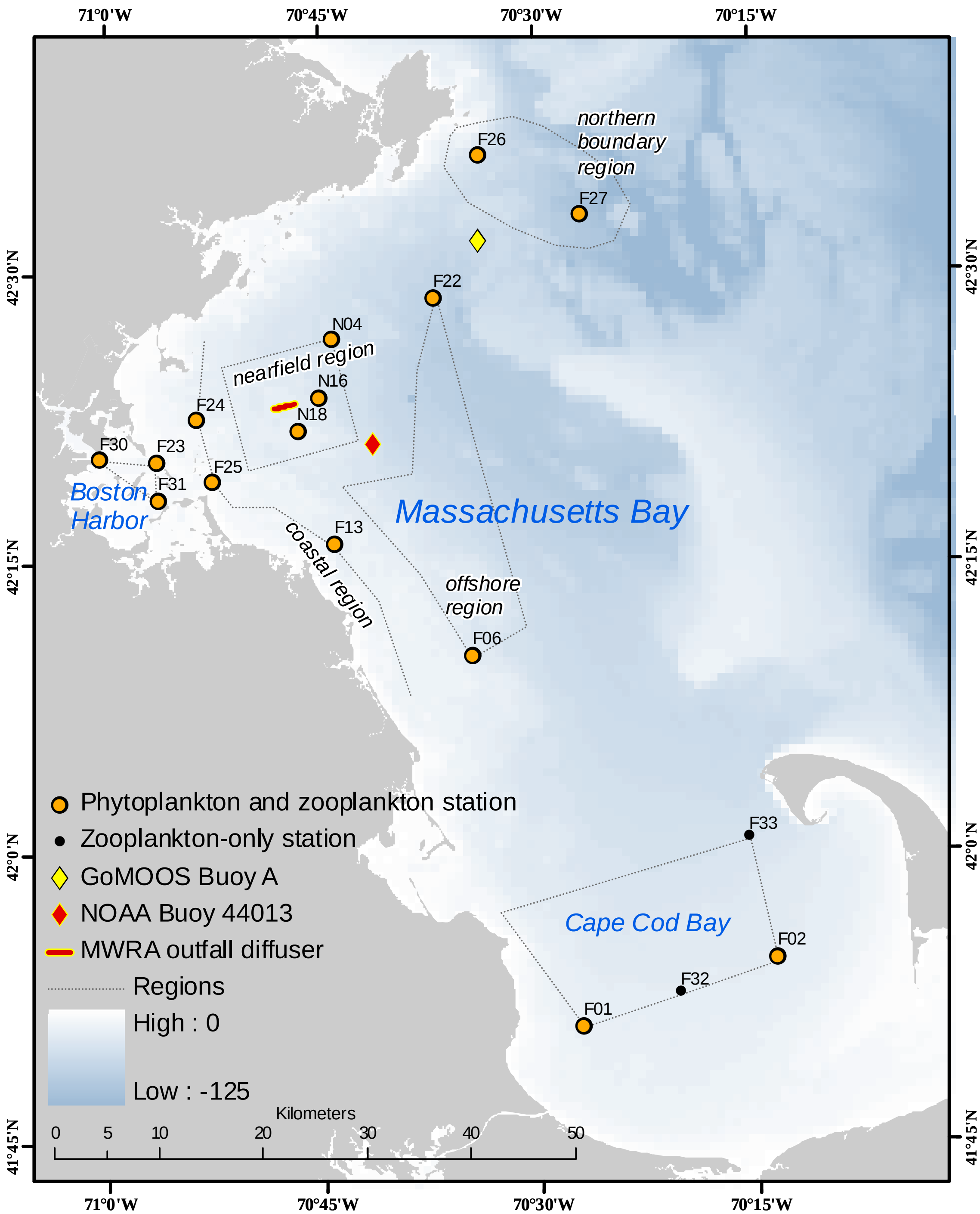


Figure 3-7. MWRA plankton stations included in water column monitoring. *The stations are a subset of those monitored for water quality. Regional groupings, the instrumented buoys, and the MWRA outfall are also shown.*

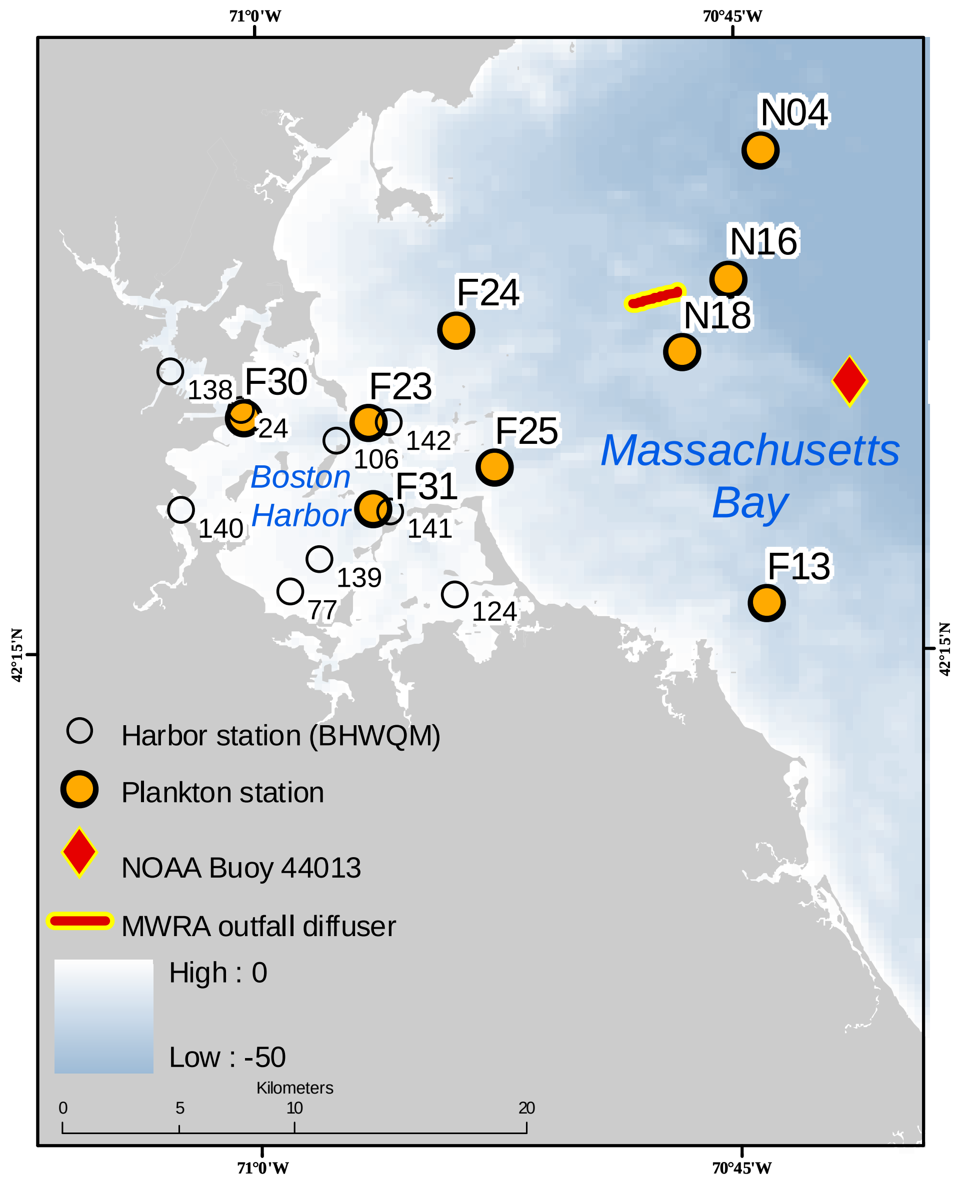


Figure 3-8. MWRA Boston Harbor Water Quality Monitoring (BHWQM) stations and nearby BWQM plankton stations. *Primary productivity is measured at Stations F23, N18, and N04.*

Ammonium is the major component of total inorganic nitrogen in the effluent. As expected from simple dilution, the discharge increased the mean concentrations of ammonium in the nearfield compared to the baseline mean (Figure 3-9). But in May 2007, the survey mean ammonium concentration was unusually low, possibly due to uptake by the April phytoplankton bloom or to a chance that the fixed sampling stations straddled the outfall plume during that survey, not capturing the elevated levels. Throughout the year, nearfield ammonium concentrations varied, sometimes being closer to the baseline mean than the post-discharge mean, a result also found in 2006. These results may also reflect the sampling regime.

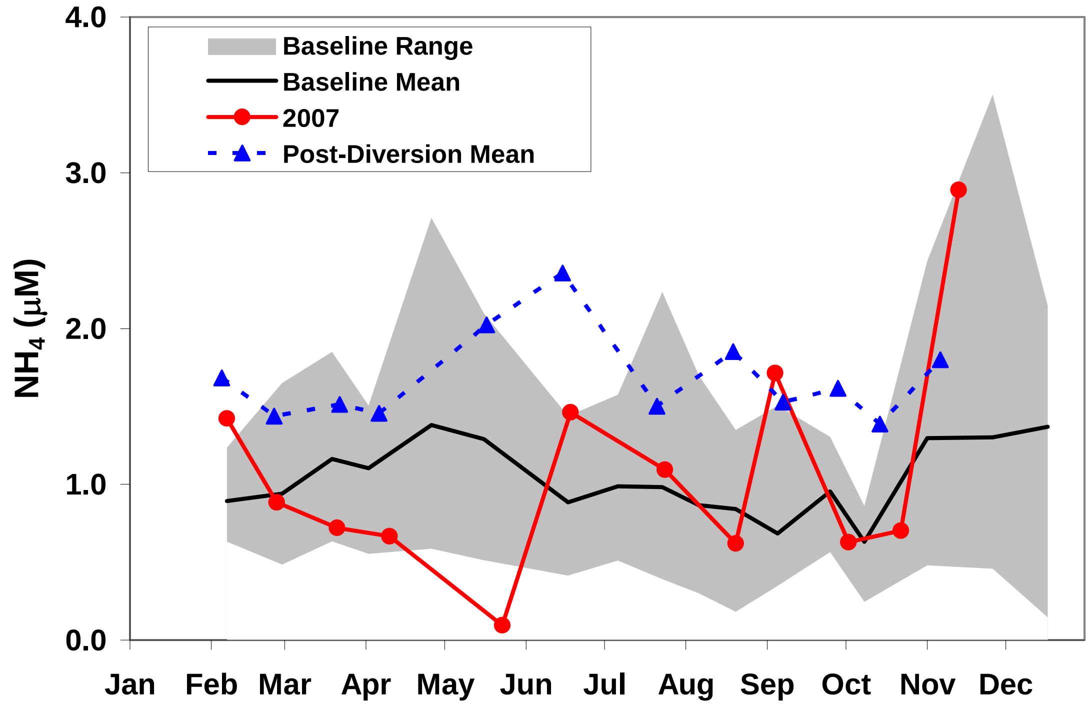


Figure 3-9. 2007 nearfield ammonium concentrations compared to the baseline range, baseline mean, and post-diversion mean.

Nitrate concentrations were elevated during the first three surveys of 2007 at the nearfield (Figure 3-10) and other stations, probably due to contributions from rivers and the Gulf of Maine. Nitrate is present in effluent but not at levels that would result in the elevated ambient levels observed. Even after averaging over the year, concentrations of nitrate are typically quite variable and reflect region-wide physical conditions and time and magnitude of phytoplankton blooms.

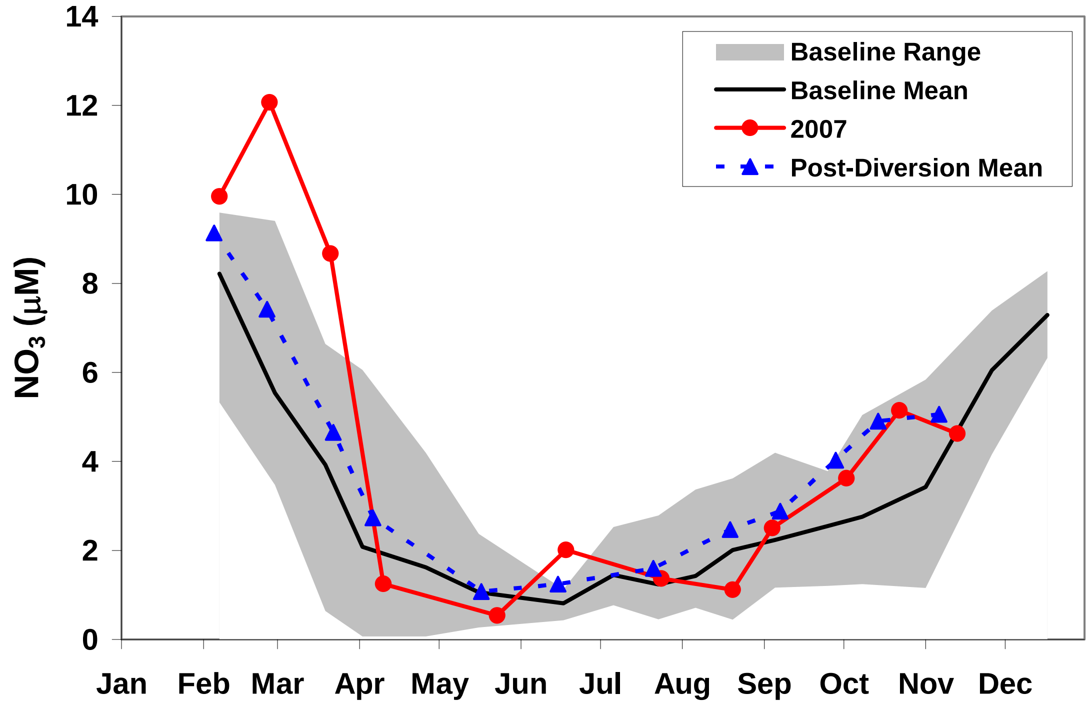


Figure 3-10. 2007 nearfield nitrate concentrations compared to the baseline range, baseline mean, and post-diversion mean.

Over the course of the monitoring program, there has been a small, localized increase in ammonium concentrations in the vicinity of the outfall, concurrent with much larger decreases in ammonium concentrations in Boston Harbor and the nearby coastal region (Figure 3-11, top row). These changes are statistically significant in both the harbor and the nearfield and can be observed across all seasons. The results match the predictions that were made prior to the diversion of the discharge from the harbor to the bay.

Changes in nitrate concentrations since the Massachusetts Bay outfall began to discharge (Figure 3-11, bottom row) have been small. During the past seven years, the bay has also experienced a background increase in nitrate concentrations during the winter/spring and fall. This increase appears to have been unrelated to the outfall and is perhaps the result of regional-scale climate and biological changes.

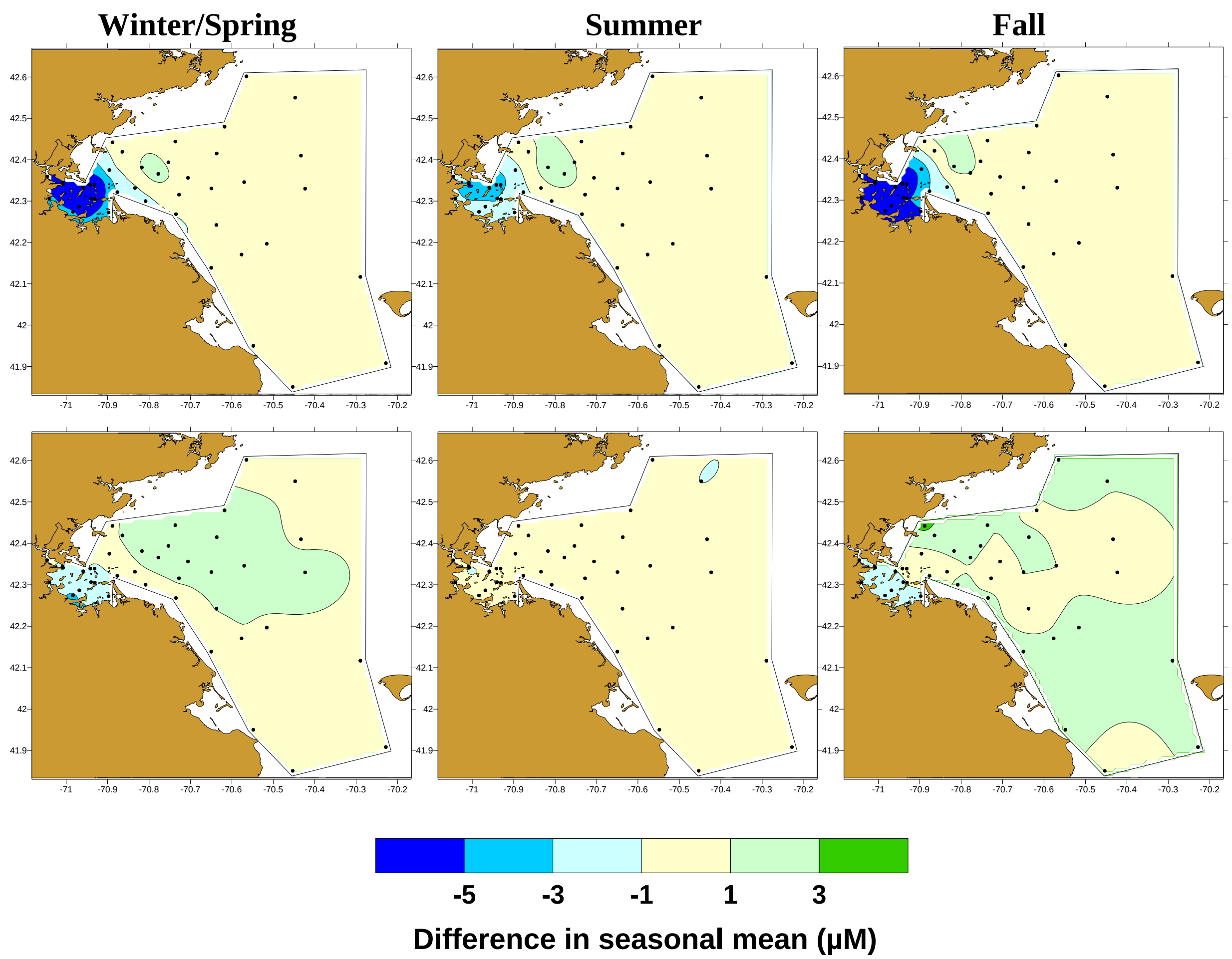


Figure 3-11. Changes in seasonal ammonium (top row) and nitrate (bottom row) concentrations (μmol) from the baseline to the post-diversion period. *There have been localized increases in ammonium concentrations near the outfall with concurrent decreases in ammonium concentrations in Boston Harbor. No changes in nitrate concentrations are attributed to the outfall diversion.*

The 2007 seasonal trends in two measures of phytoplankton biomass, chlorophyll and particulate organic carbon, were generally comparable to previous years, but as for other parameters, there were some differences from other years. During 11 of the 12 surveys, average chlorophyll concentrations were within the baseline range. During the April survey, concentrations were higher than the baseline range (Figure 3-12). Particulate organic carbon concentrations were also high during April (not shown).

These April peaks corresponded with a region-wide bloom of the colonial flagellate alga *Phaeocystis pouchetii*. The timing and sizes of phytoplankton blooms are varied, causing the chlorophyll and particulate organic carbon concentrations to vary. Since the diversion, average chlorophyll concentrations in the bay during winter/spring have been higher than during the baseline; the opposite has applied during fall (Figure 3-13).

The elevated chlorophyll concentrations during spring are the result of background blooms of *Phaeocystis pouchetii* that have occurred during every year since 2000. Occurrence of these blooms is believed to be a regional phenomenon and not caused by the outfall.

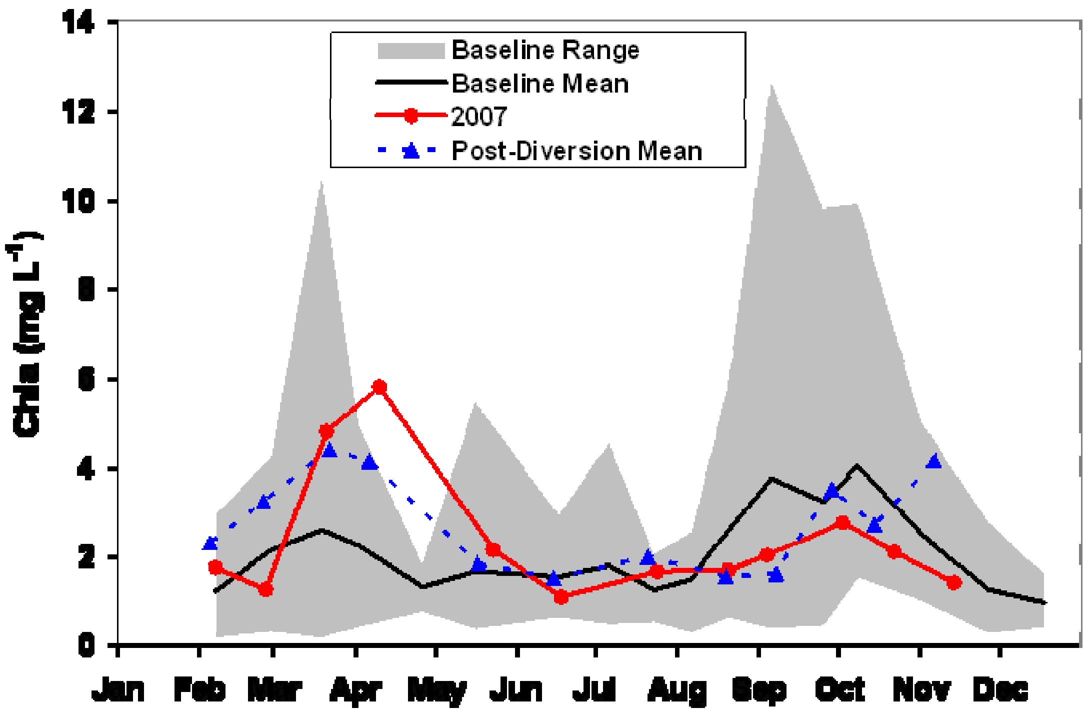


Figure 3-12. 2007 nearfield chlorophyll concentration compared to the baseline range, baseline mean, and post-diversion mean. *The April 2007 peak reflects a large* Phaeocystis pouchetii *bloom.*

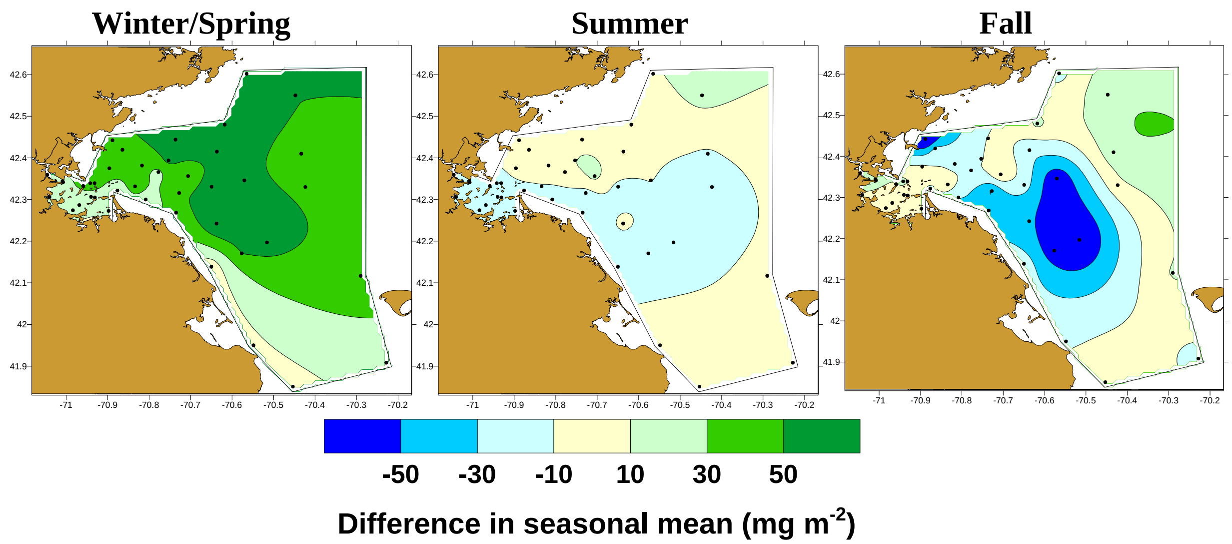


Figure 3-13. Changes in areal seasonal chlorophyll (mg m^{-2}) from the baseline to the post-diversion period. *(Post-diversion minus baseline values.) The large-scale increases during the winter/spring and decreases during the fall are too large to have been caused by the outfall.*

Except for a slight increase in February rates, primary production rates in Boston Harbor decreased after the discharge was relocated from the harbor to Massachusetts Bay. The decrease was substantial in summer, causing a bimodal pattern of spring and fall blooms, such as is characteristic of temperate waters, rather than the unimodal summer maximum that was observed when effluent was discharged to the harbor. On an annual basis, primary production at all three stations was low in 1998 and has been low every year since 2003. The higher productivity observed in other years has correlated with greater wind-induced mixing of nutrients to surface waters (data not shown). In Massachusetts Bay, there has been no statistically significant change in production since outfall diversion.

Measurements of concentrations (Figure 3-14) and percent saturation of dissolved oxygen in the nearfield bottom waters have shown no response to the outfall. There has been no change in levels or the season pattern.

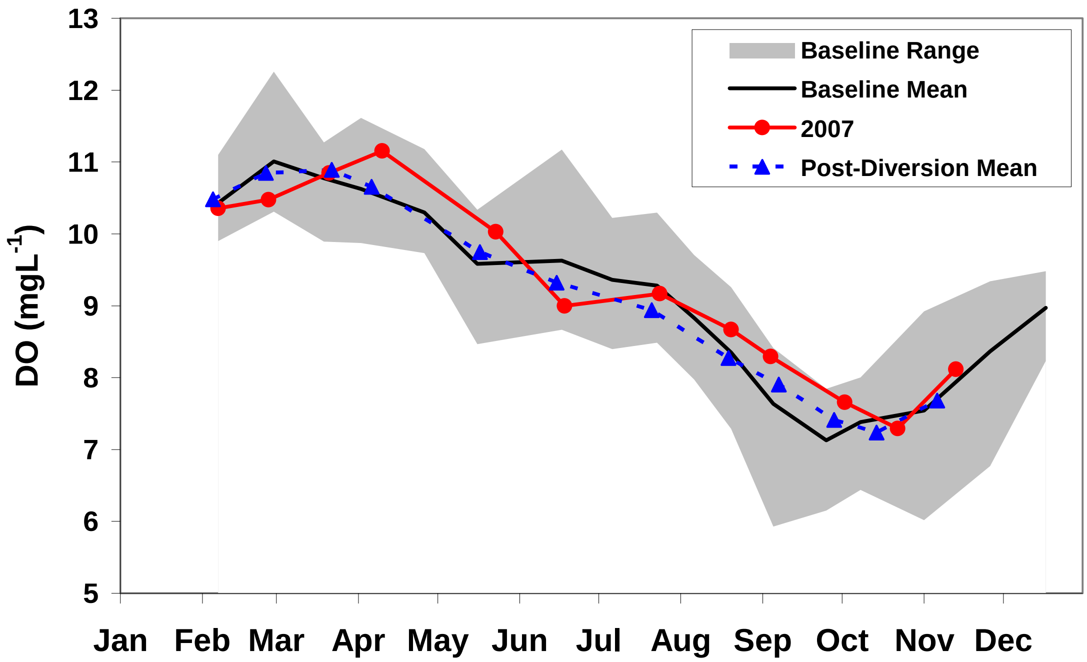


Figure 3-14. 2007 nearfield dissolved oxygen concentrations compared to the baseline range, baseline mean, and post-diversion mean. *There has been no decrease in oxygen concentrations as a result of the discharge.*

Phytoplankton Communities

The April *Phaeocystis pouchetii* bloom was the most notable event for the phytoplankton community in 2007 (Figure 3-15; Libby *et al.* 2008). As a result of that large bloom, abundance of phytoplankton in April exceeded the baseline range and the post-diversion mean (Figure 3-16). Total phytoplankton abundance was similar to the baseline mean for other survey dates in 2007.

Similar large *Phaeocystis* blooms occurred during 2000 and 2004, and smaller but longer-duration blooms occurred during 2003 and 2005. The 2004 bloom was the largest recorded throughout the monitoring program. The 2007 bloom rivaled the bloom of 2004 in size but not in duration, lasting only about 30 days. As in other years, the 2007 bloom occurred well beyond the boundaries of Massachusetts and Cape Cod bays, and there was no indication of an effect of the outfall.

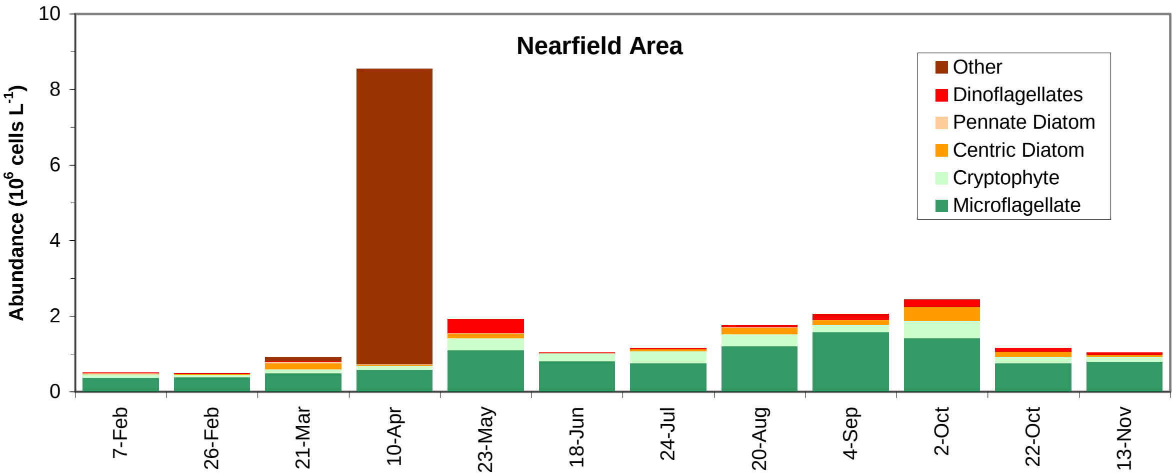


Figure 3-15. Abundance of dominant phytoplankton groups in the nearfield in 2007, *showing the* Phaeocystis pouchetii *bloom (included as "other") that was underway during the April survey.*

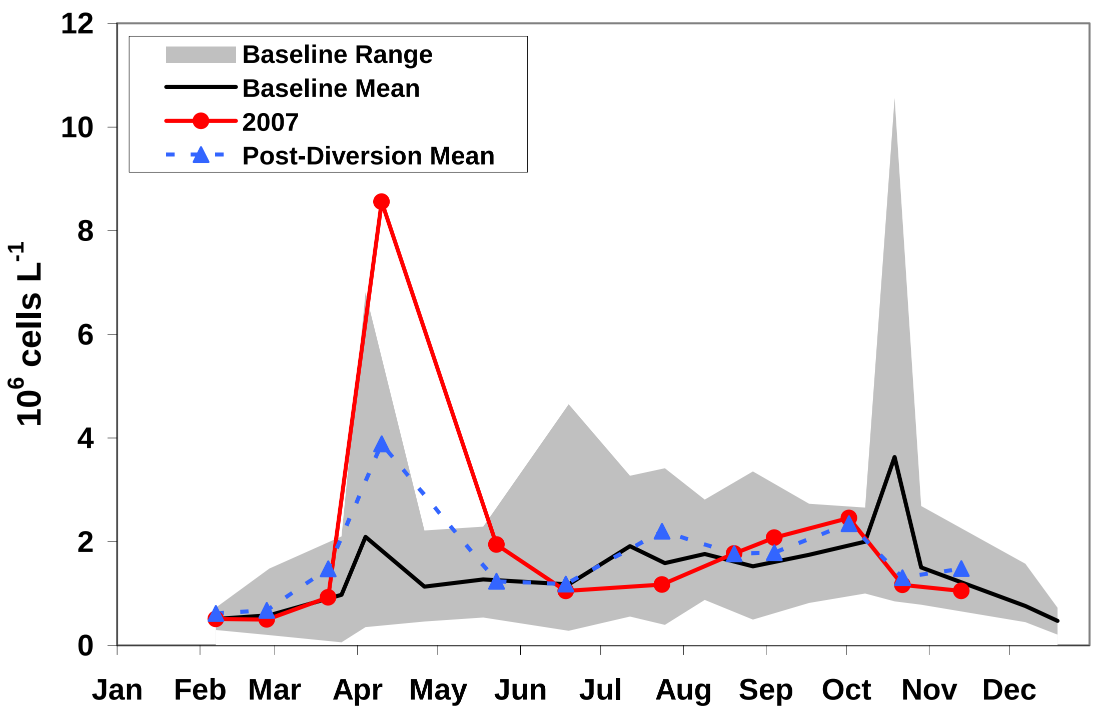


Figure 3-16. 2007 nearfield phytoplankton abundance compared to baseline range, baseline mean, and post-diversion mean. *The April peak is a result of the* Phaeocystis *bloom; other values were within the baseline range.*

There were also winter/spring, summer, and fall diatom blooms, occurring primarily in coastal waters. The nuisance phytoplankton species *Pseudo-nitzschia* spp. were recorded in low numbers during February and March. They occurred in densities far below those that would cause amnesic shellfish poisoning. The dinoflagellate *Alexandrium fundyense* was also recorded but in numbers below those that would cause a concern for paralytic shellfish poisoning (PSP). There was an *Alexandrium* red tide event in 2007, but it occurred offshore, well east of Massachusetts Bay.

Zooplankton Communities

The structure of the zooplankton community in the nearfield in 2007 was similar to that of many earlier years but did not continue to show the decline in total abundance observed from 2001 through 2006 (Figure 3-17; Libby *et al.* 2008). The decline was largely due to a decline in total copepods. During 2007, total copepod abundance rebounded to levels within the baseline range, approximating the long-term mean.

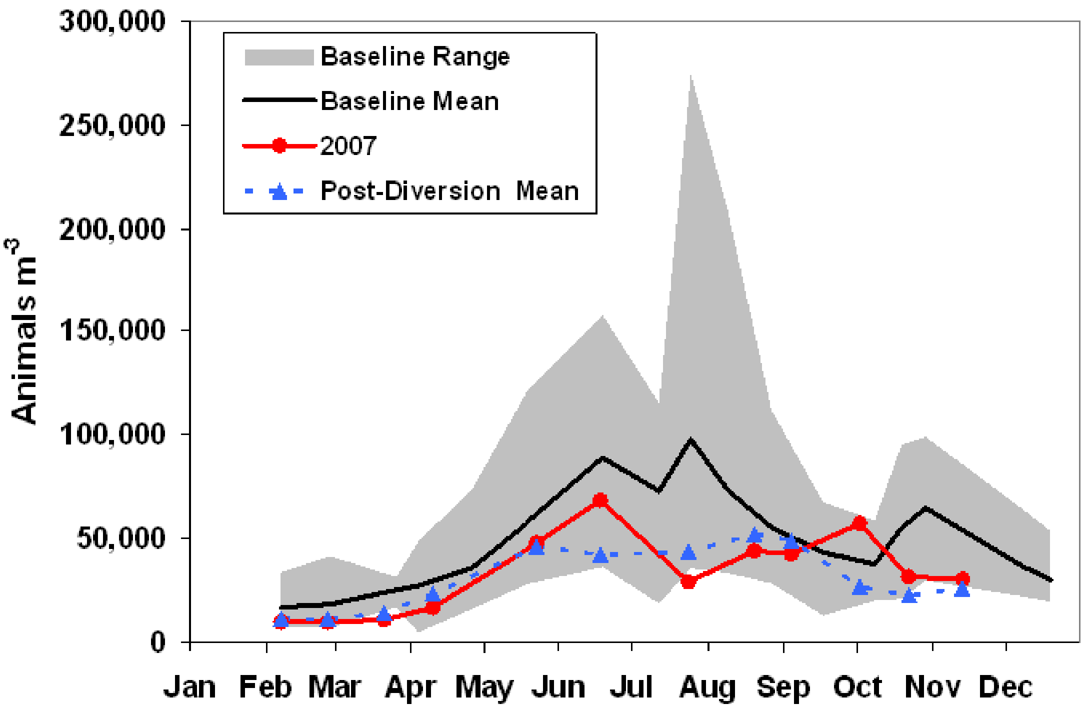
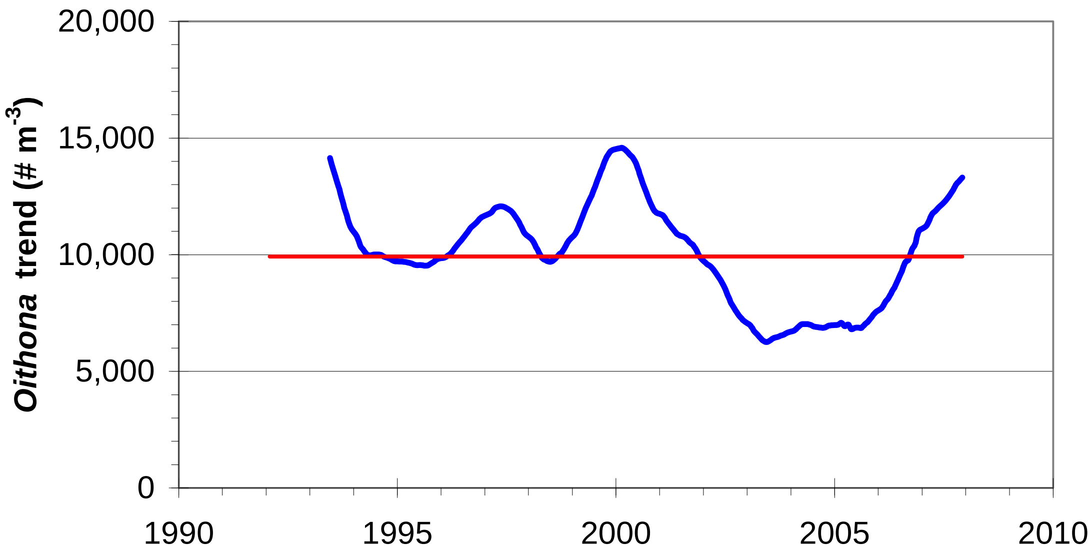


Figure 3-17. 2007 nearfield survey mean total zooplankton abundance compared to baseline range, baseline mean, and post-diversion mean. *During most surveys, values remained below the baseline mean, but overall abundance was greater than in other post-diversion years.*

Almost all the 2007 increase was accounted for by the small copepod *Oithona similis* (Figure 3-18, top), which is one of the most common zooplankton species in Massachusetts Bay. The large and less abundant copepod *Calanus finmarchicus* continued to show a different abundance pattern from *Oithona similis* and other smaller species. *Calanus* abundance was high during 2003–2005 and has declined during subsequent years, remaining low in 2007 (Figure 3-18, bottom). Reasons for these patterns are not known, but are region-wide and not thought to be related to the outfall.



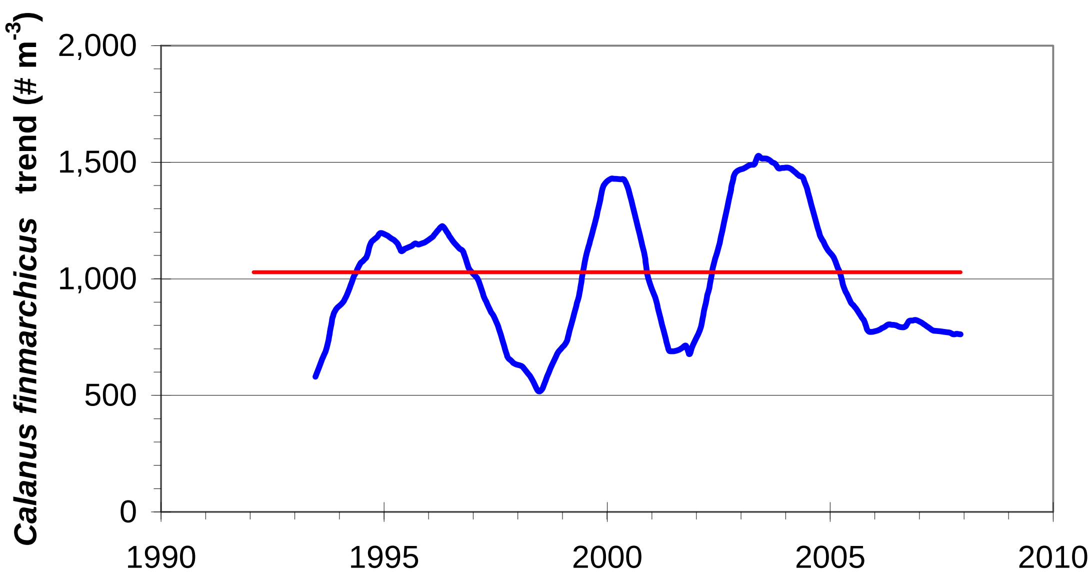


Figure 3-18. Long-term trends in nearfield abundance of the small copepod* Oithona similis *(top) and the larger copepod species* Calanus finmarchicus *(bottom). *Note differences in scales. (Data were derived from a time-series analysis of data from Stations N04, N16, and N18; red lines represent means.)*

Contingency Plan Thresholds

There was one threshold exceedance of water-column parameters during 2007 (Table 3-1). The winter/spring counts of the nuisance algal species *Phaeocystis pouchetii* exceeded the caution level. As in 2004, when that threshold was last exceeded, the wide geographical extent of the blooms indicates that regional processes rather than the outfall were responsible for the *Phaeocystis* bloom. A similar bloom occurred in 2000, before the outfall diversion took place.

The summer *Phaeocystis* caution level threshold, which had been exceeded in each year during 2002–2006, was met in 2007. That is because the 2007 bloom, while large, was not of long duration. Termination of spring *Phaeocystis* blooms appears to be related to the speed with which the surface waters warm in the spring. During 2007, waters reached temperatures of 14°C on May 25; during years with longer-duration blooms, that temperature was not exceeded until mid-June.

Table 3-1. Contingency Plan threshold values and 2007 results for water-column monitoring.

Location/ Parameter	Specific Parameter	Baseline	Caution Level	Warning Level	2007 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 = 7.29 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 = 77.4%
Bottom water Stellwagen Basin	Dissolved oxygen concentration	Background 5th percentile 6.2 mg/L	6.5 mg/L for any survey (June-October) unless background conditions lower	Lower than 6.0 mg/L for any survey (June-October) unless background conditions are lower	Lowest survey mean = 7.36 mg/L
	Dissolved oxygen percent saturation	Background 5th percentile 66.3%	Lower than 80% for any survey (June-October) unless background conditions	Lower than 75% for any survey (June-October) unless background conditions are lower	Lowest survey mean = 75.0%
Bottom water nearfield	DO depletion rate (June-October)	0.024 mg/L/d	0.037 mg/L/d	0.049 mg/L/d	0.015 mg/L/d
Chlorophyll nearfield	Annual	79 mg/m^2	118 mg/m^2	158 mg/m^2	83 mg/m^2
	Winter/spring	62 mgml^2	238 mg/m^2	None	128 mg/m^2
	Summer	51 mg/m^2	93 mg/m^2	None	55 mg/m^2
	Autumn	97 mg/m^2	212 mg/m^2	None	65 mg/m^2
Nuisance algae nearfield *Phaeocystis pouchetii*	Winter/spring	468,000 cells/L	2,020,000 cells/L	None	2,150,000 cells/L, caution exceedance
	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	78 cells/L
	Summer	14,600 cells/L	43,100 cells/L	None	Absent
	Autumn	9,940 cells/L	24,700 cells/L	None	Absent
Nuisance algae nearfield *Alexandrium fundyense*	Any nearfield sample	Baseline maximum = 163 cells/L	100 cells/L	None	6.2 cells/L
Farfield	PSP toxin extent	Not applicable	New incidence	None	No new incidence

4. Sea Floor

Sediment Characteristics and Tracers

In 2007, sixteen stations were sampled for analysis of sediment grain-size distribution, total organic carbon, and the sewage-bacteria tracer *Clostridium perfringens* spores; two stations (NF12 and NF17) were sampled for analysis of chemical contaminants (Figures 4-1 and 4-2).

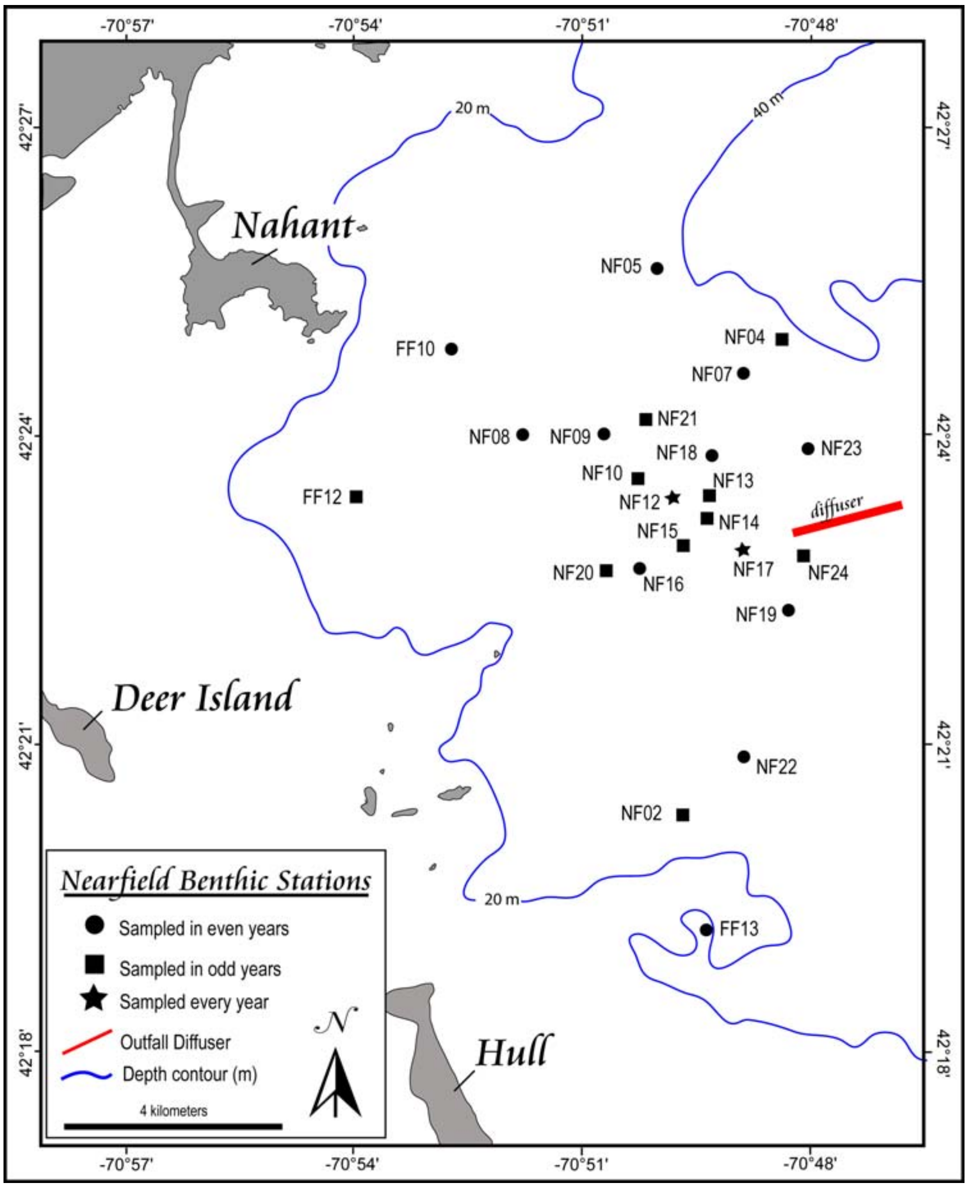


Figure 4-1. Locations of nearfield soft-bottom stations for chemical parameters, sediment-profile imaging, and community parameters.

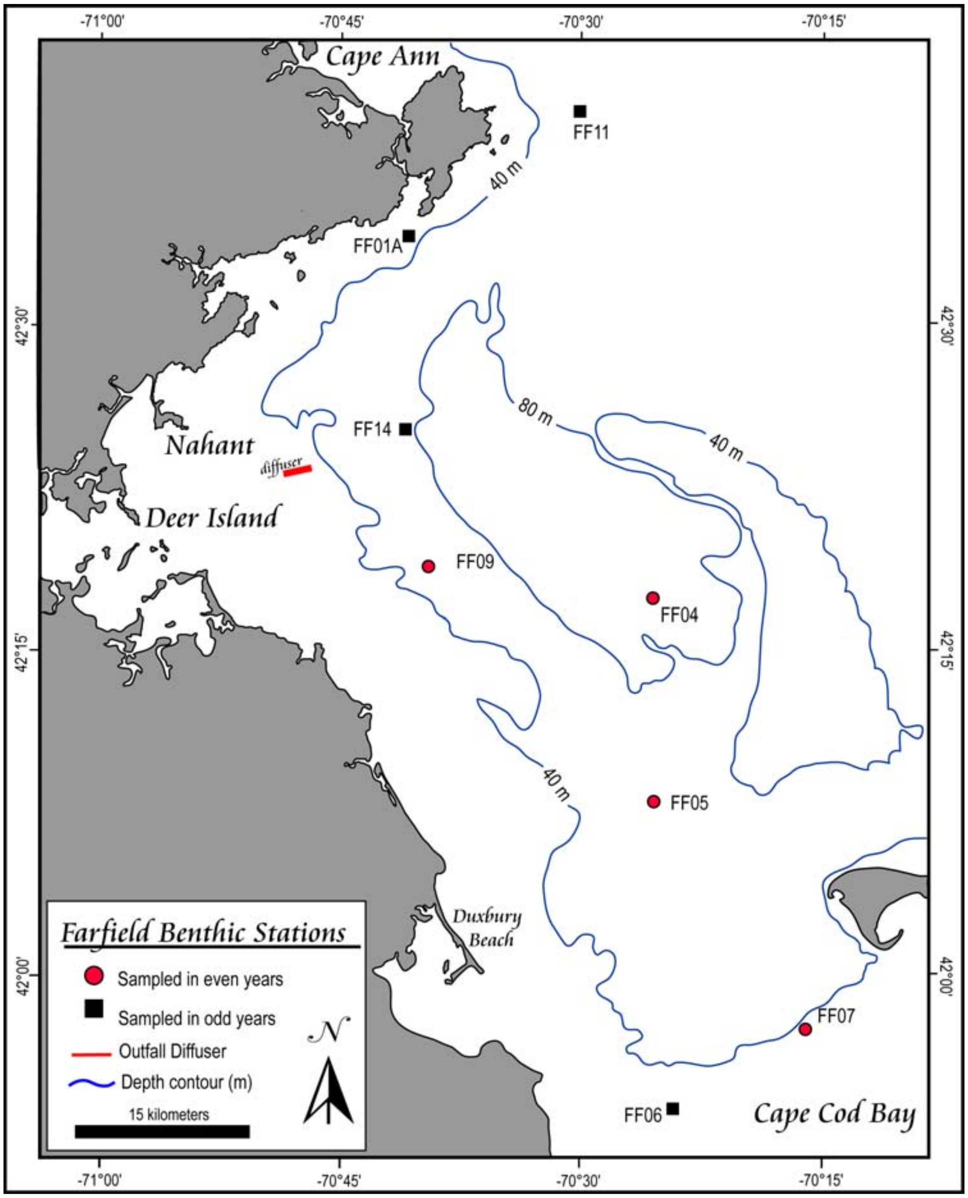


Figure 4-2. Locations of farfield soft-bottom stations for chemical parameters, sediment-profile imaging, and community parameters.

Grain-size distributions in 2007 were within the historic ranges of the monitoring program, with no indication of the coarse sediments that can result from large storms (Maciolek *et al.* 2008). Total organic carbon concentrations were particularly low, especially at nearfield stations.

As in other post-diversion years (except 2006), it was possible to detect higher counts of *Clostridium perfringens* spores in sediments collected within two kilometers of the outfall (compared to the baseline years when there was secondary treatment), and there were fewer spores in sediments collected at greater distances. 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. The presence of *Clostridium* spores helps to spatially define an area of potential outfall impact.

Concentrations of chemical contaminants in the sediments of the two stations sampled for those measurements (NF17 and NF12) were generally within the ranges measured throughout the monitoring program, with no suggestion of effects of the outfall. Concentrations of PAHs, for example, were at the low end of the baseline range (Figure 4-3). Data continued to confirm that sediment grain-size distribution and proximity to historic (previous) inputs are the main indicators of contaminant concentrations. In the nearfield, contaminant concentrations have been correlated with grain size, with the muddier stations having more organic carbon and correspondingly higher concentrations of contaminants. Sediments from farfield stations are typically finer-grained than those from the nearfield but also have lower concentrations of some contaminants, a pattern that has persisted since monitoring began.

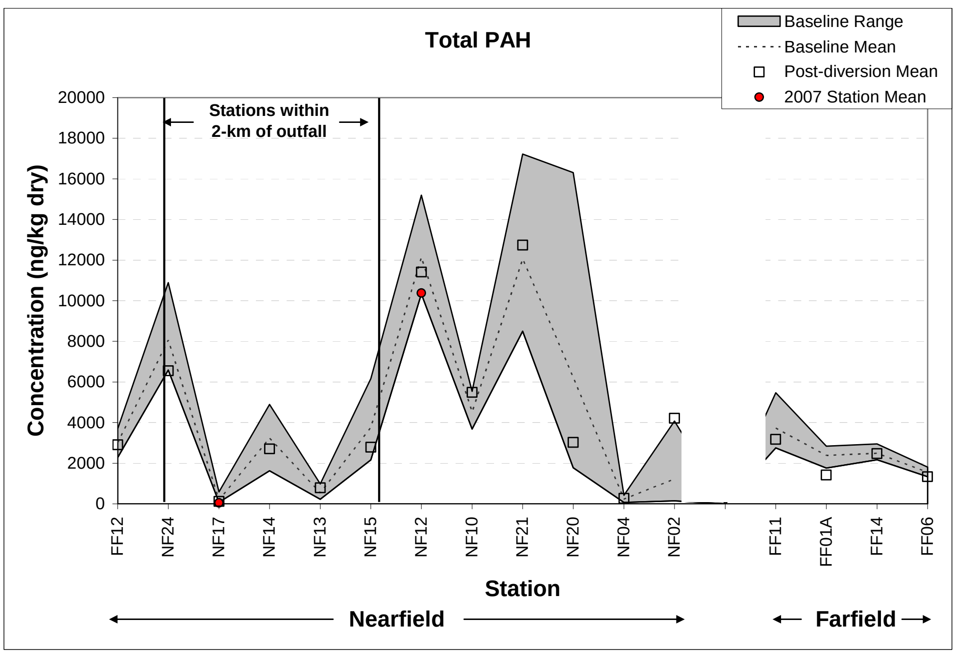


Figure 4-3. Total PAH concentrations, 1992–2007: baseline range, baseline mean, post-diversion mean, and 2007 station means. *Concentrations at the two stations (NF17 and NF12) sampled in 2007 were at the low end of the baseline range, continuing to show no elevation in response to the outfall.*

Sediment-Profile Imaging

Sediment-profile imaging measurements in 2007 were made at all western Massachusetts Bay stations shown on Figure 4-1 (including those denoted as being "sampled in even years") and continued to show no effects of the outfall (Maciolek *et al.* 2008). The concern that an increase in the amount of organic matter deposited on the sea floor would result in a shallower apparent redox potential discontinuity (RPD) has not been realized (Figure 4-4). The opposite has occurred; for most years, including 2007, the average RPD depth has been deeper than the baseline mean. The increase in RPD depth in 2007 was seen at every station where measurements have been made over all years of the program.

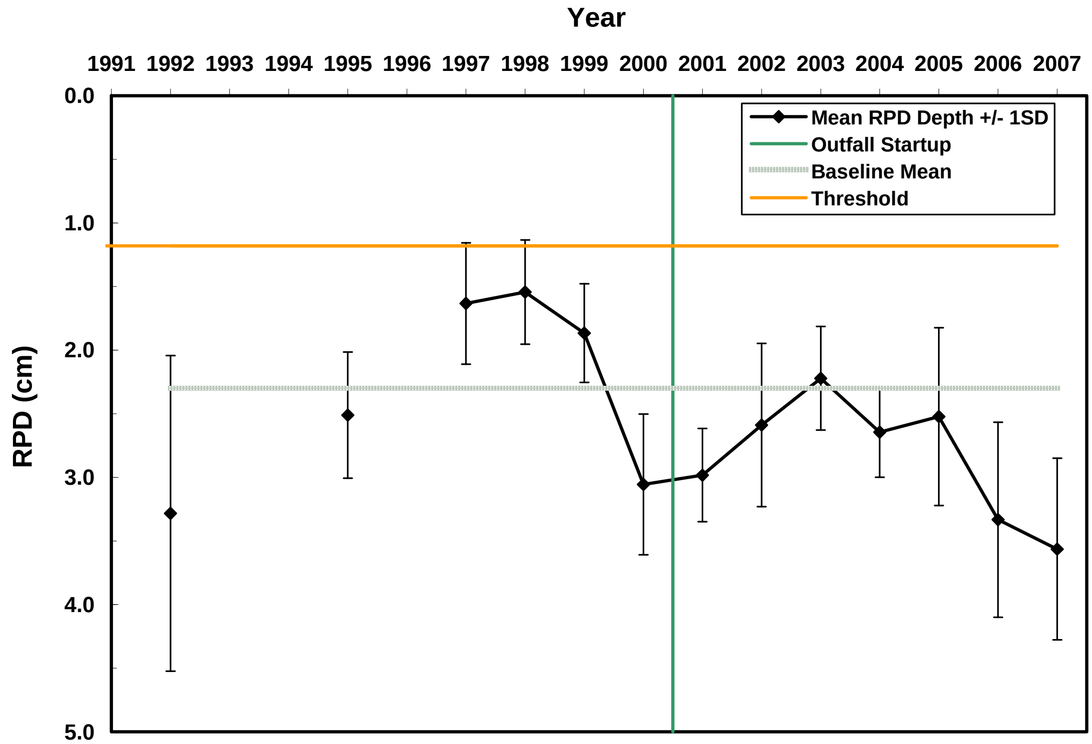


Figure 4-4. Annual apparent color RPD for data from nearfield stations sampled in 2007. *The average RPD depth in 2007 was deeper than the baseline mean, indicating that there has been no adverse effect from the discharge.*

Another measure, the organism sediment index (OSI), has provided further evidence that the outfall has not adversely affected the sea floor (Figure 4-5). Instead, the OSI suggests that some stations in the nearfield may have been stressed during some of the baseline years, but that there has been no sign of stress during the post-diversion period. The primary stress the sea-floor communities experience in western Massachusetts Bay is storm-induced sediment transport and deposition (Bothner and Butman 2007).

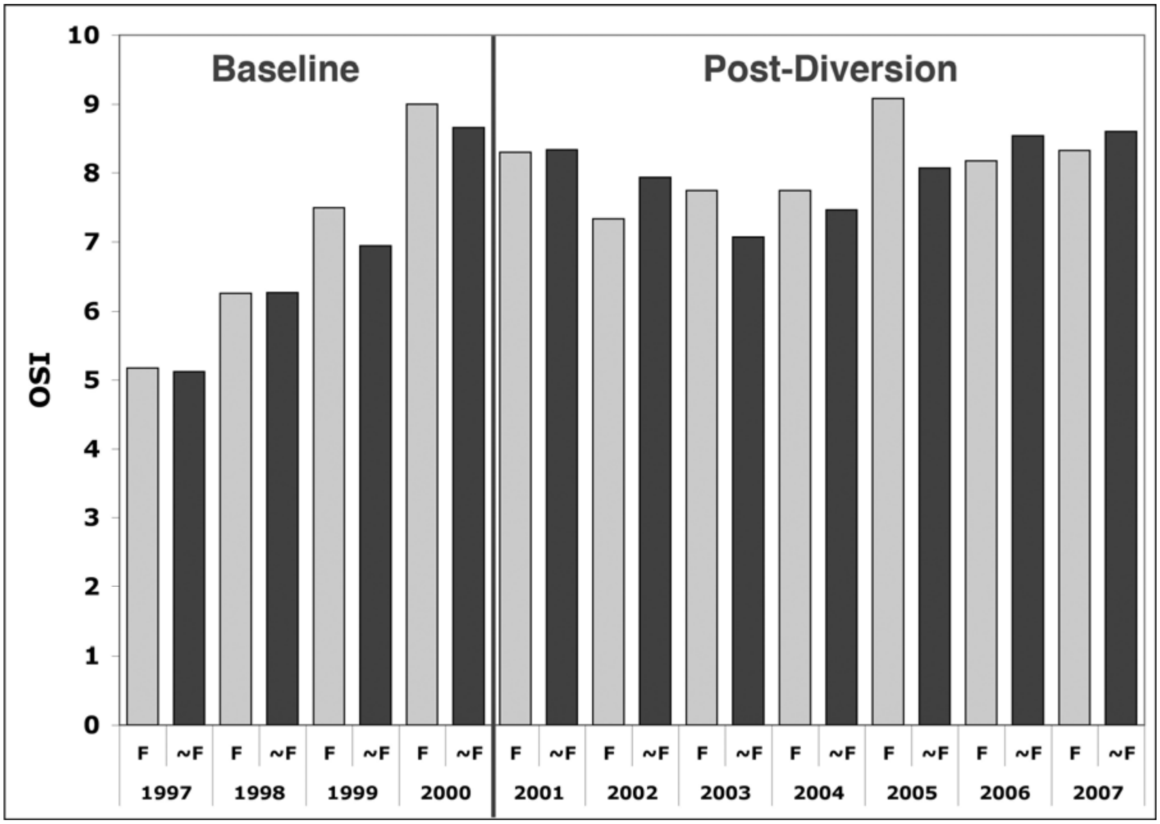


Figure 4-5. Average organism sediment index (OSI) in the nearfield by year. *There has been no evidence of stress on the soft-bottom community during the post-diversion period. (F=relatively flat topographic areas; ~F=other areas; an OSI value of less than 6 can be considered to indicate stress.)*

Soft-bottom Communities

Sixteen stations were sampled for evaluation of the soft-bottom infaunal communities in 2007. The soft-bottom communities have shown no response to the outfall over the course of the post-diversion period (Maciolek *et al.* 2008). 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. The nearfield stations fall into two major groups, those that are characterized by fine sediments dominated by polychaete worms and those that are sandier, supporting amphipod crustaceans as well as polychaetes. The farfield stations are more geographically widespread, with mostly finer sediments, and polychaetes dominate at most stations.

A tube-building spionid polychaete *Prionospio steenstrupi* has been the numerically dominant species throughout Massachusetts Bay in recent years, occurring in all sediment types. Total numbers of *Prionospio steenstrupi* have declined since reaching a peak in 2002 and 2003 (Figure 4-6), but the species remains the dominant one, with almost twice the abundance of the next most numerous species.

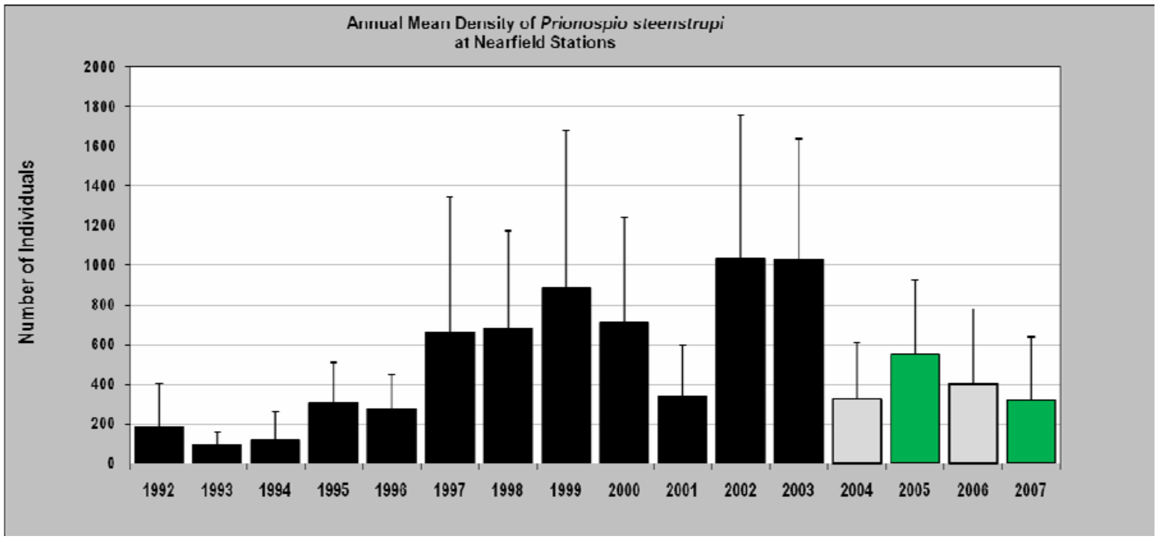


Figure 4-6. Annual mean density of the numerically dominant species* Prionospio steenstrupi *in the nearfield. *(Color differences in data for 2004–2007 reflect a splitting of stations into those sampled during even years and those sampled during odd years.)*

Because *Prionospio steenstrupi* is so dominant, its lower abundance during 2004–2007 is also reflected in the total abundance of animals per sample and the other community parameters measured by the monitoring program (Figure 4-7). Nearfield abundance and diversity (shown in Figure 4-7 as log-series alpha) have decreased somewhat since 2004 and continued to be relatively low in 2007. These results have held constant through both even and odd years, when separate subsets of stations are sampled. The measures remain within historic range of the monitoring program, are not statistically different from the baseline, and are not indicative of effects of the outfall.

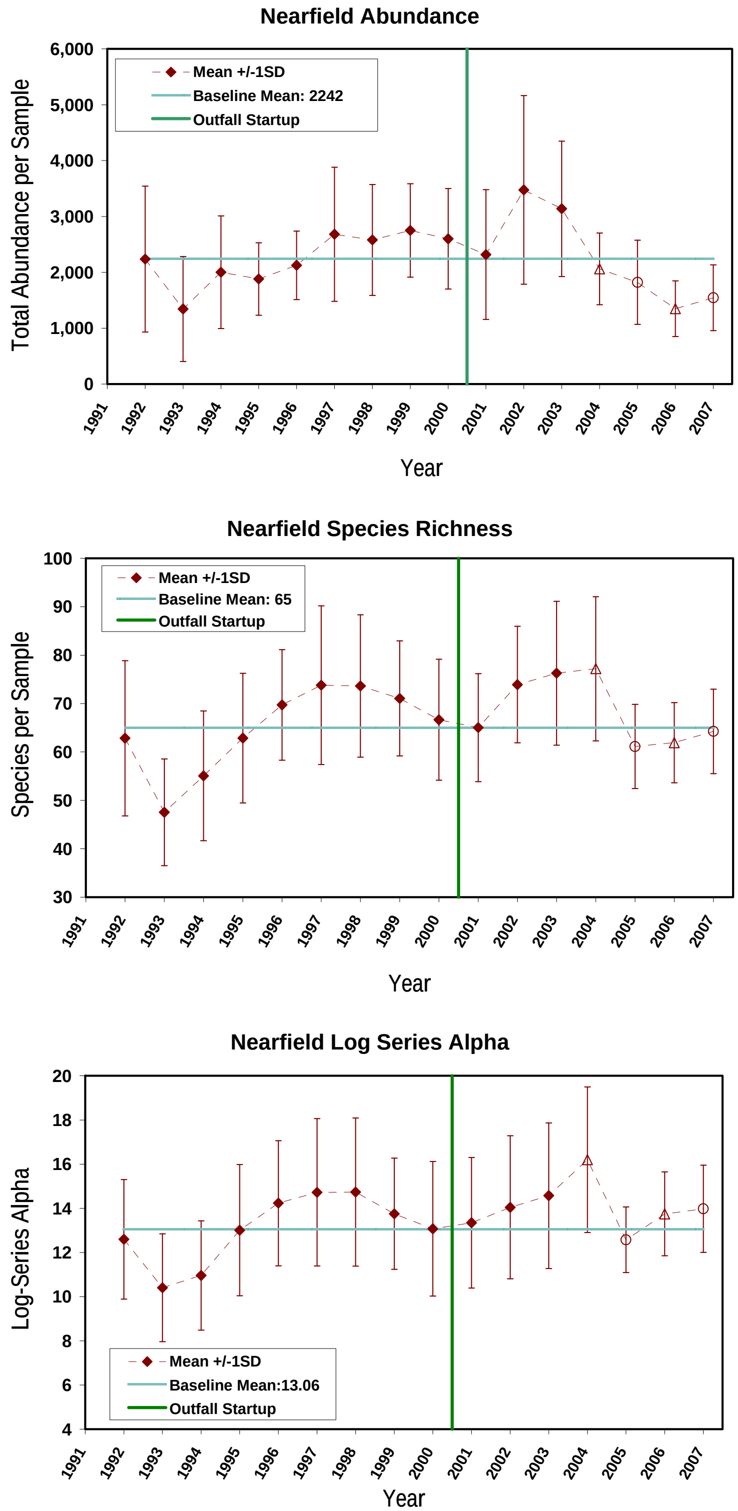


Figure 4-7. Annual community parameters in the nearfield. *(Open symbols indicate modified alternate-year sampling design, 2004–2007.)*

Hard-bottom Communities

The rocky habitats in the vicinity of the outfall and at reference locations (Figure 4-8) were surveyed in August of 2007. They continued to support robust communities of algae, invertebrates, and fish (Figure 4-9). Lush epifaunal growth, particularly sea anemones, continued to thrive on the diffuser heads, a condition unchanged since the outfall began to discharge. Sea anemones were also the most common invertebrate group observed throughout the region. Barnacles, tunicates, and the brachiopod *Terebratulina septentrionalis* were also common. Coralline algae continued to be the most common and widely distributed algal group. Cunner was the most common fish species.

Some changes in the hard-bottom communities have been detected since the outfall began operation, but they have been modest, and it has been difficult to attribute them to the outfall (Maciolek *et al*. 2008). For example, there have been increases in lobster and cod at some stations, particularly cod, which is good news, as much of Massachusetts Bay has been included in a Massachusetts Division of Marine Fisheries Cod Conservation Zone designed to protect the species. There have been decreases in the number of upright algae at many stations, but these decreases began in the 1990s before the outfall went on-line, and the trend appears to be reversing. Other species, such as *Cancer* crabs, also appear to exhibit cycles of abundance.

Throughout the region, and particularly at several northern stations, there have been increases in sediment drape and concurrent decreases in abundance of coralline algae, the historically most abundant and widely distributed taxonomic grouping. These decreases have been most noticeable since 2005. Decline in coralline algae abundance had been postulated as a possible indicator of outfall effects. However, the northern stations at which the decreases have been noted were considered to be reference sites, out of range of any expected outfall effects. These stations appear have been affected by tanker traffic; tankers bearing liquefied natural gas (LNG) have frequently been seen to be anchored in the area, sometimes affecting MWRA survey schedules. In 2007, Station T7-1, which once supported a lush growth of upright algae, was found to be composed of overturned boulders, barren of life other than a new set of barnacles. There was no sediment drape at that recently disturbed location. Station T9-1 was similarly disturbed, and anchor scars from the LNG tankers were evident. Such physical disturbances illustrate that the seafloor is subject to non-outfall-related disturbances. The anchoring activity may compromise the utility of these sites as reference stations for the MWRA program.

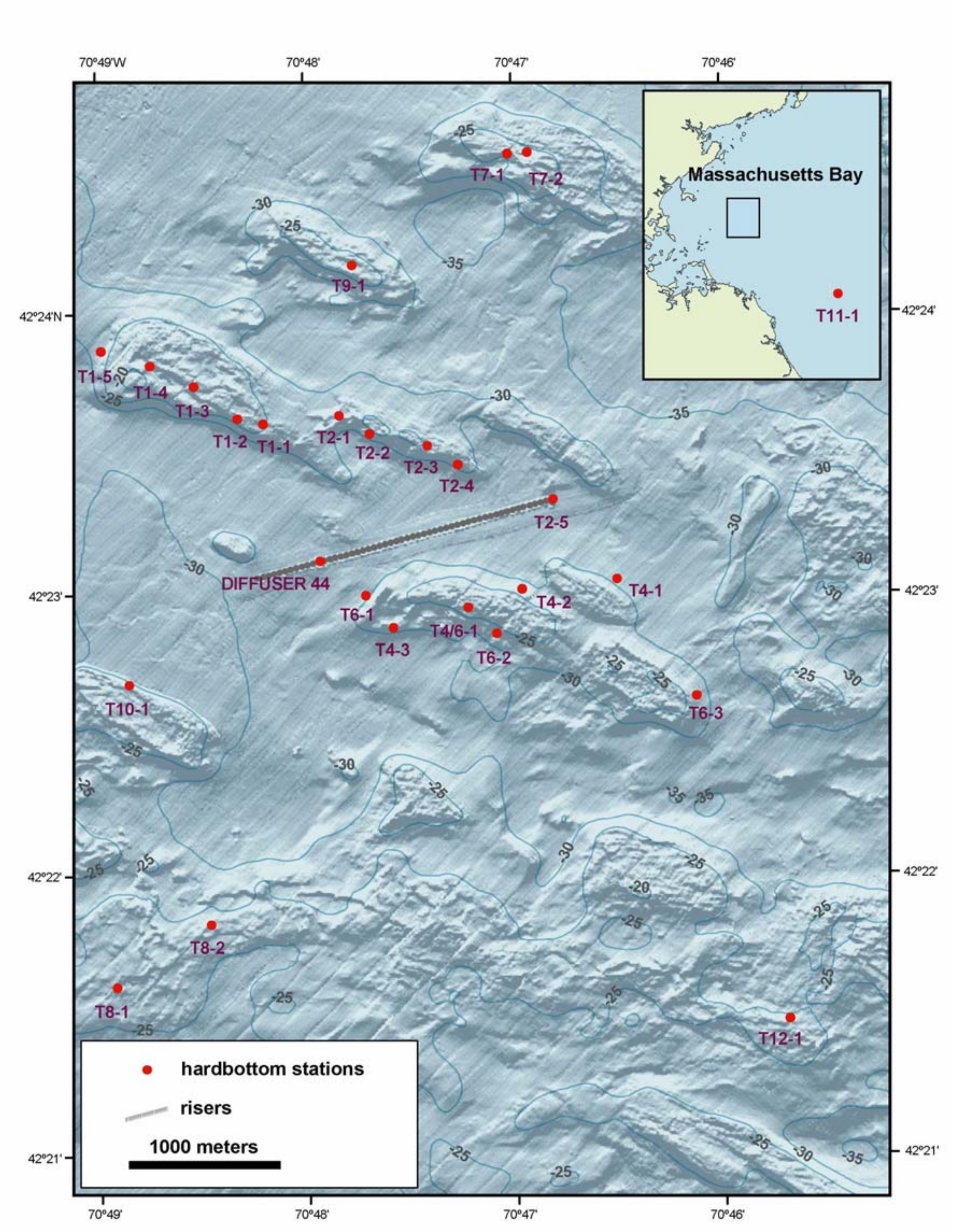


Figure 4-8. Locations of hard-bottom stations.

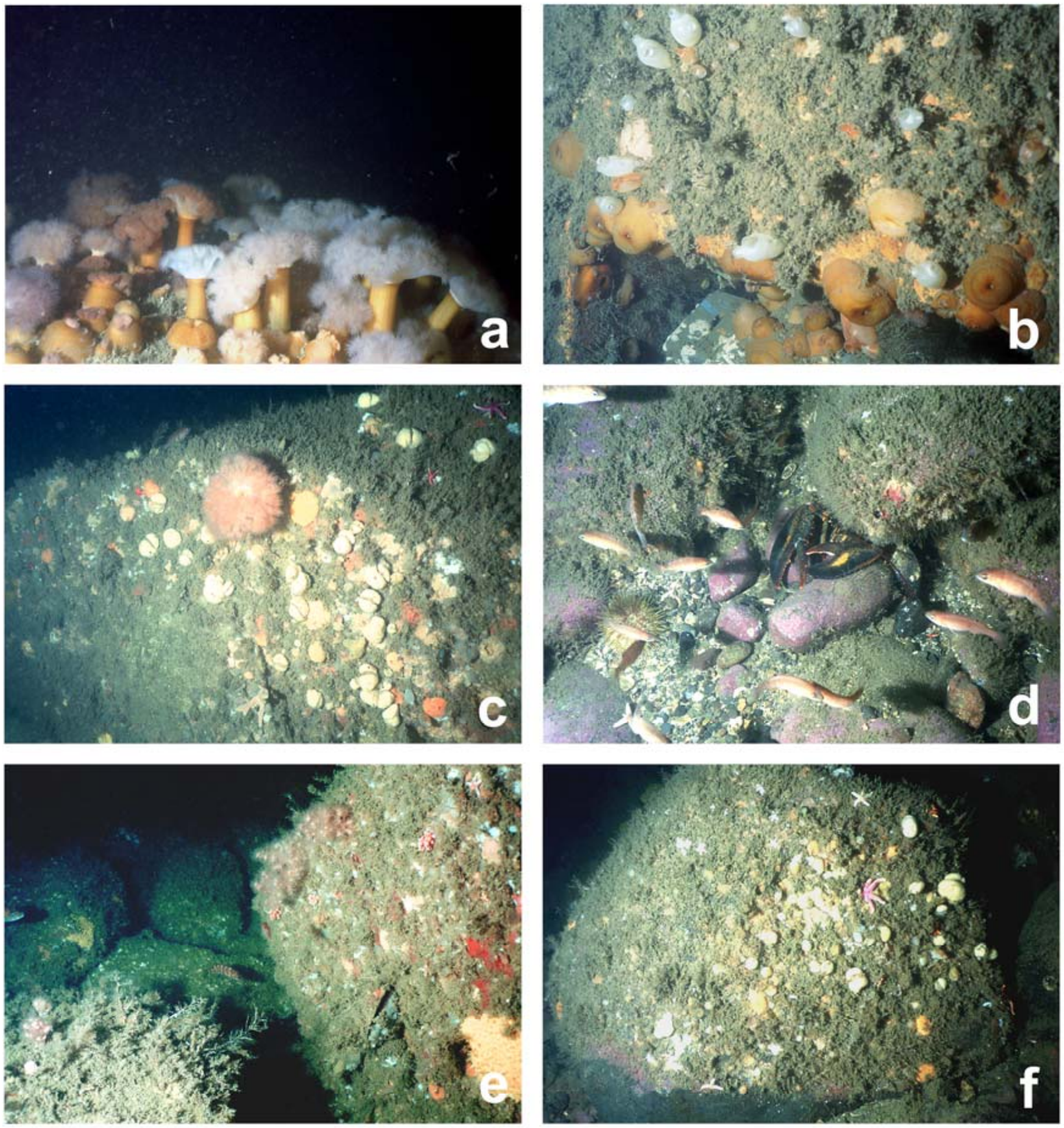


Figure 4-9. Photographs of the hard bottom taken in 2007. *(a) the top of an active diffuser head, showing colonization by many anemones; (b) the side of the inactive diffuser head showing colonization by sea-peach tunicates and frilled anemones; (c) a rock at a site just north of the outfall (T2-4) showing an anemone, brachiopods, and other encrusting organisms; (d) numerous cunner and a lobster in its burrow at a site south of the outfall (T4/6-1); (e) a boulder at a southern reference site (T10-1), colonized by soft corals; (f) a boulder at a northern reference site with brachiopods, sea stars, and encrusting organisms.*

Contingency Plan Thresholds

No Contingency Plan thresholds for sea-floor monitoring were exceeded in 2007 (Table 4-1). There have been no threshold exceedances for any sea-floor parameter during the course of the monitoring program. RPD depth was almost 50% deeper than the baseline mean; the caution threshold was set as 50% shallower, so the results indicate no adverse effects from the discharge. Soft-bottom community parameters were within normal ranges, and the percent of the soft-bottom community composed of opportunistic species remained low, more than an order of magnitude below the caution threshold.

Table 4-1. Contingency Plan threshold values and 2007 results for sea-floor monitoring.

Location	Parameter	Caution Level	Warning Level	2007 Results
Sediments, nearfield	RPD depth	1.18 cm	None	3.47 cm
Odd years, benthic diversity, nearfield	Species per sample	<46.52 or >79.95	None	64.05
	Fisher's log-series alpha	<9.95 or >15.17	None	13.74
	Shannon diversity	<3.30 or >3.91	None	3.67
	Pielou's evenness	<0.56 or >0.66	None	0.61
Benthic opportunists	% opportunists	>10%	>25%	0.78%

5. Winter Flounder

Fifty sexually mature winter flounder were taken from each of four sampling sites (Figure 5-1) during late April and early May 2007 (Nestler *et al.* 2008).

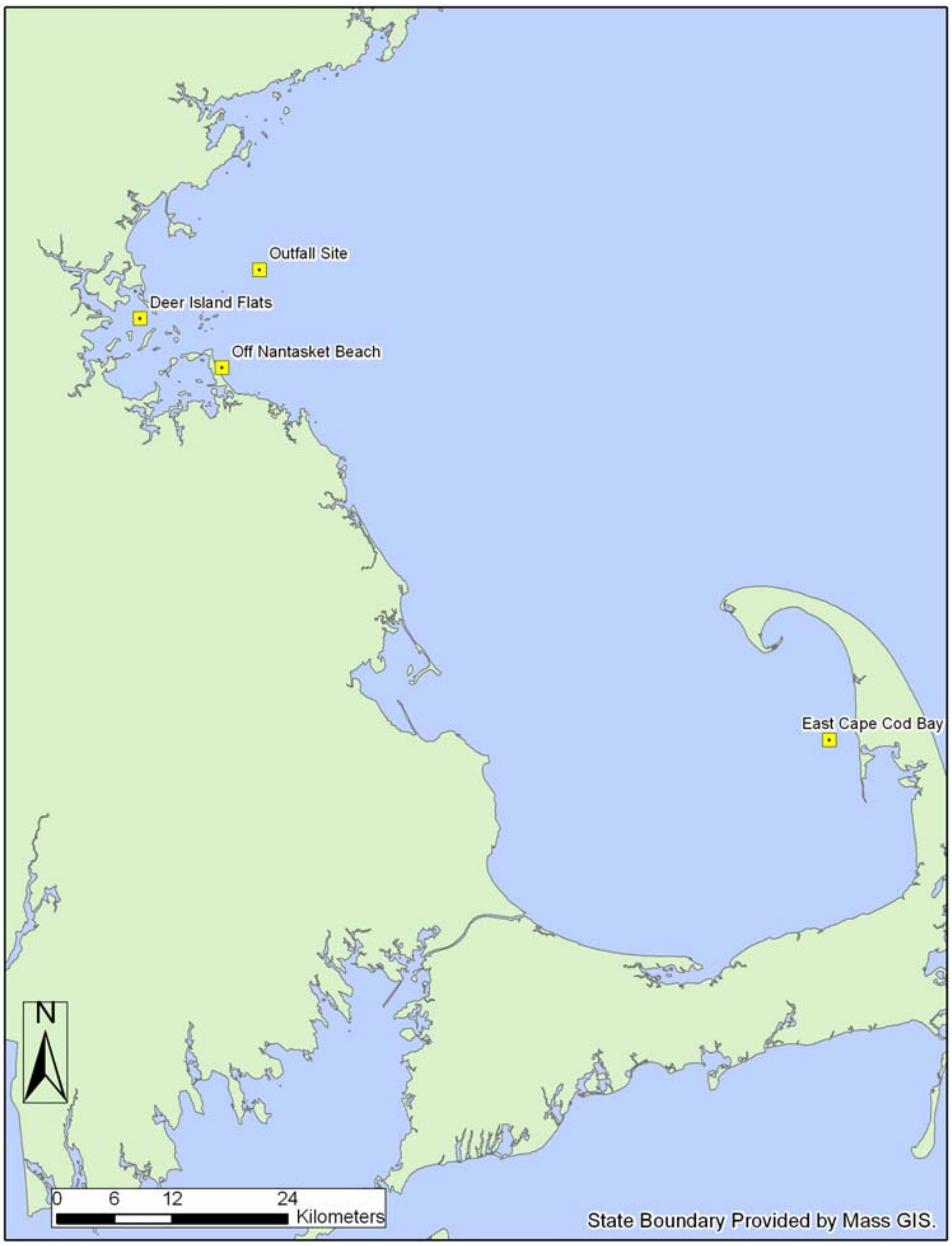


Figure 5-1. Winter flounder sampling sites.

Catch per unit effort remained low compared to 2001–2004 but was within the historic range and similar to the years before the outfall began to discharge. Similar to the last several years, fish collected at all stations tended to be older, longer, and heavier than fish caught in the mid-to-late 1990s. The percentage of female fish in the catch has also increased during that period, and almost every fish sampled was female (Figure 5-2). Skewed sex ratios are not unusual in flounder, and the region-wide incidence suggests that the outfall likely does not play a role.

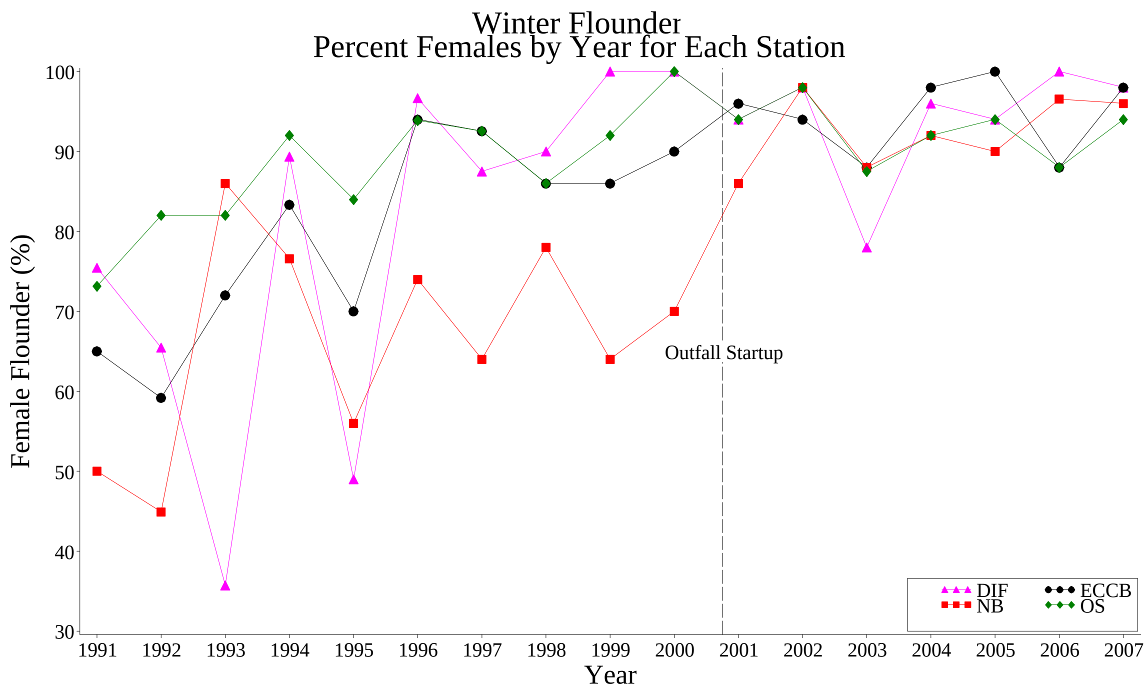


Figure 5-2. Annual percent females in winter flounder samples. *(DIF = Deer Island Flats, OS = Outfall Site, ECCB = Eastern Cape Cod Bay, NB = Nantasket Beach)*

Fin erosion, a parameter that can be indicative of poor water quality, remained within the historic range, except at Deer Island Flats, where incidence has been somewhat elevated since 2005. Even at Deer Island Flats, the incidence of skin lesions remained well below that observed in the region during the early 1980s.

Blind-side ulcers, which were first detected in 2003, were uncommon, continuing an ongoing decline since they were first noted (Figure 5-3).

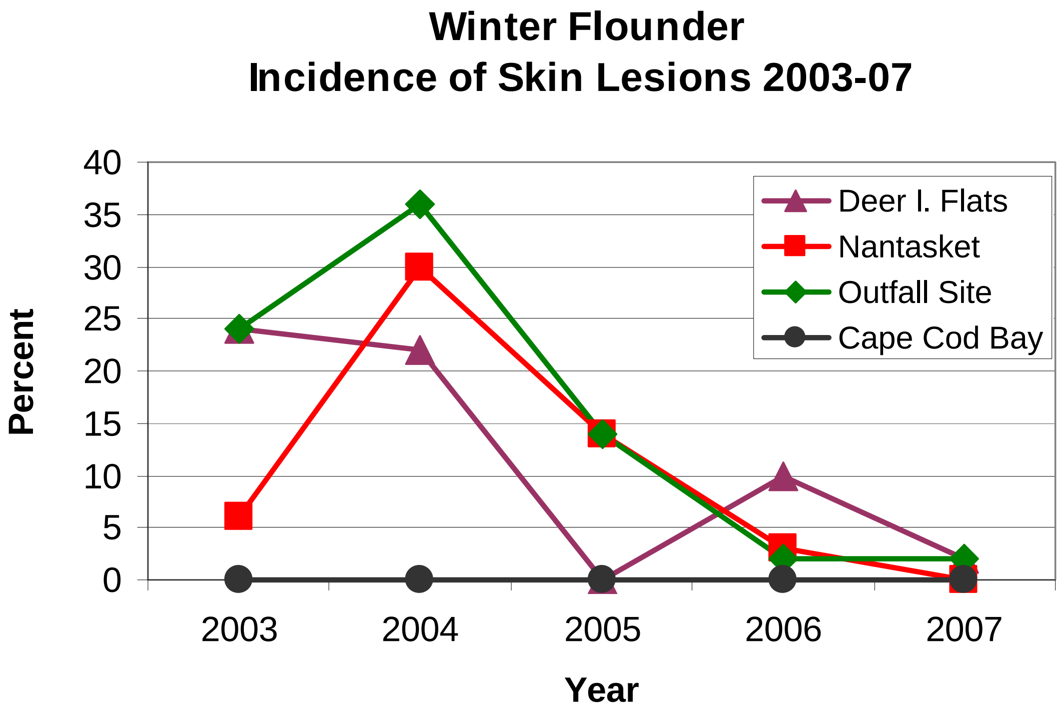


Figure 5-3. Incidence of skin lesions in flounder collected from four locations, 2003–2007.

No liver neoplasms (which can include cancer) were observed in any fish from any site. Incidence of neoplasia has been rare throughout the area since routine monitoring started in 1991, though levels were as high as 12% in harbor flounder during the 1980s. Neoplasia has never been observed in fish taken from the outfall site. The incidence of centrotubular hydropic vacuolation (CHV), a mild liver condition associated with exposure to contaminants, remained low (Figure 5-4). Incidence of CHV in fish from the outfall site continued to be lower than the incidence in the years before the outfall began to discharge. Incidence at Deer Island Flats has also declined since the outfall began operation, continuing to suggest that there has been no adverse effect from the outfall diversion. At Nantasket Beach, the 2007 incidence was higher than in recent years but lower than many baseline years.

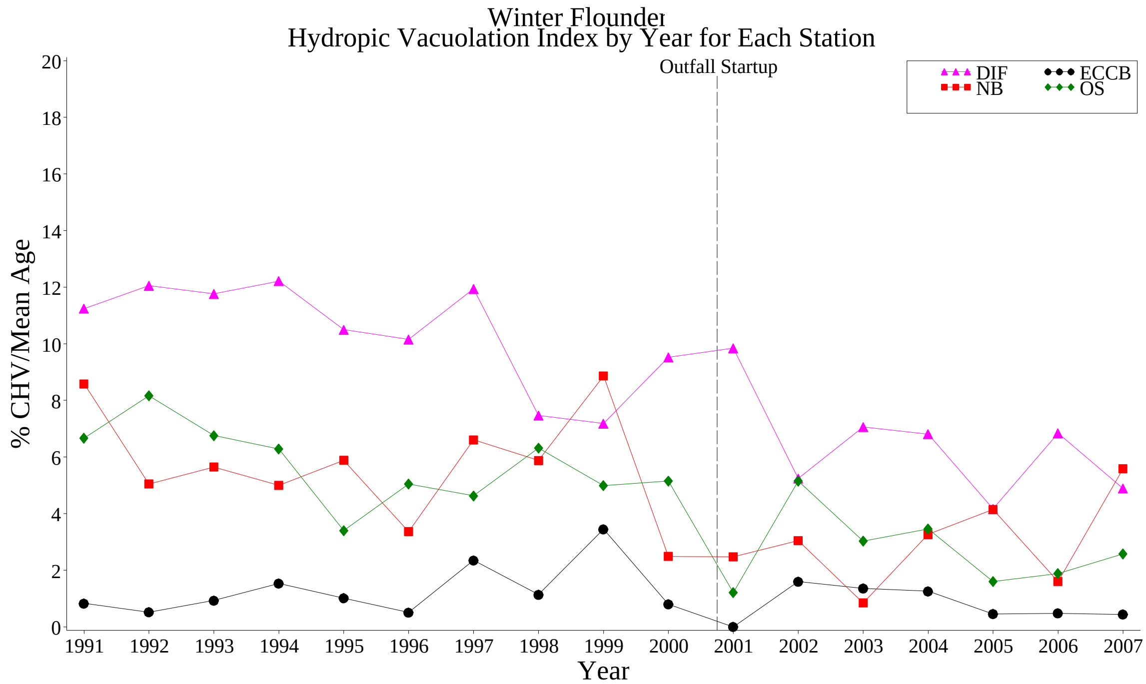


Figure 5-4. Annual prevalence of centrotubular hydropic vacuolation (CHV), corrected for age. *(DIF = Deer Island Flats, OS = Outfall Site, ECCB = Eastern Cape Cod Bay, NB = Nantasket Beach)*

Contingency Plan Thresholds

Only one threshold parameter for fish and shellfish was measured in 2007 (Table 5-1). Incidence of CHV, the most common indicator of liver disease in the winter flounder of the region, was 12% in fish taken from the vicinity of the outfall site. This value was less than half the 24.4% observed during the baseline period and well below the caution level.

Table 5-1. Contingency Plan threshold values and 2007 results for fish and shellfish monitoring.

Parameter Type/ Location	Parameter	Baseline	Caution Level	Warning Level	2007 Results
Flounder nearfield	Liver disease (CHV)	24.4%	44.9%	None	12%

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. Recent special studies included:

- Analysis of floatables in the effluent and ambient waters near the outfall site.
- Nutrient flux at the sediment-water interface.
- Marine mammal observations.
- Advanced statistical evaluation of the fish-and-shellfish contaminant monitoring program.
- Effects of combined sewer overflow (CSO) discharges on Boston Harbor sediments.
- Bacteria monitoring in the harbor and its tributary rivers.

Floatables Monitoring

In 2002, as part of its effluent monitoring study, MWRA developed an effluent sampler (Figure 6-1) that screened debris from the disinfection basin for sampling floatables in effluent from DITP. After a pilot study, MWRA began regular quantitative effluent floatables sampling in 2003. Petroleum hydrocarbons (PHC) are measured as part of Contingency Plan monitoring, and fats; oil and grease (FOG) are also measured. In addition, MWRA has been sampling the water for floatables at the outfall site and at a control site using a plankton net on every nearfield water column survey since 2000.

Effluent floatables

The mean volume of debris sampled during effluent monitoring was 168 parts per billion (ppb), and mean weight was 45 ppb. On average, non-degradable materials were present at 6 ppb by weight. Total floatables comprised about 86% degradable and 14% non-degradable material. Floatables of most concern—plastic bags—were rare; condoms and tampon applicators were sometimes found. Most of the non-degradable material was in small pieces, for example, fruit labels and cellophane-type wrappers. Much of the degradable material was bits of fat and plant matter.

Figure 6-1. Effluent floatables sampler at the Deer Island Treatment Plant.

The amount of floatable material increased with increasing flow rates through the plant, which may have resulted from both more matter in influent (street runoff) and reduced removal efficiency at higher flow rates. However, even at the highest flows, material was present at only <200 ppb by weight. Since 2003, quantities of effluent floatables at DITP have decreased (Figure 6-2), likely a result of physical improvements to the secondary treatment facilities, such as improved tip tubes, which skim floating material from the secondary clarifiers, and improvements to the biological process.

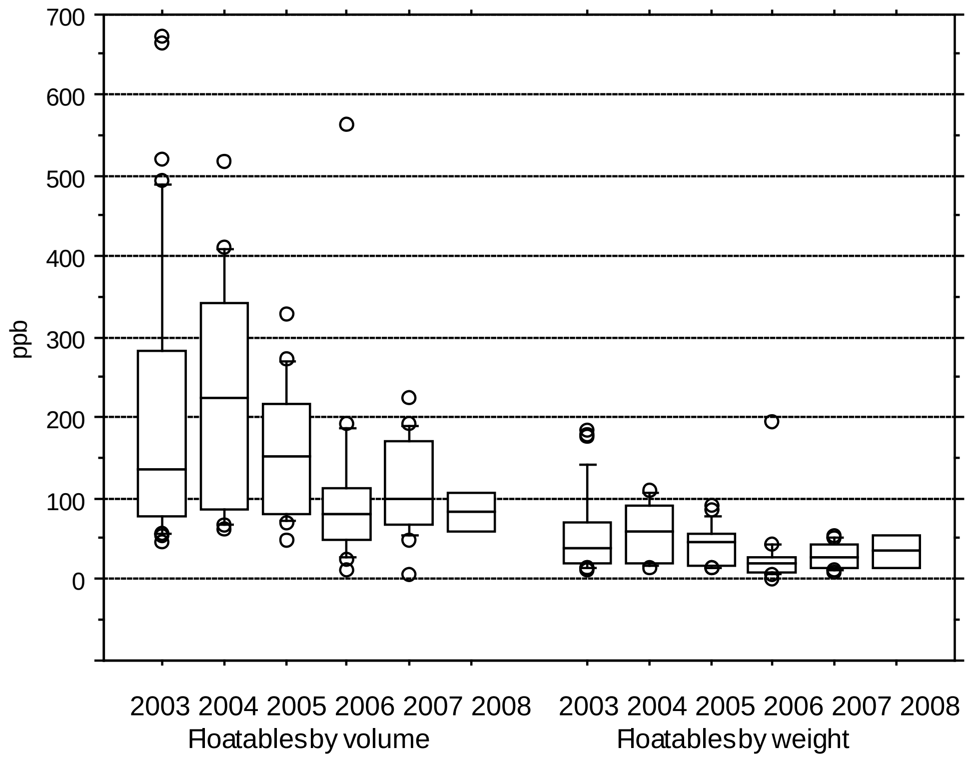


Figure 6-2. Box plot showing decreases in effluent floatables from 2003 through January 2008.

For FOG, 96% of effluent samples were below the laboratory detection limit; the mean value of FOG was 3.89 mg/L (assuming ½ the detection limit for samples below detection limits), and the maximum weekly mean was 13.6 mg/L. For PHC, 61% of the samples were below the laboratory detection limit; the mean value was 0.165 mg/L, and the maximum weekly mean was 0.7 mg/L, well below the Contingency Plan threshold of 15 mg/L weekly average.

Floatable debris (both degradable and non-degradable), FOG, and PHC were found at very low levels in DITP effluent. In particular, materials of concern such as petroleum, grease, and plastics, which are aesthetically offensive or could harm wildlife, are rare in the effluent.

Ambient floatables

Debris tows (Figures 6-3 and 6-4) at both the outfall site and at a control site north of the outfall, conducted during 2000–February 2008, found plastics and paper that are characteristic of trash discarded from land or boats. Plastic was found in 33% of tows at the outfall site and 24% of tows at the control site; paper was found in 8% of tows at the outfall site and 6% of tows at the control site. No paper or plastic debris characteristic of sewage was found at either site. Although at both sampling sites, the frequency of observations of paper debris decreased in the post-diversion ("after outfall") period, and observations of plastic increased, these apparent differences could result from the relatively small number of samples collected before the outfall went on-line. However, small fat particles were observed in 37% of tows at the outfall site and 5% of tows at the control site. These particles are similar to the particles observed in effluent samples at the treatment plant and presumably come from the outfall. The prevalence of observations of fat particles in the outfall tows from 2004 onward was substantially higher than 2000–2003, but it is likely that this finding is due to improvements in the field crews' awareness of and ability to see them in the tow samples. Such particles are only rarely directly observed in the environment; they must be concentrated in the net tows to be seen and do not have a significant aesthetic impact.

Results of the floatables study are presented in more detail in Rex *et al.* 2008.

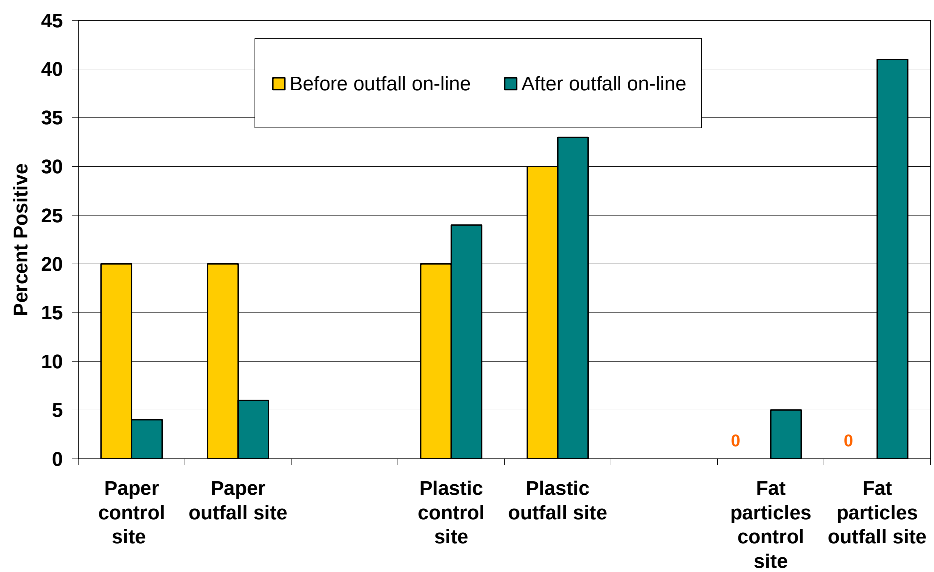


Figure 6-3. Results of ambient marine debris observations, February 2000–February 2008*. Ten samples were collected at the both the control and outfall sites before the outfall went on-line, and 95 samples were collected at each site after the outfall went on-line.*

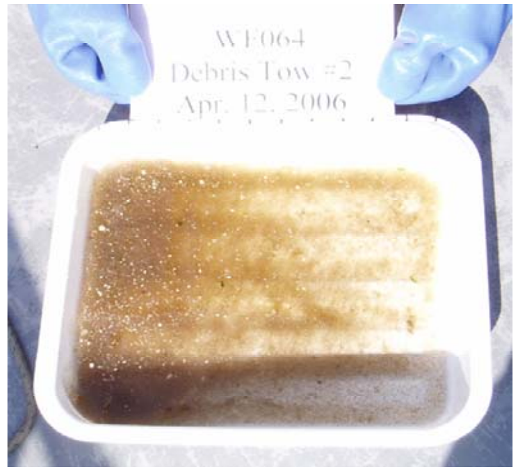


Figure 6-4. Samples of marine debris tows at the outfall site. *On the left, a sample collected before the outfall went on-line has plastic marine debris. The picture on the right, collected after the outfall went on-line, shows the fat particles which are sometimes seen.*

Nutrient Flux

One concern about the outfall was that increased loads of organic matter might enhance benthic respiration and increase fluxes of nutrients between the sediments and the water column in the nearfield. 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.

These concerns have not been realized (Tucker *et al.* 2008). In fact, in ongoing studies of three nearfield stations and one station in Stellwagen Basin, fluxes have changed very little or decreased since the outfall began to discharge (Table 6-1). Meanwhile, there have been significant decreases in fluxes at four stations in Boston Harbor, reflecting great improvements to the benthic environment.

Table 6-1. Average sediment oxygen demand and nutrient fluxes in Massachusetts Bay and Boston Harbor. *Oxygen demand and flux units are mmol m^{-2} d^{-1}; baseline is 1993–2000 in Massachusetts Bay and 1992–2000 in Boston Harbor; denitrification averages for both Massachusetts Bay and Boston Harbor are for two stations rather than four. Positive sediment oxygen demand values reflect net oxygen uptake by the sediments; positive nutrient flux values indicate net release of nutrients from the sediments.*

Parameter	Massachusetts Bay		Boston Harbor	
	Baseline	Post-diversion	Baseline	Post-diversion
Sediment oxygen demand	17.2	15.2	69.4	36.1
Ammonium flux	0.7	0.3	3.6	2.1
Nitrate/nitrite flux	0.2	0.3	2.2	0.8
Phosphate flux	0.1	0.0	0.5	0.2
Silica flux	5.1	3.3	8.0	5.5
Denitrification	3.4	2.1	5.5	3.1

In 2007, rates of sediment oxygen demand at the nearfield stations averaged lower than the baseline mean. Dissolved inorganic nitrogen and silica fluxes were also lower than baseline means. Other measurements also continued to provide assurance that there have been no adverse effects of the outfall.

Results suggest that the outfall did not increase loadings of organic matter to the sediments. In 2007, the total organic carbon (TOC) content of sediments from the nearfield averaged 1.3%, near the center of the baseline range of 1.2–1.7%. One elevated TOC value was measured at the most northern nearfield station in May, but TOC content at this station declined again through the season, reaching low levels by October.

In Boston Harbor in summer 2007, scientists were surprised to discover that Station BH02 was heavily colonized by benthic infauna. This pollution-impacted station, located at the mouth of the Charles River, had previously had few animals. However, in 2007, bioturbation had caused a dramatic deepening of the surface oxidized layer, and fluxes at BH02 were anomalously high (Figure 6-5), a pattern that had been observed previously at stations colonized by amphipod mats. Rather than being a sign of degradation, the investigators regard the increased metabolic activity in the sediments at BH02 as a further step in the harbor's recovery, similar to conditions at another Boston Harbor station, BH03, in 1993 and 1995.

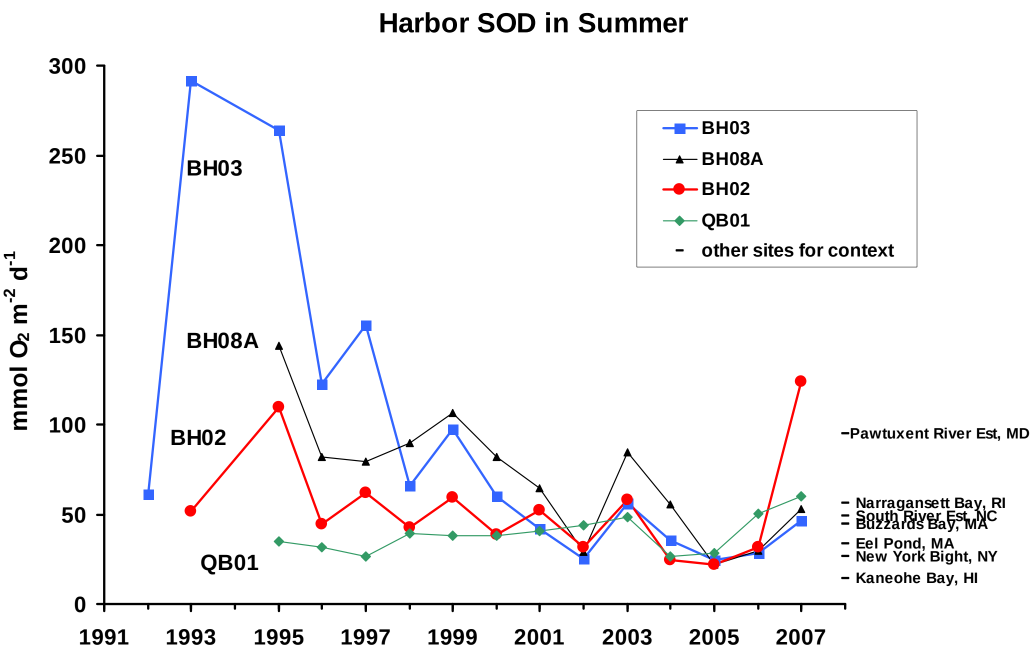


Figure 6-5. Long-term trends in summer (average of July and August) sediment oxygen demand at the four harbor stations, *showing extreme rates at BH03 in 1993 and 1995 as context for high rates at BH02 in 2007. Measurements from other locations are also provided for reference.*

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 2007, observers were included on twelve nearfield water quality surveys and three farfield surveys (Wisneski *et al.* 2008). 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.

The surveys are not designed to determine possible effects of the outfall on marine mammals, but they do provide general information. During the 2007 surveys, 17 individual whales, more than 13–18 Atlantic white-sided dolphins, and approximately 6 unidentified dolphins or porpoises were directly observed by the trained observers and other members of the monitoring team. The total number of whales sighted by a team member whose sole job was whale observation was low compared to 2006 but in the same range as the numbers sighted during 2002 and 2003. Most whale sightings occurred in or near the Stellwagen Bank National Marine Sanctuary, and several whales were sighted in the vicinity of the outfall.

Records of the Whale Center of New England (www.whalecenter.org) indicated that there were high numbers of whales in Massachusetts Bay and Stellwagen Bank during both 2006 and 2007. Adult humpback and fin whales were observed feeding on Stellwagen Bank, and humpback whale mother-calf pairs were also more abundant than they had been in recent years. During April and early May, northern Atlantic right whales were also present in higher-than-average numbers.

The Provincetown Center for Coastal Studies (www.coastalstudies.org), which conducts systematic surveys of Cape Cod Bay, reported that twice the usual number of right whales visited the area in 2007. The length of time that individual whales remained in or near Cape Cod Bay was also longer than has been typical in recent years.

Contaminants in Fish and Shellfish

The MWRA monitoring program includes measurements of contaminants in winter flounder, lobsters, and mussels in Boston Harbor and Massachusetts and Cape Cod bays. MWRA recently completed a review and statistical analysis (using a “before-after-control-impact” model) of data collected during the years immediately prior to the outfall start-up (1995–2000) and the post-diversion years (2001–2006) (Kane-Driscoll *et al.* 2008). The analysis examined whether contaminant levels have changed since the Massachusetts Bay outfall began to discharge, whether any changes could be attributed to the outfall, and whether the current levels of contaminants in fish and shellfish pose risks to human health or the environment.

Statistical analyses of contaminants in winter flounder fillet and liver tissues indicated that there were no adverse changes that could be attributed to the outfall diversion. Concentrations of some contaminants remained the same or decreased following the outfall start-up. Mercury concentrations in fillets from fish caught near the outfall site were higher in the post-diversion years than the baseline, but levels were also higher in samples from Cape Cod Bay (the control site), suggesting a regional source. Similarly, post-diversion concentrations of PCBs in flounder livers were higher in fish from both the outfall site and Cape Cod Bay. Concentrations of mercury in livers of fish taken near the outfall were unchanged from the pre-diversion years, while levels fell in the livers of fish taken from Cape Cod Bay.

There were also no indications of outfall effects in analyses of lobster meat and hepatopancreas. Concentrations of mercury in meat and hepatopancreas, chlordanes in meat and hepatopancreas, and PCBs and DDE in hepatopancreas were lower in the years after the outfall had begun to discharge compared to the baseline period.

It was possible to detect changes in response to the outfall in mussels that were deployed within the mixing zone of the outfall diffusers. Elevated concentrations of PCBs, PAHs, chlordanes, and DDE were measured in the post-diversion years. Meanwhile, there was an indication that moving the outfall away from Boston Harbor resulted in lower levels of chlordanes in mussels deployed near the site of the former discharge (Figure 6-6).

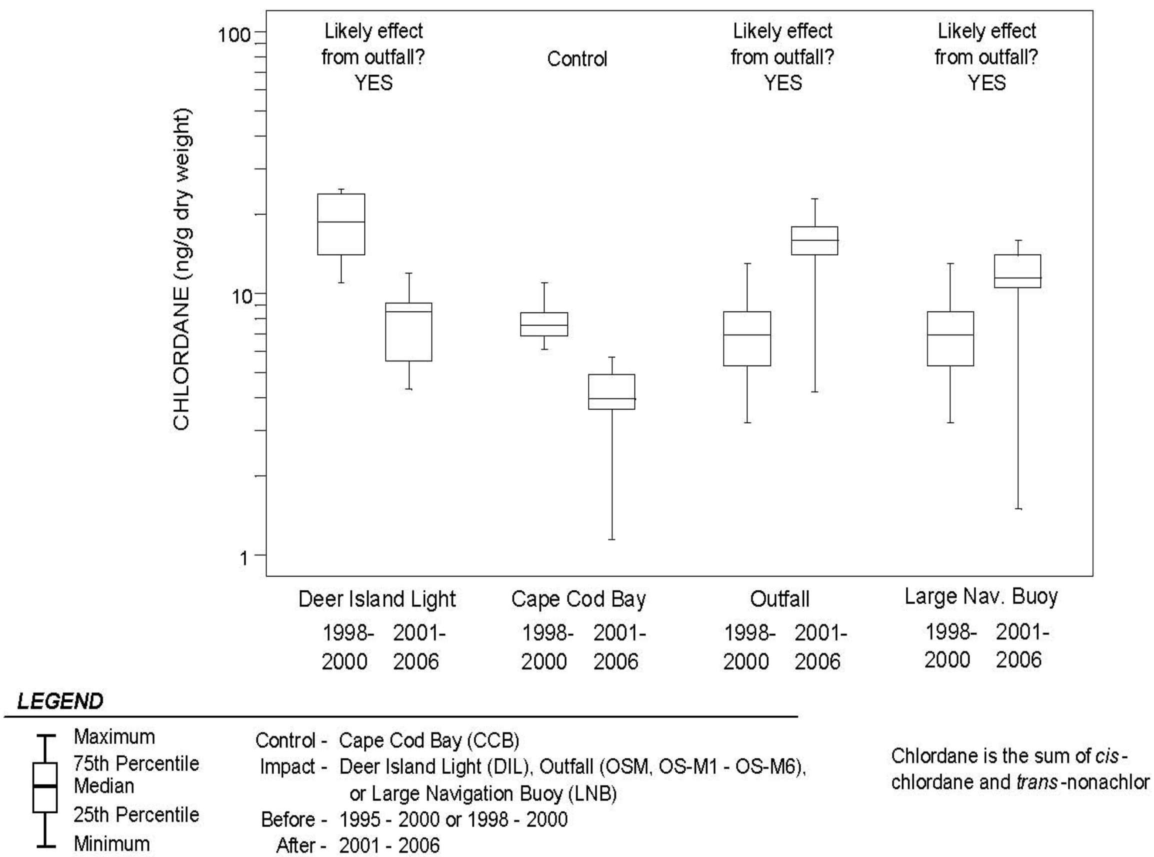


***Figure 6-6. Levels of chlordane in mussels** deployed at the outfall, large navigation buoy, and Deer Island Light ("impact" sites) and at Cape Cod Bay ("control" site). Compared to the Cape Cod Bay control site, results show statistically significant increases near the outfall and the buoy and statistically significant decreases at the former Deer Island Light discharge site following the diversion. The actual concentrations of chlordane were very low at all locations for all sampling periods.*

Overall, the analysis suggested that region-wide, concentrations of contaminants in flounder, lobster, and mussels did not change as a result of the discharge into Massachusetts Bay. Levels are generally below thresholds for the protection of public health and the environment. The data suggest that continued monitoring of contaminants in the effluent will provide sufficient information to assure continued protection of resources and wildlife.

Effects of CSOs on Sediments

During heavy rains, overflows from systems designed to carry both sewage and stormwater runoff (combined sewer overflows or CSOs) can result in direct discharges into local waters. MWRA's CSO Control Plan is designed to limit these discharges. To document improvements resulting from these controls, MWRA periodically surveys the sediments in Boston Harbor. Sampling has occurred at four-year intervals since 1990, with the most recent sediment survey taking place in 2006 (Pala *et al.* 2008). Seventeen stations designated as "near" and "far" from CSO discharges were sampled in the harbor, primarily in Dorchester Bay (Figure 6-7). Samples were analyzed for grain size, TOC, the sewage tracer *Clostridium perfringens* spores, PAHs, PCBs, pesticides, and selected metals.

Concentrations of the sewage tracer *Clostridium perfringens* spores at "near" stations decreased greatly after 1990 (Figure 6-8, top), a decrease that has been attributed to implementation of secondary treatment and the end of discharges of treated effluent to the southern part of the harbor, as well as to improvements at the Fox Point and Commercial Point CSOs. Slow declines have occurred at "far" stations.

Data on concentrations of organic contaminants in sediments have been difficult to interpret, probably reflecting multiple sources and the influences of physical factors, such as storms. For example, PAH concentrations have generally been higher at "near" stations than "far" stations but have not shown consistent patterns of decline. Concentrations of PCBs, DDTs (Figure 6-8, middle), and chlordanes have declined slowly in response to bans put on the chemicals as well as to discharge controls. Metals concentrations (for example, silver, Figure 6-8, bottom) have also been mostly higher at "near" stations and have also declined since the 1990s.

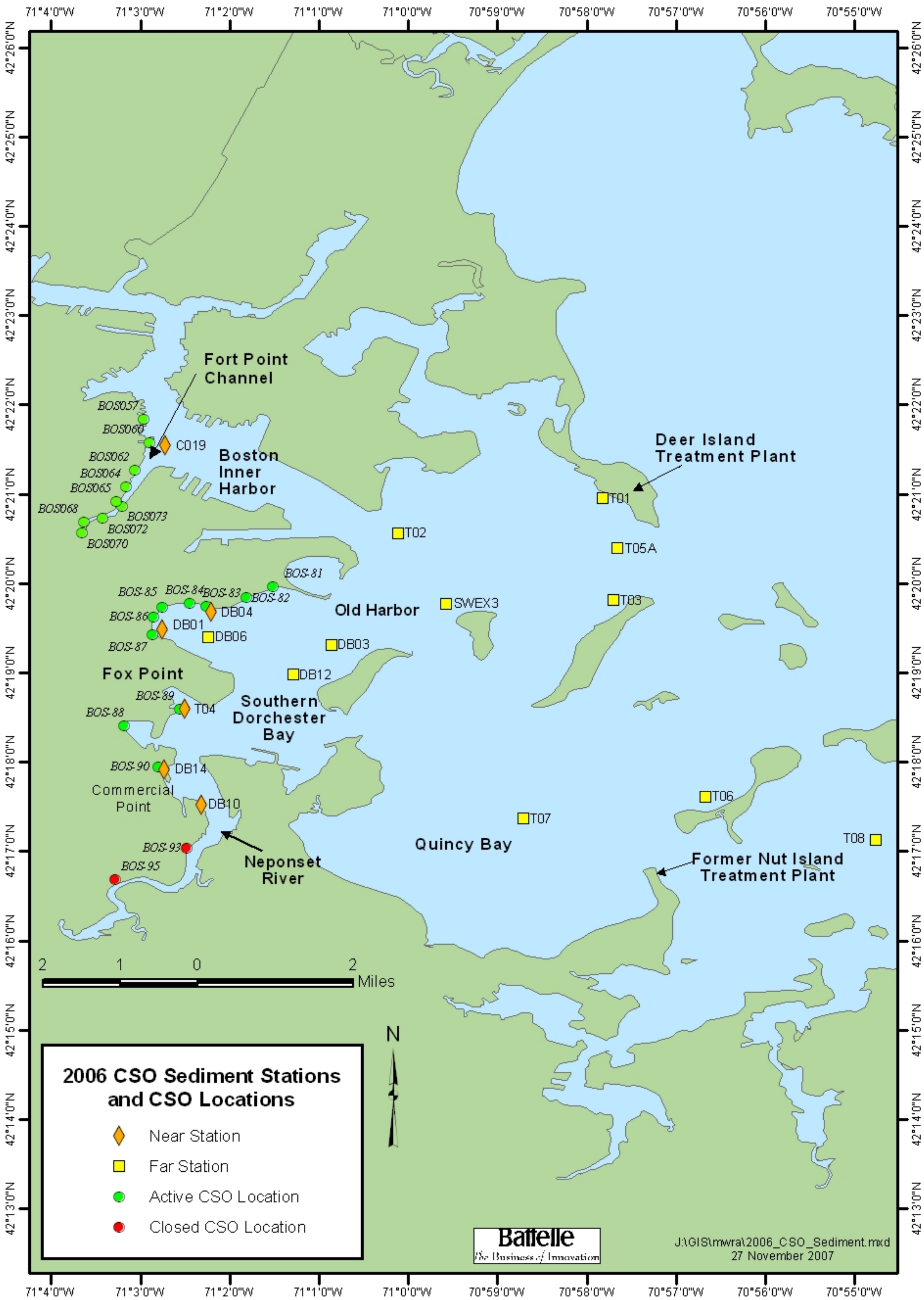
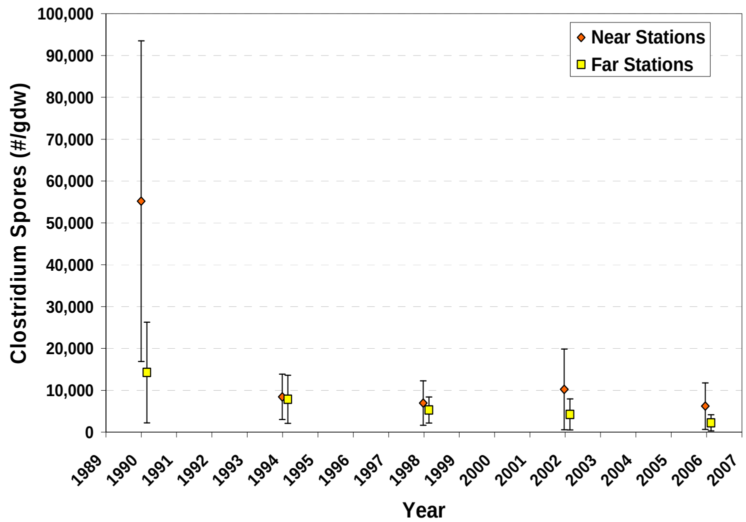
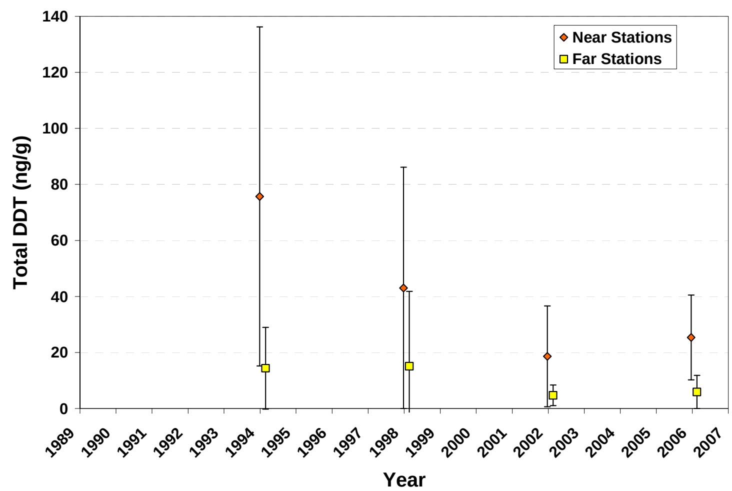


Figure 6-7. Sampling stations and locations of CSOs in Boston Harbor.





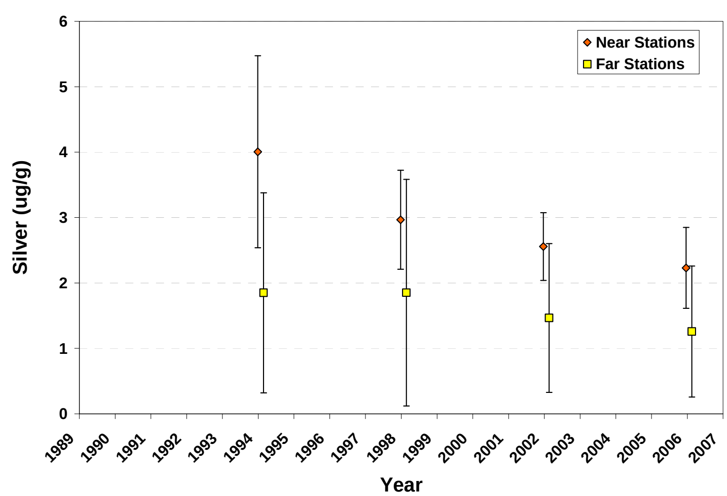


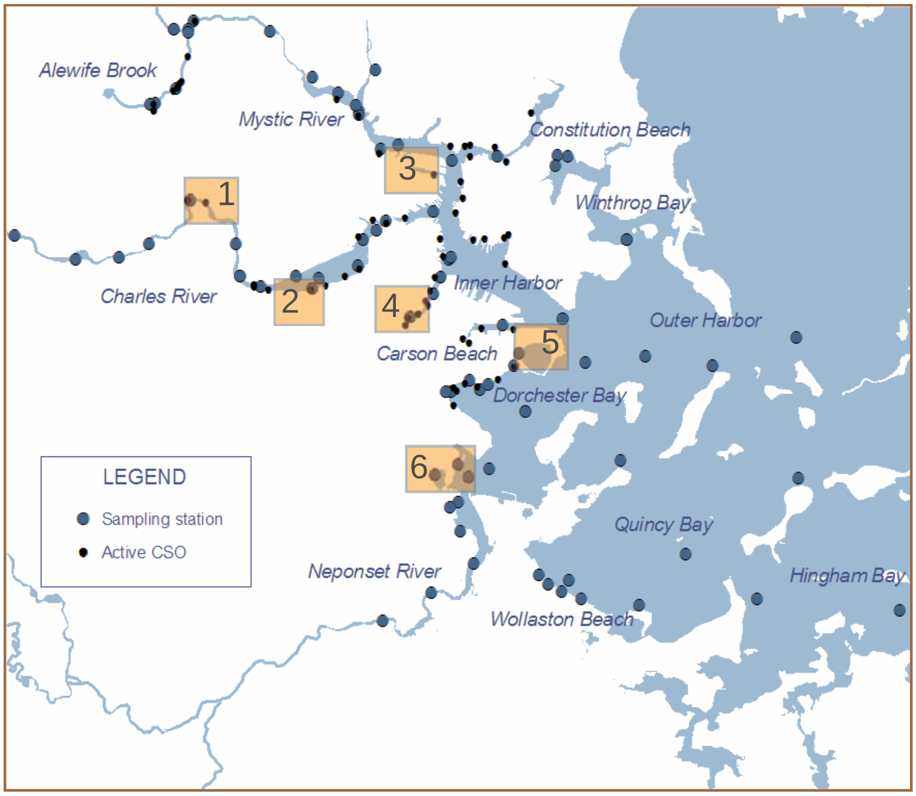
Figure 6-8. Concentrations of* Clostridium perfringens *spores (top), total DDTs (middle), and silver (bottom) at stations "near" and "far" from CSO discharges.

Harbor and River Bacteria Monitoring

MWRA's long-term bacteria monitoring of Boston Harbor and its tributary rivers has shown that tributary rivers, which are affected by CSOs and stormwater, have been consistently more impacted by bacterial contamination than the outer harbor where the two old treatment plants discharged. Since 1988, MWRA and the four communities with CSOs—Boston, Cambridge, Somerville, and Chelsea—have completed 21 major projects, reducing CSOs by 81%. CSO control projects have been completed during three major time periods: Phase 1, 1988–1991 (Early Improvements); Phase 2, 1992–1997 (System Optimization); and Phase 3 1998–2015 (Long-term CSO Control Plan). Figure 6-9 shows where CSO projects have recently been completed. In areas severely affected by CSOs, such as the Charles and Neponset rivers and the Inner Harbor, water quality improved dramatically as CSO projects came on-line (Table 6-2).

Table 6-2. Percent of samples meeting the **Enterococcus** ***limit,*** *"single-sample maximum" of 104 colonies/100 mL, in areas of Boston Harbor, its beaches, and tributary rivers over three time periods corresponding to phases of the CSO plan.*

Area	CSO Phase		
	1991 – 1997	1998 – 2000	2001 – 2007
Inner Harbor	77%	88%	82%
Winthrop Bay	96%	96%	96%
Constitution Beach	93%	88%	91%
Charles River	48%	70%	68%
Mystic River	74%	76%	73%
Alewife Brook	8%	12%	16%
Dorchester Bay	82%	83%	87%
Carson Beach	91%	95%	94%
Pleasure Bay Beach	90%	95%	95%
Neponset River	32%	38%	50%
Wollaston Beach	87%	87%	87%
Quincy Bay (offshore)	90%	98%	99.7%
Hingham Bay	96%	97%	100.0%



1

Two Cambridge CSOs closed

November 2007. CAM009 and CAM011 near the Eliot Bridge on the Charles River closed.

2

Stony Brook Sewer Separation

September 2006. Combined sewers tributary to Stony Brook Conduit and Back Bay Fens and the Charles River, were separated into storm drains and sanitary sewers, reducing CSO discharges from 22 activations (44.5 MG) to 2 activations (0.13 MG) annually.

3

Charlestown Storage Conduit

March 2007. CSO storage conduit provides 670,000 gallons of storage, reducing annual discharge volume to Little Mystic Channel in the Inner Harbor by 86%, from 4.4 million gallons to 0.6 million gallons.

4

Fort Point Channel Sewer Separation

March 2007. Sewer separ-ation eliminated discharges from two CSOs in Fort Point Channel in the Inner Harbor.

Union Park Detention and Treatment Facility

April 2007. New Union Park facility provides 2 MG storage, and treats CSO flows >2MG, reducing CSO discharges to the head of Fort Point Channel from 25 untreated to 17 treated activations annually.

5

Pleasure Bay Storm Drain Improvements

March 2006. Pleasure Bay storm drain improvements ended all wet weather discharges to the beach.

6

South Dorchester Bay Sewer Separation

November 2007. Fox Point and Commercial Point CSOs were decommissioned after sewer separation in South Dorchester Bay, eliminating CSO discharges to South Dorchester Bay.

Figure 6-9. Map of major CSO projects recently completed and locations of bacteria sampling stations.

Figure 6-10 shows *Enterococcus* counts in wet and dry weather in 12 areas of the harbor and its tributaries. Wet weather counts are substantially higher than dry weather counts, except where sampling locations are fairly distant from the shoreline (Winthrop Bay, Quincy Bay, and Hingham Bay). Where CSOs have been a major source (Inner Harbor, Charles River, and Neponset River), wet weather water quality has improved over time.

***Enterococcus* Counts 1991-2007 in Wet and Dry Weather**
(Geometric mean colonies/100 mL)

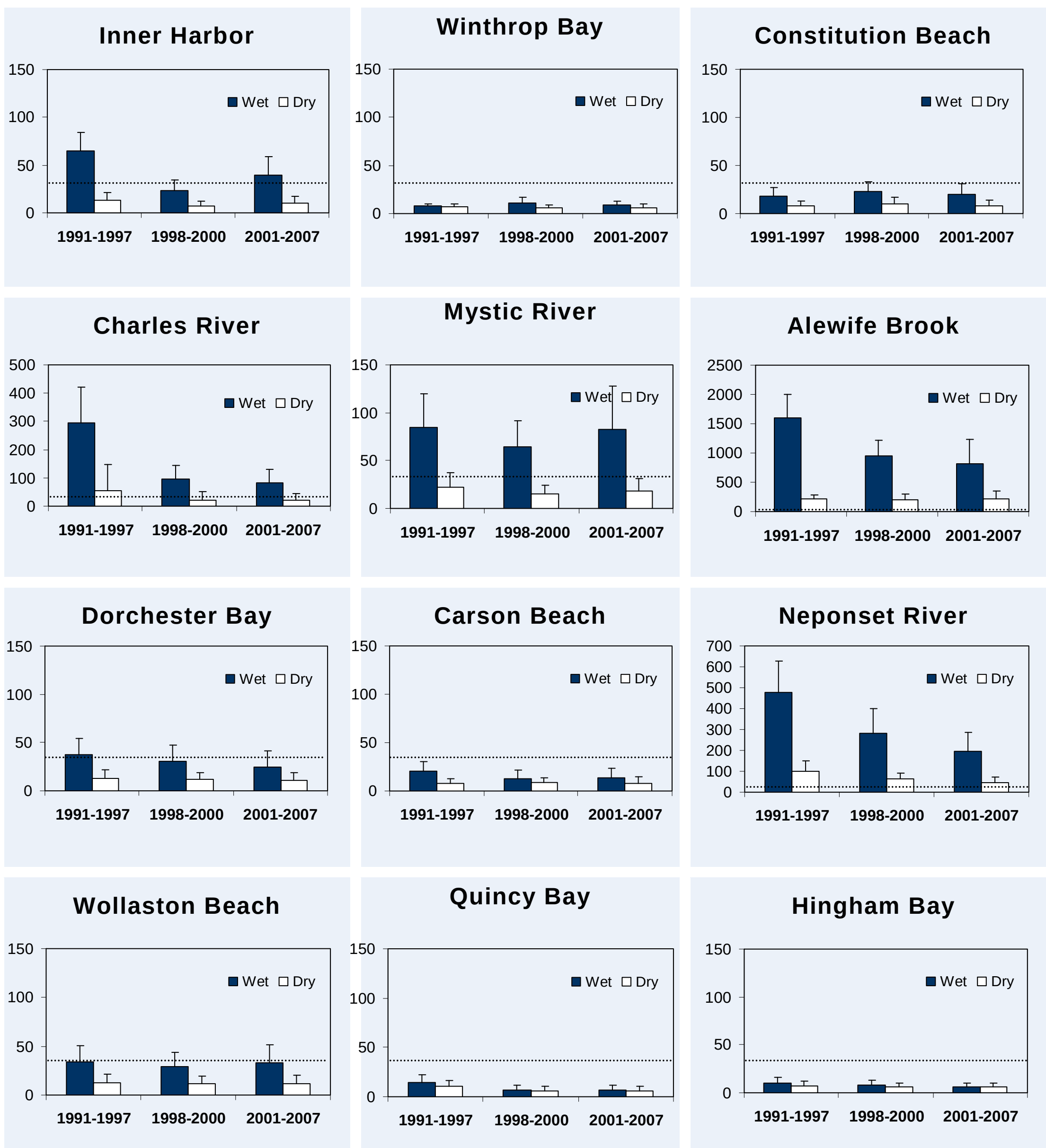


Figure 6-10. Changes in* Enterococcus *counts during wet and dry weather, 1991–2007 *in 12 areas of Boston Harbor and its tributaries. Wet = Rain > 2 inches of the previous 2 days. Dry = No rain over the previous 3 days. Dotted lines show the standard, 35 colonies/100 ml.*

7. Stellwagen Bank National Marine Sanctuary

Water Column

Overall, water quality within the Gerry E. Studds Stellwagen Bank National Marine Sanctuary is excellent, and the condition and characterization reports prepared by the NOAA National Marine Sanctuaries (available at http://sanctuaries.noaa.gov) have noted that chemical contaminant concentrations are low, water-quality conditions are favorable for habitat and living resources, and human activities are not having adverse effects on water quality. The 2007 MWRA water-quality monitoring efforts at the stations in and near the sanctuary (Figure 7-1) continued to support those findings. Water quality continued to be good, with dissolved oxygen, nutrient concentrations, and plankton community measures and abundances within expected ranges for this region of Massachusetts Bay. There was no indication of any effect of the Massachusetts Bay outfall (Libby *et al.* 2008).

Annual mean inorganic nitrogen (ammonium and nitrate) concentrations vary from year to year in Massachusetts Bay, including within the sanctuary. The present understanding is that nutrient levels within Massachusetts Bay are mostly driven by nutrient levels in the very large water masses entering at the northern boundary region, with some influence of local or nearby sources. Consistent with this understanding is the coherence between the pattern of ammonium concentration in the sanctuary with that in the nearfield (Figure 7-2, top). After the outfall went on-line, the nearfield pattern resembles that in the sanctuary plus about 1uM. The long-term pattern of other areas within Massachusetts Bay also showed some influence of ammonium from the Gulf of Maine, but less so in Cape Cod Bay which is shown for reference (Libby et al 2008). Figure 7-2 (bottom) shows long-term nitrate concentrations. These have trended upward in the sanctuary, the nearfield, and other areas of Massachusetts Bay.

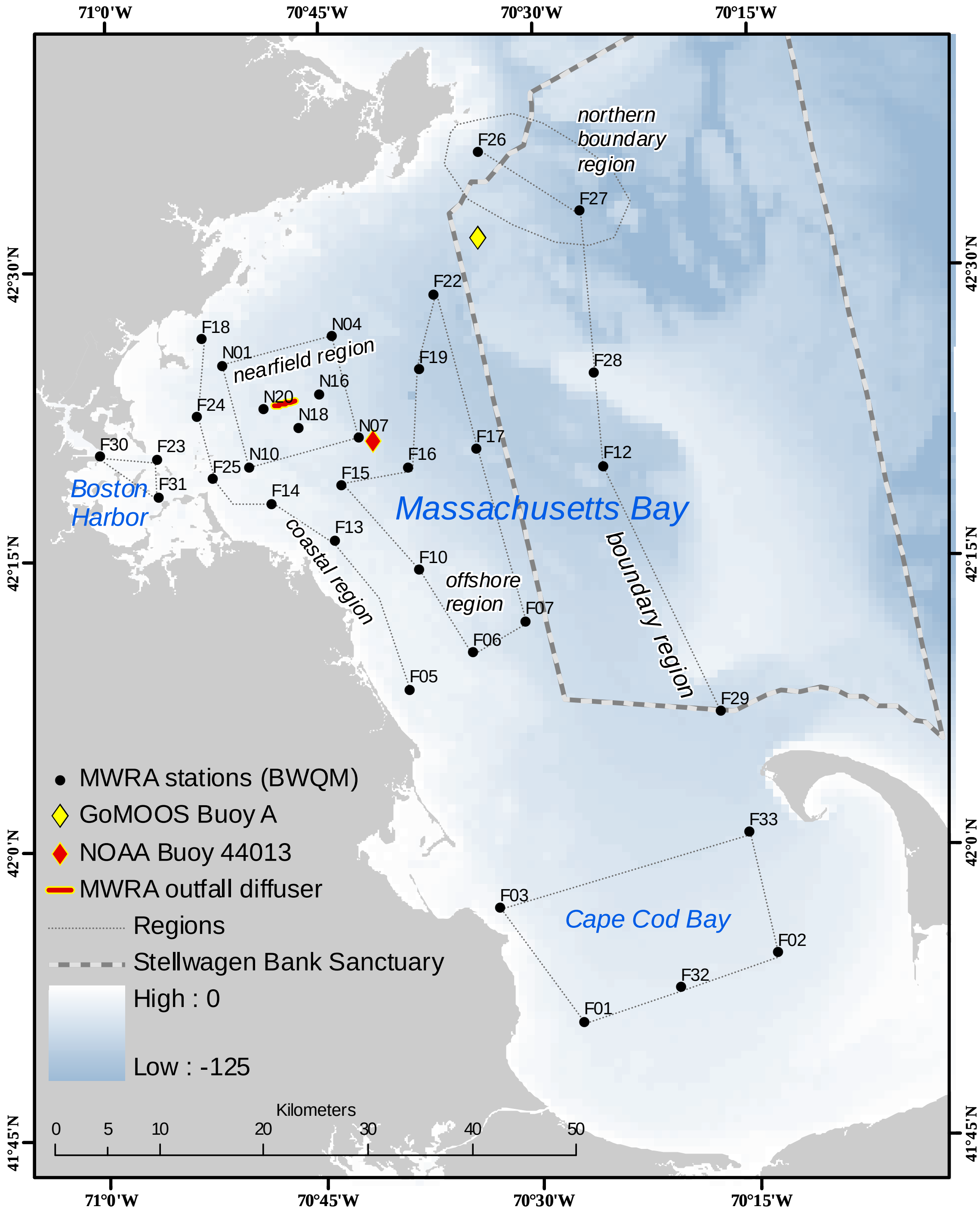


Figure 7-1. Water column stations, including those in and near the Stellwagen Bank National Marine Sanctuary (F27, F28, F12).

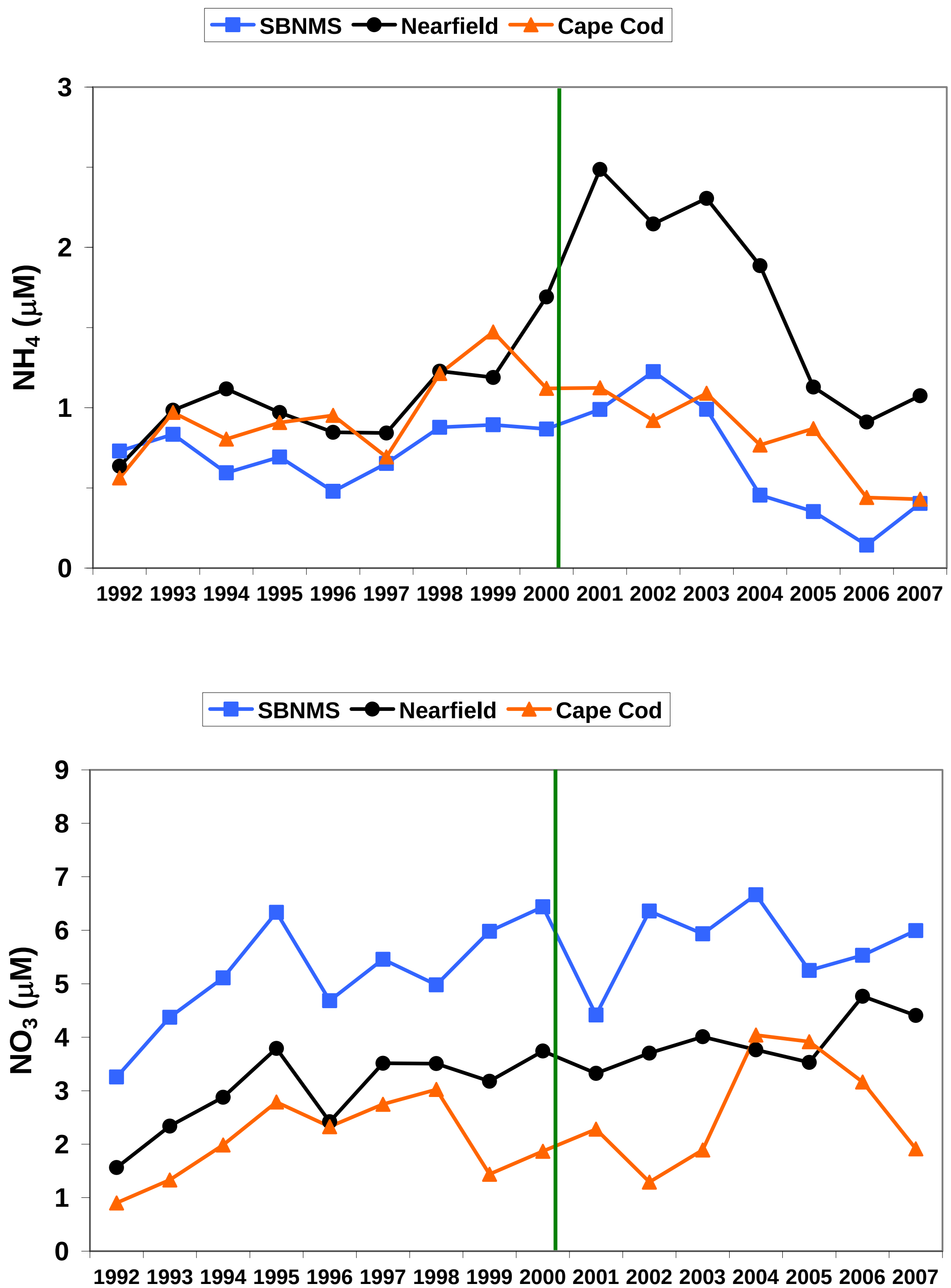


Figure 7-2. Annual mean ammonium (top) and nitrate (bottom) at the Stellwagen Bank National Marine Sanctuary (SBNMS), the outfall nearfield, and Cape Cod Bay. *No changes that can be attributed to the outfall have occurred in the stations in or near the sanctuary.*

The annual mean areal chlorophyll levels increased slightly at the sanctuary stations and in Cape Cod Bay in 2007, while slightly declining in the nearfield (Figure 7-3). This result did not significantly diverge from the general pattern. There was a large peak in chlorophyll levels during the April *Phaeocystis pouchetii* bloom. This wide-scale bloom was not related to the outfall (see Section 3, Water Column). Chlorophyll levels were within the baseline range during the rest of the year.

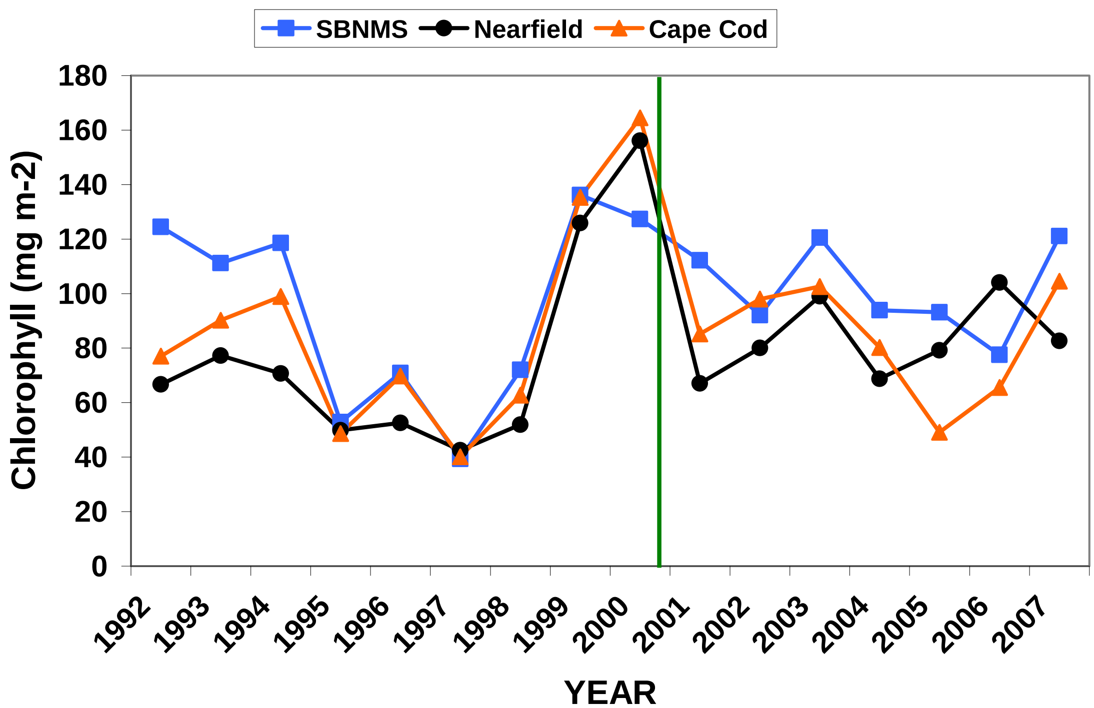


Figure 7-3. Annual chlorophyll at the Stellwagen Bank National Marine Sanctuary (SBNMS), the outfall nearfield, and Cape Cod Bay. *Over the course of monitoring, annual chlorophyll levels have varied, but similar patterns have been seen in samples in or near the sanctuary, the nearfield, and Cape Cod Bay.*

Concentrations of dissolved oxygen (Figure 7-4) and percent saturation have remained unchanged in Stellwagen Basin as well as in the nearfield. There have been no decreases in dissolved oxygen concentrations or percent saturation, as had been a concern before the outfall began to discharge.

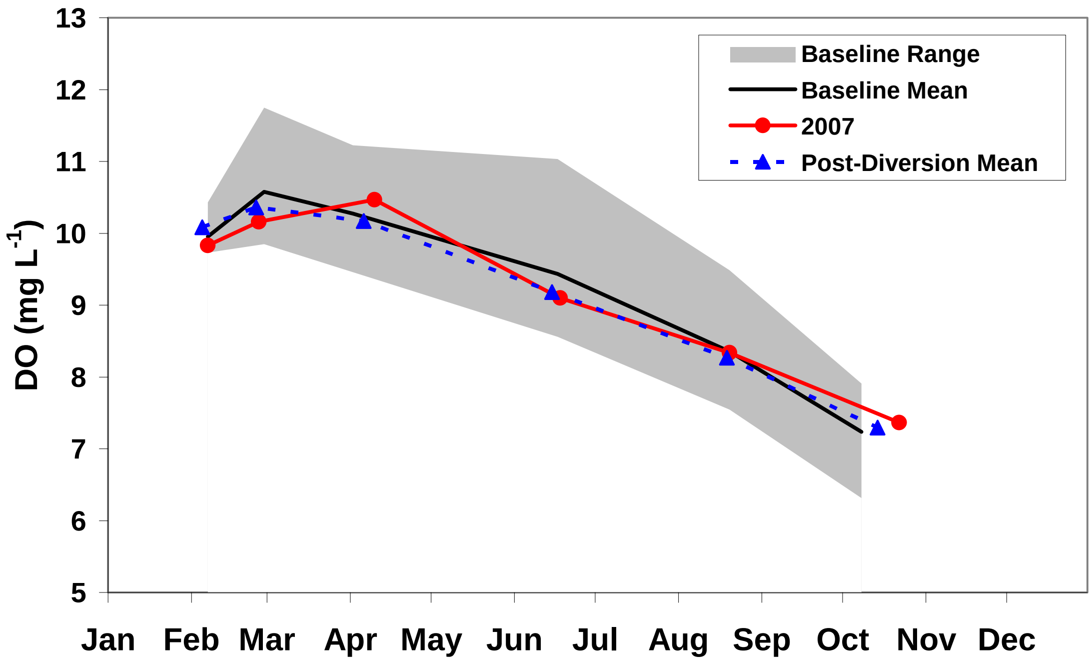


Figure 7-4. 2007 bottom water dissolved oxygen (DO) concentrations in Stellwagen Basin compared to baseline range, baseline mean, and post-diversion mean. *There has been no change in patterns of dissolved oxygen concentrations (or saturation) since the outfall began to discharge.*

Sea Floor

No changes in concentrations of sewage tracers or sewage-related contaminants were observed in the sediment samples from stations (FF05 and FF11) within or near the sanctuary (Figure 7-5), and there have been no changes in community parameters since the outfall began operation (Maciolek *et al.* 2008).

The deep-water stations sampled in 2007 continued to support a distinct infaunal community with recognizable differences from communities in the nearfield and Cape Cod Bay. Benthic community parameters at individual stations showed no pattern of change following start-up of the outfall in 2000. The total number of individual organisms remained within the baseline range for stations in or near the sanctuary (Figure 7-6). The numbers of species per sample and the diversity of organisms within the sample were also within the baseline range. No consistent patterns that relate to outfall diversion have been found.

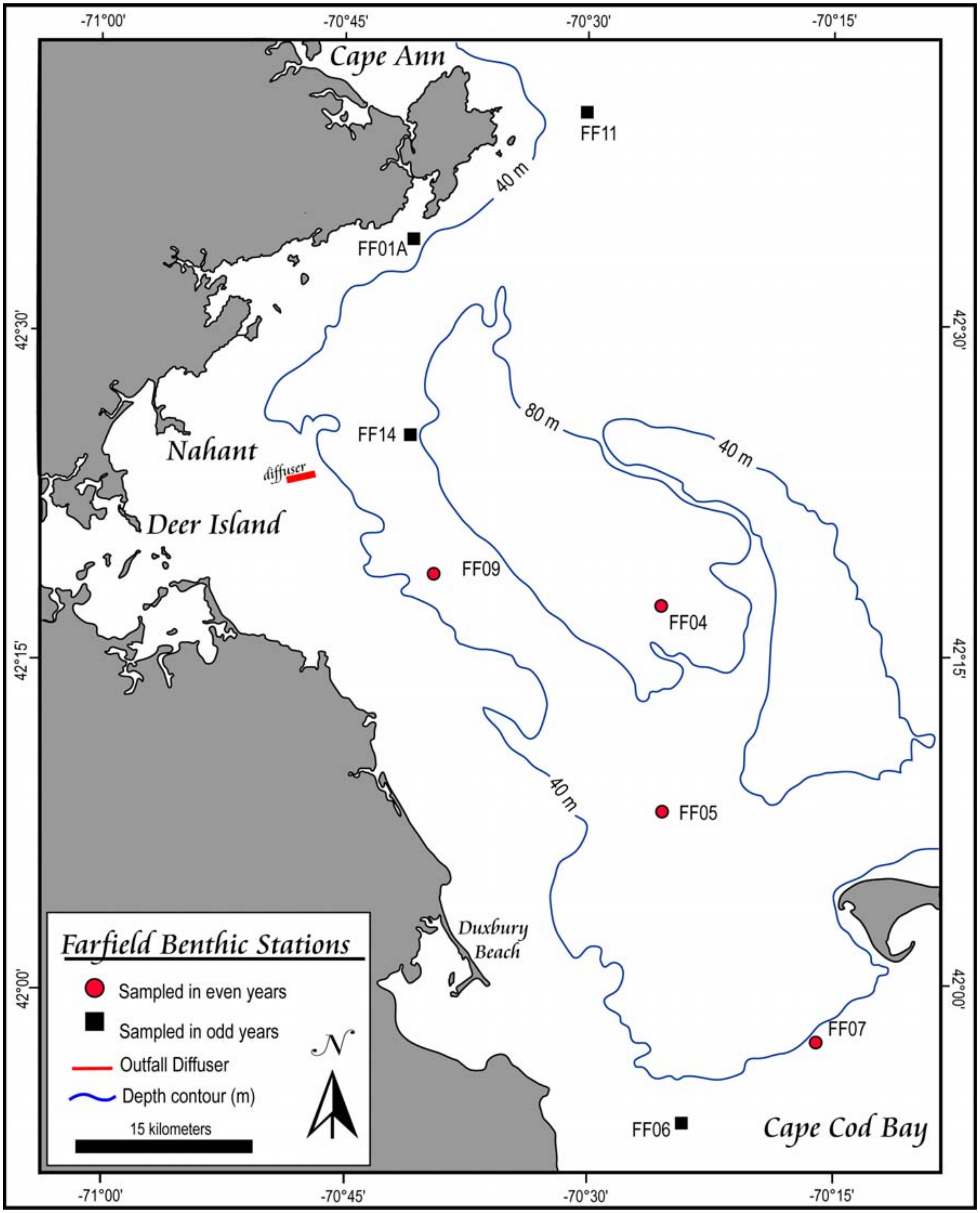


Figure 7-5. Farfield benthic stations. *Stations FF05, FF04, FF11, and FF14 are in or near the Stellwagen Bank National Marine Sanctuary. FF11 and FF14 were sampled in 2007.*

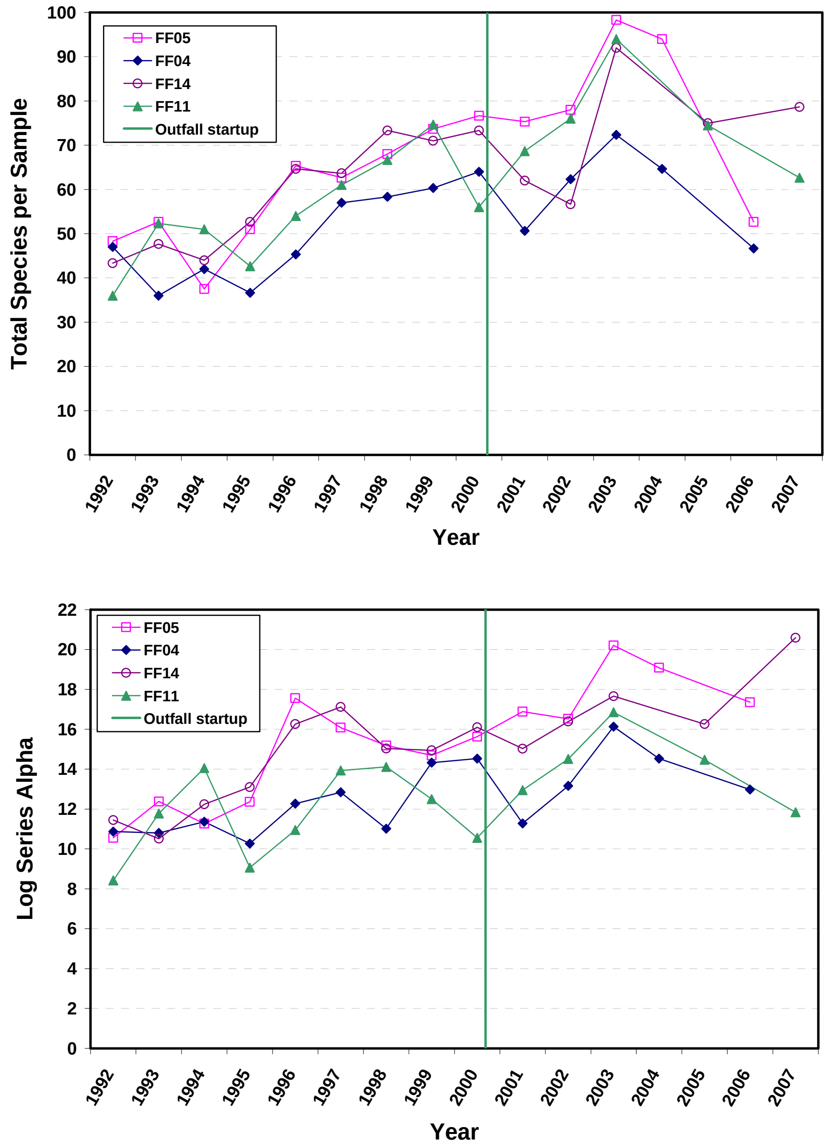


Figure 7-6. Community parameters at stations in or near the Stellwagen Bank National Marine Sanctuary.

8. Monitoring Questions and Answers: 2007

Prior to beginning the monitoring program, an Outfall Monitoring Task Force formulated a series of questions focusing on environmental issues that could be plausible unanticipated consequences of the effluent discharge. Monitoring has answered those original questions (Table 8-1).

Table 8-1. Answers to the monitoring questions as of the end of 2007.

Monitoring Question	Answer
Do effluent pathogens exceed the permit limits?	No. Compliance with permit limits, secondary treatment and disinfection effectively remove pathogens.
Does acute or chronic toxicity of effluent exceed the permit limit?	General compliance with permit limits.
Do effluent contaminant concentrations exceed permit limits?	No. Compliance with permit limits, discharges of priority pollutants well below SEIS predictions and in most cases meet receiving water quality criteria even before dilution.
Do conventional pollutants in the effluent exceed permit limits?	No. Compliance with permit limits, discharges of solids and BOD have decreased by 80% compared to the old treatment plant.
What are the concentrations of contaminants in the influent and effluent and their associated variability?	High removal by treatment system with consistently low concentrations since secondary treatment brought on line.
Do levels of contaminants in water outside the mixing zone exceed water quality standards?	No. Water quality standards not exceeded, confirmed by plume studies conducted in 2001 and ongoing effluent monitoring.
Are pathogens transported to shellfish beds at levels that might affect shellfish consumer health?	No. Dilution is sufficient for pathogens to reach background concentrations before reaching shellfish beds, confirmed by plume studies conducted in 2001.
Are pathogens transported to beaches at levels that might affect swimmer health?	No. Dilution is sufficient for pathogens to reach background concentrations before reaching beaches, confirmed by plume studies conducted in 2001.
Has the clarity and/or color of the water around the outfall changed?	No. Although clarity and color have not changed, there are occasional observations of tiny bits of grease, similar to samples collected at the treatment plant.
Has the amount of floatable debris around the outfall changed?	Floatable debris of concern is rare in the effluent. Signs of effluent can occasionally be detected in the field.
Are the model estimates of short-term (less than one day) effluent dilution and transport accurate?	Yes. Model estimates accurate, confirmed by plume studies conducted in 2001.

Monitoring Question	Answer
What are the nearfield and farfield water circulation patterns?	Flow is controlled by general circulation in the Gulf of Maine, and influenced by tides and local wind. Bottom currents around the outfall can flow in any direction with no mean flow direction.
What is the farfield fate of dissolved, conservative, or long-lived effluent constituents?	Changes in farfield concentrations of salinity and dissolved components not detected within tens of meters of outfall and not observed in farfield water or sediments.
Have nutrient concentrations changed in the water near the outfall; have they changed at farfield stations in Massachusetts Bay or Cape Cod Bay, and, if so, are they correlated with changes in the nearfield?	Changes consistent with model predictions. The effluent signature is clearly observed in the vicinity of the outfall but is diluted over a few days and 10s of kilometers.
Do the concentrations (or percent saturation) of dissolved oxygen in the water column meet the state water quality standards?	Yes. Conditions unchanged from 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 not changed from baseline.
Has the phytoplankton biomass changed in the vicinity of the outfall or at selected farfield stations in Massachusetts Bay or Cape Cod Bay, and, if so, can these changes be correlated with effluent or ambient water nutrient concentrations, or can farfield changes be correlated with nearfield changes?	No. No substantial change detected.
Have the phytoplankton production rates changed in the vicinity of the outfall or at selected farfield stations, and, if so, can these changes be correlated with effluent or ambient water nutrient concentrations, or can farfield changes be correlated with nearfield changes?	Productivity patterns in Boston Harbor may be changing, as the area transitions from eutrophic conditions to a more typical coastal regime. No concurrent increase in productivity in Massachusetts Bay.
Has the abundance of nuisance or noxious phytoplankton changed in the vicinity of the outfall?	Frequency of *Phaeocystis* blooms has increased, but the phenomenon is regional in nature. *Alexandrium* blooms in 2005 and 2006 were regional and have not been attributed to the outfall.
Has the species composition of phytoplankton or zooplankton changed in the vicinity of the outfall or at selected farfield stations in Massachusetts Bay or Cape Cod Bay? If so, can these changes be correlated with effluent of ambient water nutrient concentrations, or can farfield changes be correlated with nearfield changes?	Increase in frequency of *Phaeocystis* blooms is the most marked change in the phytoplankton community, but that change is not attributed to the outfall. No marked changes in the zooplankton community.

Monitoring Question	Answer
What is the level of sewage contamination and its spatial distribution in Massachusetts and Cape Cod bays sediments before discharge through the new outfall?	Effects of historic inputs from Boston Harbor and other sources detected.
Has the level of sewage contamination or its spatial distribution in Massachusetts and Cape Cod bays sediments changed after discharge through the new outfall?	Effluent signal detected as *Clostridium perfringens* spores, the most sensitive sewage tracer, within a few kilometers of the outfall.
Has the concentration of contaminants in sediments changed?	No general increase in contaminants. Effluent signal can be detected as some tracers within 2 km of the diffuser.
Has the soft-bottom community changed?	Changes have occurred but are not significant and cannot be attributed to the outfall.
Have the sediments become more anoxic; that is, has the thickness of the sediment oxic layer decreased?	No. The sediment RPD has been deeper during post-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?	No changes detected, even within 2 km of the outfall.
Has the hard-bottom community changed?	No substantial changes detected. Decreases in coralline algae detected at some stations, but the geographic pattern does not suggest an outfall effect.
How do the sediment oxygen demand, the flux of nutrients from the sediment to the water column, and denitrification influence the levels of oxygen and nitrogen in the water near the outfall?	Described by baseline monitoring; conditions do not suggest adverse changes have resulted from moving the outfall offshore.
Have the rates of these processes changed?	No changes detected.
Has the level of contaminants in the tissues of fish and shellfish around the outfall changed since discharge began?	No substantial change in flounder or lobster contaminant body burdens, with concentrations remaining very low. Detectable increases in concentrations of some contaminants in mussel arrays deployed at the outfall.
Do the levels of contaminants in the edible tissue of fish and shellfish around the outfall represent a risk to human health?	No changes that would pose a threat to human health. Regional patterns have persisted since the baseline period, and there appears to be a general long-term downward trend for most contaminant levels.
Are the contaminant levels in fish and shellfish different between the outfall, Boston Harbor, and a reference site?	Differences documented during baseline monitoring. Regional patterns have persisted since the diversion, with concentrations being highest in Boston Harbor and lowest in Cape Cod Bay.
Has the incidence of disease and/or abnormalities in fish or shellfish changed?	No increases in disease or abnormalities in response to the outfall; long-term downward trend in liver disease in fish from near Deer Island and near the outfall.

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List of Acronyms

BOD	Biochemical oxygen demand
cBOD	Carbonaceous biochemical oxygen demand
BHWQM	Boston Harbor Water Quality Monitoring
BWQM	Bay Water Quality Monitoring
CCB	Cape Cod Bay
CHV	Centrotubular hydropic vacuolation
CSO	Combined sewer overflow
DDE	Dichlorodiphenylethylene
DDT	Dichlorodiphenyltrichloroethane
DIF	Deer Island Flats
DIL	Deer Island Light
DITP	Deer Island Treatment Plant
DO	Dissolved oxygen
ECCB	Eastern Cape Cod Bay
FOG	Fats, oil, and grease
GoMOOS	Gulf of Maine Ocean Observation System
HMW	High molecular weight
LC50	50% mortality concentration
LMW	Low molecular weight
LNB	Large Navigational Buoy
LNG	Liquefied natural gas
MGD	Million gallons per day
MWRA	Massachusetts Water Resources Authority
NA	Not analyzed/not applicable
NB	Nantasket Beach
NDBC	National Data Buoy Center
NOAA	National Oceanic and Atmospheric Administration
OS	Outfall site
OSI	Organism sediment index
PAH	Polycyclic aromatic hydrocarbon
PCB	Polychlorinated biphenyl
PHC	Petroleum hydrocarbon
PSP	Paralytic shellfish poisoning
RPD	Redox potential discontinuity
SBNMS	Stellwagen Bank National Marine Sanctuary
TOC	Total organic carbon
TKN	Total Kjeldahl nitrogen

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Outfall monitoring overview BACKGROUND

Massachusetts Water Resources Authority

Environmental Quality Department
Report 2008-18

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Outfall Monitoring Overview
BACKGROUND

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Summary

Since its creation by an act of state legislature in 1984, the Massachusetts Water Resources Authority (MWRA) has worked to minimize the effects of wastewater discharge on the marine environment. The MWRA program has taken steps to reduce the amount of pollutants entering the waste stream, improve treatment before discharge, and provide for better dilution upon discharge of treated effluent into marine waters. In September 2000, MWRA ended discharge into the more confined waters of Boston Harbor and began to discharge at a deeper site in the more open waters of Massachusetts Bay. Subsequent years are referred to as being "post-diversion."

One condition of the National Pollutant Discharge Elimination System (NPDES) permit for the Massachusetts Bay discharge is that MWRA prepare an annual document summarizing the year's monitoring results. Outfall monitoring overview documents were prepared for most years prior to the permit being in place and for each post-diversion discharge year. Overviews prepared for the years through 2006 included the background information that is the basis for this document.

With the 2007 monitoring year, it had become apparent that most or all of the questions developed prior to the discharge diversion had been answered. As had been anticipated, it was possible to detect minimal effects in the immediate vicinity of the outfall, but there has been no indication of unexpected or broad-range changes. As part of a new focus on verification of continued protection and anticipation of new challenges, MWRA has decided to focus the annual overviews on new and interesting results. The background information, which does not change from year-to-year, has been placed into this separate document.

This document presents background information on environmental concerns, monitoring design, and Contingency Plan thresholds for effluent, water-column, sea-floor, and fish-and-shellfish monitoring. Also described are MWRA's special studies and its commitment to reporting data relevant to the Stellwagen Bank National Marine Sanctuary.

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1. Introduction

Background

For more than two decades, the Massachusetts Water Resources Authority (MWRA) has worked to minimize the effects of wastewater discharge on the marine environment. MWRA was created by an act of the Massachusetts state legislature in December 1984 and in 1985 embarked upon what has become known as the Boston Harbor Project. Before then, the Boston metropolitan area discharged both sewage biosolids and inadequately treated sewage effluent into the confined waters of Boston Harbor from outfalls located at Deer Island in the northern part of the harbor and at Nut Island in Quincy Bay, in the southern part of the harbor. MWRA ended discharge of municipal biosolids into Boston Harbor in 1991, when biosolids from both treatment plants began to be barged to a processing plant in Quincy and made into fertilizer pellets. Steps to minimize effects of effluent discharge have included:

- **Source reduction** to prevent pollutants from entering the waste stream.
- **Improved treatment** before discharge.
- **Better dilution** once the effluent enters the marine environment.

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

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

Efforts to improve treatment continued in 2005, when MWRA initiated studies aimed at maximizing flow through the secondary treatment system. These studies built on several capital projects, including improvements to the secondary treatment facilities and upgrades to the oxygen-generation plant. In 2005, the final piece of the cross-harbor tunnel, which connected DITP to the Fore River biosolids pelletizing plant was completed. Pipes within the tunnel now transport digested biosolids from DITP to the pelletizing plant; the liquid waste from biosolids thickening at Fore River is piped back to DITP. Before the tunnel was completed, liquid (rich in nutrients) was removed from the biosolids at DITP in batches, in preparation for barging to the pelletizing plant, and was added in batches to the influent stream at the beginning of the effluent treatment process. This sporadic addition of nutrients made it more difficult to maintain a stable microbial secondary process. Now, the liquid is removed at the pelletizing plant and piped back to DITP in a relatively steady stream, facilitating a more stable process.

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

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

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

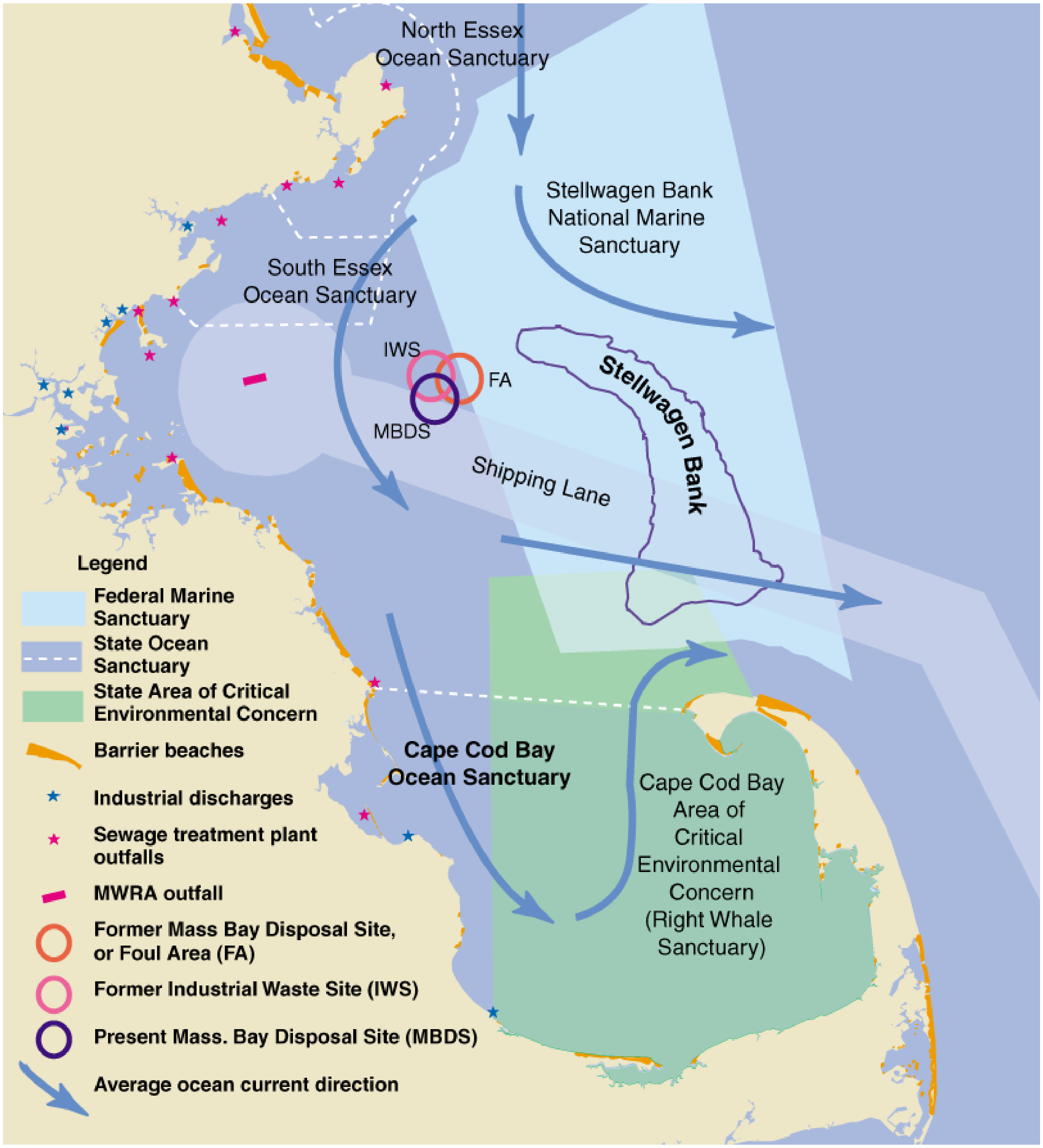

Figure 1-1. Massachusetts and Cape Cod bays, including the location of the MWRA outfall and other factors that were important to the siting process.

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

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

These concerns were recognized by MWRA and by the permit for the outfall issued jointly by the U.S. Environmental Protection Agency (EPA) and the Massachusetts Department of Environmental Protection (MADEP). An outfall monitoring program, which had already been initiated, was formally established in MWRA's National Pollutant Discharge Elimination System (NPDES) permit.

Outfall Permit

The permit issued by EPA and MADEP under NPDES became effective on August 9, 2000 and continues to be in effect, although it formally expired on August 9, 2005. The permit limits discharges of pollutants and requires reporting on the treatment plant operation and maintenance. The permit requires MWRA to continue its ongoing pollution prevention program and to employ best management practices aimed at preventing accidental discharge of pollutants to the sewer system.

The permit requires MWRA to monitor the effluent and the ambient receiving waters for compliance with permit limits and in accordance with monitoring plans (MWRA 1991, 1997a, 2004) developed in response to the EPA Supplemental Environmental Impact Statement (SEIS) prepared as part of the outfall-siting process (EPA 1988). It requires that MWRA implement a Contingency Plan (MWRA 1997b, 2001), which identifies relevant environmental quality parameters and thresholds that, if exceeded, would require a response.

In 1998, in anticipation of the permit, EPA and MADEP established an independent panel of scientists to review monitoring data and provide advice on key scientific issues related to the permit. This panel, the Outfall Monitoring Science Advisory Panel (OMSAP, Table 1-1), conducts peer reviews of monitoring reports, evaluates the data, and advises EPA and MADEP on scientific implications. OMSAP also provides advice concerning any proposed modifications to the monitoring or contingency plans.

OMSAP may form specialized focus groups when specific technical issues require expanded depth or breadth of expertise. One long-standing OMSAP focus is the Model Evaluation Group, which has met periodically since 1992 to evaluate the Bays Eutrophication Model. Two standing sub-committees also advise OMSAP. The Public Interest Advisory Committee (PIAC) represents local, non-governmental organizations and environmental groups and advises OMSAP on values and uses of the harbor and the bays. The Inter-agency Advisory Committee (IAAC) represents state and federal agencies and provides OMSAP with advice concerning environmental regulations.

Table 1-1. List of panel and committee organizations.

Outfall Monitoring Science Advisory Panel (OMSAP)	
Woods Hole Oceanographic Institution University of Rhode Island Massachusetts Institute of Technology Sea Grant University of Massachusetts at Boston Harvard School of Public Health	
Inter-agency Advisory Committee (IAAC)	**Public Interest Advisory Committee (PIAC)**
US Geological Survey MA Coastal Zone Management US Army Corps of Engineers Stellwagen Bank National Marine Sanctuary MA Department of Environmental Protection MA Division of Marine Fisheries US Environmental Protection Agency National Marine Fisheries Service	Save the Harbor/Save the Bay Center for Coastal Studies Wastewater Advisory Committee Conservation Law Foundation Massachusetts Audubon Society New England Aquarium MWRA Advisory Board Association for the Preservation of Cape Cod Safer Waters in Massachusetts The Boston Harbor Association Cape Cod Commission

Monitoring Program

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

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

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

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

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

Table 1-3. Monitoring program objectives and analyses.

Task	Objective	Analyses
Effluent		
Effluent sampling	Characterize wastewater discharge from Deer Island Treatment Plant	Flow Organic material (cBOD) Solids pH Bacterial indicators Total residual chlorine Toxicity Nutrients Toxic contaminants Floatables
Water Column		
Nearfield surveys	Collect water quality data near outfall location	Temperature Salinity Dissolved oxygen Nutrients Solids Chlorophyll Water clarity Photosynthesis Respiration Phytoplankton Zooplankton
Farfield surveys	Collect water quality data throughout Massachusetts and Cape Cod bays	
Moorings (GoMOOS and USGS)	GoMOOS mooring is near Cape Ann. USGS mooring was near outfall and provided continuous oceanographic data until February 2006.	Currents Temperature Salinity Water clarity Chlorophyll
Remote sensing	Provides oceanographic data on a regional scale through satellite imagery	Surface temperature Chlorophyll
Sea Floor		
Soft-bottom studies	Evaluate sediment quality and benthos in Boston Harbor and Massachusetts Bay	Sediment chemistry Sediment profile imagery Community composition
Hard-bottom studies	Characterize marine benthic communities in rock and cobble areas	Topography Substrate Community composition
Fish and Shellfish		
Winter flounder	Determine contaminant body burden and population health	Tissue contaminant concentrations Physical abnormalities, including liver histopathology
American lobster	Determine contaminant body burden	Tissue contaminant concentrations Physical abnormalities
Blue mussel	Evaluate biological condition and potential contaminant bioaccumulation	Tissue contaminant concentrations

Baseline monitoring was initially planned to last for a minimum of three years, as the outfall was originally planned for completion in 1995. Delays in construction allowed a relatively long period for baseline studies. Consequently, MWRA's nine years of baseline monitoring were able to document greater natural variability and develop a better understanding of the system than would have been possible in a briefer baseline period. MWRA was also able to evaluate the environmental responses in Boston Harbor to other facilities improvements (*e.g.*, Leo *et al.* 1995; Pawlowski *et al.* 1996; Rex and Connor 1997; Rex 2000; Rex *et al.* 2002; Taylor 2002, 2003, 2004, 2005a, 2005b, 2006). The extended period also meant that the discharge to Massachusetts Bay, when it did begin, had the benefit of nearly complete implementation of secondary treatment.

The monitoring plan is a "living document." That is, every effort is made to incorporate new scientific information and improved understanding resulting from the monitoring program into appropriate continued measurements. MWRA's NPDES permit allows an annual list of proposed changes to the monitoring plan.

Contingency Plan

The MWRA Contingency Plan (MWRA 1997b, 2001) describes how, if monitoring results indicate a possible environmental problem, MWRA and the regulatory agencies will respond to determine the cause of the problem and to specify the corrective actions that should be taken if the problem appears to be related to the discharge. The Contingency Plan identifies parameters that represent environmentally significant components of the effluent or the ecosystem and that, if specific threshold levels are exceeded, indicate a potential for environmental risk (Table 1-4). The plan provides a process for evaluating parameters that exceed thresholds and formulating appropriate responses.

Table 1-4. Contingency Plan threshold parameters.

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

Threshold values, the measurements selected as indicators of the need for action, are based on permit limits, state water quality standards, and expert opinion. To alert MWRA to any changes, some parameters have more conservative "caution" as well as more serious "warning" thresholds. Exceeding either caution or warning thresholds could indicate a need for increased attention or study. If a caution threshold is exceeded, MWRA, with guidance from OMSAP and the regulatory agencies, may expand the monitoring to track effluent quality and environmental conditions. The data are examined to determine whether it is likely that an unacceptable effect resulting from the outfall has occurred.

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

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

Data Management

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

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

Reporting

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

Reports are posted on MWRA's web site (www.mwra.com/harbor/html/npdes.htm), and copies are placed in repository libraries in Boston and on Cape Cod. OMSAP also holds public workshops at which outfall monitoring results are presented.

Table 1-5. Monitoring reports submitted to OMSAP.

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

Outfall Monitoring Overview

Among the many reports that MWRA completes, the outfall monitoring overview has been prepared for most baseline-monitoring years and for each year that the permit has been in place (Galya *et al.* 1996, 1997a, 1997b; Werme and Hunt 2000a, 2000b, 2001, 2002, 2003, 2004, 2005, 2006, 2007). The reports include scientific summaries for the year of monitoring. Overviews for 1994 through 1999 included only baseline information. With the Massachusetts Bay outfall discharging, subsequent reports have included information relevant to the Contingency Plan, including threshold exceedances, responses, and corrective actions. When data suggest that monitoring activities, parameters, or thresholds should be changed, the report summarizes those recommendations.

Overviews prepared through the 2006 monitoring year included the background information that is the basis for this document, the Outfall Monitoring Overview Background. After nine years of baseline monitoring and six years of post-diversion monitoring, however, it became clear that most or all of the monitoring questions that had been developed by the OTMF had been answered. As had been expected, monitoring has been able to detect minimal effects in the immediate vicinity of the outfall, but there has been no indication of unexpected or broad-range changes.

As MWRA began to focus monitoring on verification of continued protection of the environment and anticipation of potential new challenges, it became clear that the annual overviews should focus on new and interesting results rather than on the background. Overviews for 2007 and subsequent years focus on those results and on comparison of results to the Contingency Plan thresholds.

This background document presents information that does not change from year-to-year—the environmental concerns that have driven the monitoring program, monitoring designs, and Contingency Plan thresholds for effluent, water-column, sea-floor, and fish-and-shellfish monitoring. It also describes MWRA special studies and its commitment to reporting of data relevant to the Stellwagen Bank National Marine Sanctuary.

2. Effluent

Background

Pollution Prevention and Wastewater Treatment

Ensuring that the final effluent is clean is the most important element in MWRA's strategy to improve the environmental quality of Boston Harbor without degrading Massachusetts and Cape Cod bays. MWRA ensures clean effluent through its vigorous pretreatment program and by proper maintenance and operation of DITP.

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

Secondary treatment further reduces the concentrations of contaminants of concern, except for nutrients. DITP removes approximately 85–90% of the suspended solids and biochemical oxygen demand (BOD), 50–90% of the toxic chemicals, and about 15% of the nitrogen from the influent.

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

Environmental Concerns

Sewage contains a variety of contaminants that could, at too high levels, affect the marine environment, public health, and aesthetics. The MWRA permit sets limits on these contaminants so as to ensure that these attributes will be protected. Several specific questions in the MWRA ambient monitoring plan respond to public concerns and possible environmental responses by addressing whether the effluent is meeting permit limits (Table 2-1). Other questions require the use of effluent data in conjunction with plume-dilution studies, which were completed in 2001, and water-column monitoring (see Section 3, Water Column).

Table 2-1. Monitoring questions developed by OTMF related to the effluent.

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

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

- **Pathogens**, including bacteria, viruses, and protozoa, are found in human and animal waste and can cause disease. Human exposure to water-borne pathogens can occur through consumption of contaminated shellfish or through ingestion or physical contact while swimming.
- **Toxic contaminants** include heavy metals, such as copper and lead, polychlorinated biphenyls (PCBs), pesticides, polycyclic aromatic hydrocarbons (PAHs), and petroleum hydrocarbons. Toxic contaminants can lower survival and reproduction rates of marine organisms. Some toxic contaminants can accumulate in marine life, potentially affecting human health through seafood consumption.
- **Organic material**, a major constituent of untreated sewage, consumes oxygen as it decays. Even under natural conditions, oxygen levels decline in bottom waters during the late summer, so any effluent component that might further decrease oxygen levels is a concern. Too much organic material could also disrupt animal communities on the sea floor.
- **Suspended solids**, small particles in the water column, decrease water clarity and consequently affect growth and productivity of algae and other marine plants. Excess suspended solids also detract from people's aesthetic perception of the environment.
- In marine waters, nitrogen is the limiting **nutrient** that controls growth of algae and other aquatic plants. Excess nitrogen can be detrimental, leading to eutrophication and low levels of dissolved oxygen, excess turbidity, and nuisance algal blooms. Nutrients, particularly dissolved forms, are the only components of sewage entering the treatment plant that are not substantially reduced by secondary treatment.
- **Oil and grease** slicks and floating debris known as **floatables** pose aesthetic concerns. Plastic debris can be harmful to marine life, as plastic bags are sometimes mistaken for food and clog the digestive systems of turtles and marine mammals. Plastic and other debris can also entangle animals and cause them to drown.
- Sewage effluent is disinfected by addition of a form of **chlorine**, sodium hypochlorite, which is the active ingredient in bleach. While sodium hypochlorite is effective in destroying pathogens, at high enough concentrations, it is harmful to marine life. Consequently, MWRA dechlorinates the effluent with sodium bisulfite before discharge.

- Seawater is noted for its buffering capacity, that is, its ability to neutralize acids and bases. However, state water quality standards dictate that effluent discharges not change the **pH** of the ambient seawater more than 0.5 standard units on a scale of 1 to 14. Consequently, the outfall permit sets both upper and lower values for pH of the effluent.

Monitoring Design

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

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

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

The Contingency Plan also sets limits for overall plant performance, annual nitrogen load, floatables, and oil and grease. Floatables are measured as part of a special study.

Table 2-2. Reporting requirements of the outfall permit.

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

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

The monitoring plan also calls for an evaluation of indicators of human pathogens. To date, MWRA has collected data on anthropogenic viruses, viral indicators, and *Enterococcus* bacteria in the influent and effluent.

Table 2-3. Monitoring plan parameters for effluent.

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

Contingency Plan Thresholds

Contingency Plan thresholds for effluent monitoring include warning levels for all parameters and caution levels for PCBs, plant performance, and nitrogen loads (Table 2-4). Floatable debris is present in low amounts in the effluent, and appropriate methods for assessing it before discharge have remained in development. Meanwhile, presence of debris is assessed by net tows in the vicinity of the outfall site during water-column surveys.

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

Parameter	Caution Level	Warning Level
pH	None	<6 or >9
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)
Chlorine, residual	None	631 µg/L daily, 456 µg/L monthly
Total suspended solids	None	45 mg/L weekly 30 mg/L monthly
cBOD	None	40 mg/L weekly, 25 mg/L monthly
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
PCBs	Aroclor=0.045 ng/L	
Plant performance	5 violations/year	Noncompliance >5% of the time
Flow	None	Flow >436 for annual average of dry days
Total nitrogen load	12,500 mtons/year	14,000 mtons/year
Floatables	Thresholds remain under development	
Oil and grease	None	15 mg/L weekly

3. Water Column

Background

Circulation and Water Properties

Circulation, water properties, and consequently, the biology of Massachusetts and Cape Cod bays are driven by the larger pattern of water flow in the Gulf of Maine (Figure 3-1) and by regional and local winds. A coastal current flows southwestward along the Maine and New Hampshire coasts; it may enter Massachusetts Bay to the north of Boston at Cape Ann. This current drives an average counterclockwise circulation in Massachusetts Bay and (sometimes) Cape Cod Bay. Water flows back out of the bays at Race Point, located at the tip of Cape Cod. Whether the coastal current enters Massachusetts Bay and whether it continues south into Cape Cod Bay depends on the strength of the current and the direction, duration, and speed of the wind. Because the coastal current is strongest during the spring period of high runoff from rivers and streams, the spring circulation pattern is more consistent than that of the summer and fall (Geyer *et al.* 1992, Jiang *et al.* 2006).

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

As in many coastal waters, during the winter the water is well-mixed from top to bottom and nutrient levels are high. As light levels increase in the early spring, phytoplankton populations often begin a period of rapid growth known as a spring bloom. Contrary to popular wisdom, however, strong spring blooms do not occur every year. During the years in which they occur, spring blooms begin in the shallowest waters of Cape Cod Bay. Blooms in the deeper Massachusetts Bay waters follow two to three weeks later. Spring phytoplankton blooms are typically followed by an increase in zooplankton abundance. These zooplankton populations are food for many animals, including the endangered right whale.

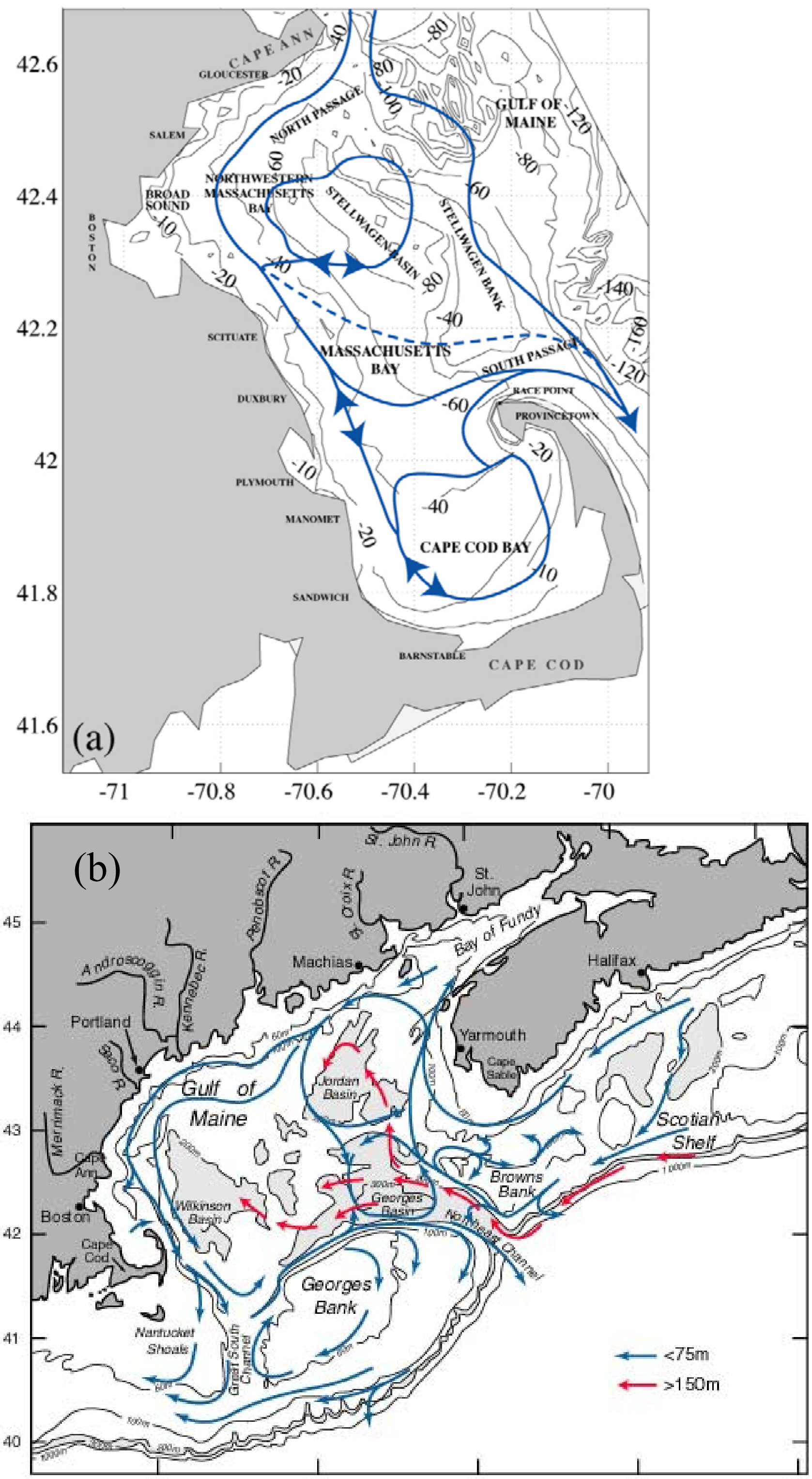

Figure 3-1. (a) General circulation within Massachusetts Bay. Reprinted from Journal of Marine Systems, Vol. 29, Author: PFJ Lermusiaux, "Evolving the subspace of the three-dimensional multiscale ocean variability: Massachusetts Bay," pp 385-422 © 2001 with permission from Elsevier. (b) General circulation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

Later in the spring, the surface waters warm, and the water column stratifies. Inputs of freshwater from rivers contribute to the stratification, with lighter, less saline water remaining at the surface. Stratification effectively separates the surface and bottom waters, preventing replenishment of nutrients to the surface and oxygen to the bottom. Phytoplankton in the surface waters deplete the available nutrients and then undergo senescence, sinking through the pycnocline to the bottom. While oxygen levels remain high in the surface waters throughout the year, levels fall in the bottom waters, as bottom-dwelling animals respire, and bacteria use up oxygen as the phytoplankton decompose. Bottom-water oxygen levels are typically lowest during the late summer or early fall.

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

Environmental Concerns

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

The monitoring program looks extensively at possible effects of discharging nutrient-rich effluent into Massachusetts Bay. One concern was that excess nutrients, particularly nitrogen, could over-stimulate algal blooms, which would be followed by low levels of dissolved oxygen in the bottom waters when the phytoplankton organisms die, sink, and decompose. Another concern was that changes in the relative levels of nutrients could stimulate growth of undesirable algae. Three nuisance or noxious species or species groups were of particular concern: the dinoflagellate *Alexandrium fundyense* (*A. fundyense* and *A. tamarense*, which are varieties of the same species), the diatom *Pseudo-nitzschia multiseries*, and the colonial flagellate *Phaeocystis pouchetii*.

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

Is it safe to eat fish and shellfish? *Will pathogens in the effluent be transported to shellfishing areas where they could accumulate in the edible tissues of shellfish and contribute to human health problems?* ▪ Are pathogens transported to shellfish beds at levels that might affect shellfish consumer health?
Are natural/living resources protected? *Will nutrient enrichment in the water column contribute to an increase in primary production?* *Will nutrient enrichment in the water column contribute to changes in plankton community structure?* ▪ Have nutrient concentrations changed in the water near the outfall; have they changed at farfield stations in Massachusetts Bay or Cape Cod Bay, and, if so, are they correlated with changes in the nearfield? ▪ Has the phytoplankton biomass changed in the vicinity of the outfall or at selected farfield stations in Massachusetts Bay or Cape Cod Bay, and, if so, can changes be correlated with effluent or ambient water nutrient concentrations, or can farfield changes be correlated with nearfield changes? ▪ Have the phytoplankton production rates changed in the vicinity of the outfall or at selected farfield stations, and, if so, can these changes be correlated with effluent or ambient water nutrient concentrations, or can farfield changes be correlated with nearfield changes? ▪ Has the abundance of nuisance or noxious phytoplankton species changed in the vicinity of the outfall? ▪ Has the species composition of phytoplankton or zooplankton changed in the vicinity of the outfall or at selected farfield stations in Massachusetts Bay or Cape Cod Bay? If so, can these changes be correlated with effluent or ambient water nutrient concentrations, or can farfield changes be correlated with nearfield changes? *Will increased water-column and benthic respiration contribute to depressed oxygen levels in the water?* ▪ Do the concentrations (or percent saturation) of dissolved oxygen in the vicinity of the outfall and at selected farfield stations meet the state water quality standard? ▪ Have the concentrations (or percent saturation) of dissolved oxygen in the vicinity of the outfall or at selected farfield stations in Massachusetts Bay or Cape Cod Bay changed relative to pre-discharge baseline or a reference area? If so, can changes correlated with effluent or ambient water nutrient concentrations, or can farfield changes be correlated with nearfield changes?
Is it safe to swim? *Will pathogens in the effluent be transported to waters near swimming beaches, contributing to human health problems?* ▪ Are pathogens transported to beaches at levels that might affect swimmer health?
Are aesthetics being maintained? *Will changes in water clarity and/or color result from the direct input of effluent particles or other colored constituents, or indirectly through nutrient stimulation of nuisance plankton species?* *Will the loading of floatable debris increase, contributing to visible degradation?* ▪ Has the clarity and/or color of the water around the outfall changed? ▪ Has the amount of floatable debris around the outfall changed?
Information on transport and fate necessary to answer all the questions ▪ Are model estimates of short-term (less than 1 day) effluent dilution and transport accurate? ▪ What are the nearfield and farfield water circulation patterns? ▪ What is the farfield fate of dissolved, conservative, or long-lived effluent constituents?

Alexandrium fundyense blooms are known in New England as red tides. They produce a toxin, which when sufficiently concentrated by shellfish that take up the algae, causes paralytic shellfish poisoning (PSP), a condition that can be fatal to marine mammals, fish, and humans. At high concentrations (more than 1 million cells per liter), some diatoms in the genus *Pseudo-nitzschia* may produce sufficient quantities of toxic domoic acid to cause a condition known as amnesic shellfish poisoning, which is marked by gastrointestinal and neurological symptoms, including dementia. *Phaeocystis pouchetii* is not toxic, but individual cells can aggregate in gelatinous colonies that may be aesthetically displeasing or provide poor food for zooplankton.

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

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

Monitoring Design

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

Table 3-2. Components of water-column monitoring.

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

Nearfield surveys provide vertical and horizontal profiles of physical, chemical, and biological characteristics of the water column in the area around the outfall, where some effects of the effluent were expected and have been observed. Farfield surveys assess differences across the bays and seasonal changes over a large area. Several farfield stations mark the boundary of the monitoring area and are in or near the Stellwagen Bank National Marine Sanctuary. Two of those stations denote the "northern boundary," representing water entering Massachusetts Bay from the Gulf of Maine. Other stations are in Boston Harbor, coastal and offshore regions, and in Cape Cod Bay (Figures 3-2, 3-3, and 3-4). Since 2004, typically, twelve surveys of seven nearfield stations and six surveys of 25 farfield stations are conducted each year.

Parameters measured in the water column include dissolved inorganic and organic nutrients, particulate forms of nutrients, chlorophyll, total suspended solids, dissolved oxygen, productivity, respiration, phytoplankton abundance and species composition, and zooplankton abundance and species composition (Tables 3-3 and 3-4). Nutrients measured include the major forms of nitrogen, phosphorus, and silica. The measurements focus on the dissolved inorganic forms, which are most readily used by phytoplankton. The surveys also include observations and net tows in the outfall area to assess the presence of floatable debris.

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

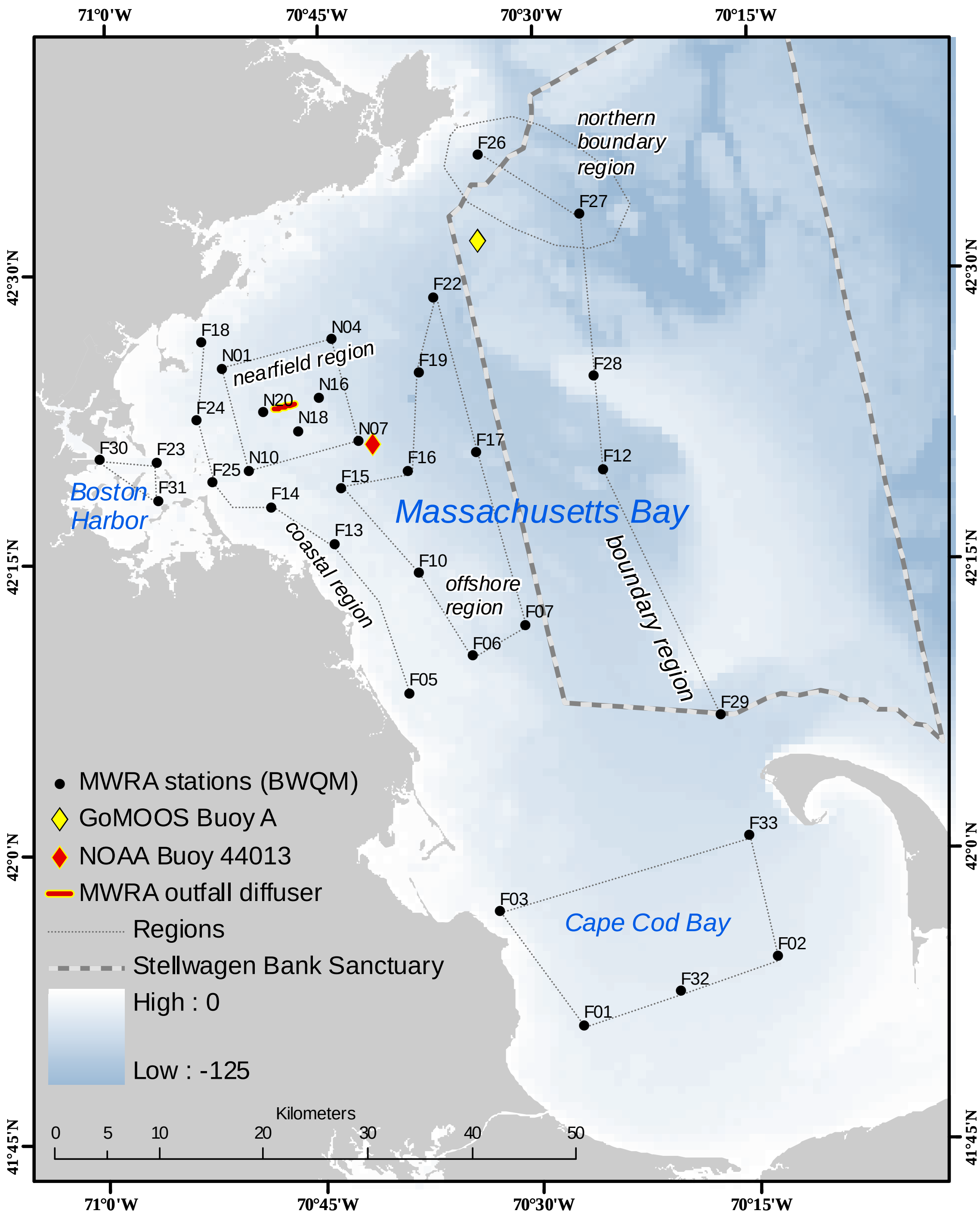

Figure 3-2. MWRA Bay Water Quality Monitoring (BWQM) stations and regional groupings included in the program. "Farfield" stations include all stations in Boston Harbor; the coastal, offshore, and northern boundary regions; and Cape Cod Bay. Also shown are the MWRA outfall; two instrumented buoys, one 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 Marine Sanctuary.

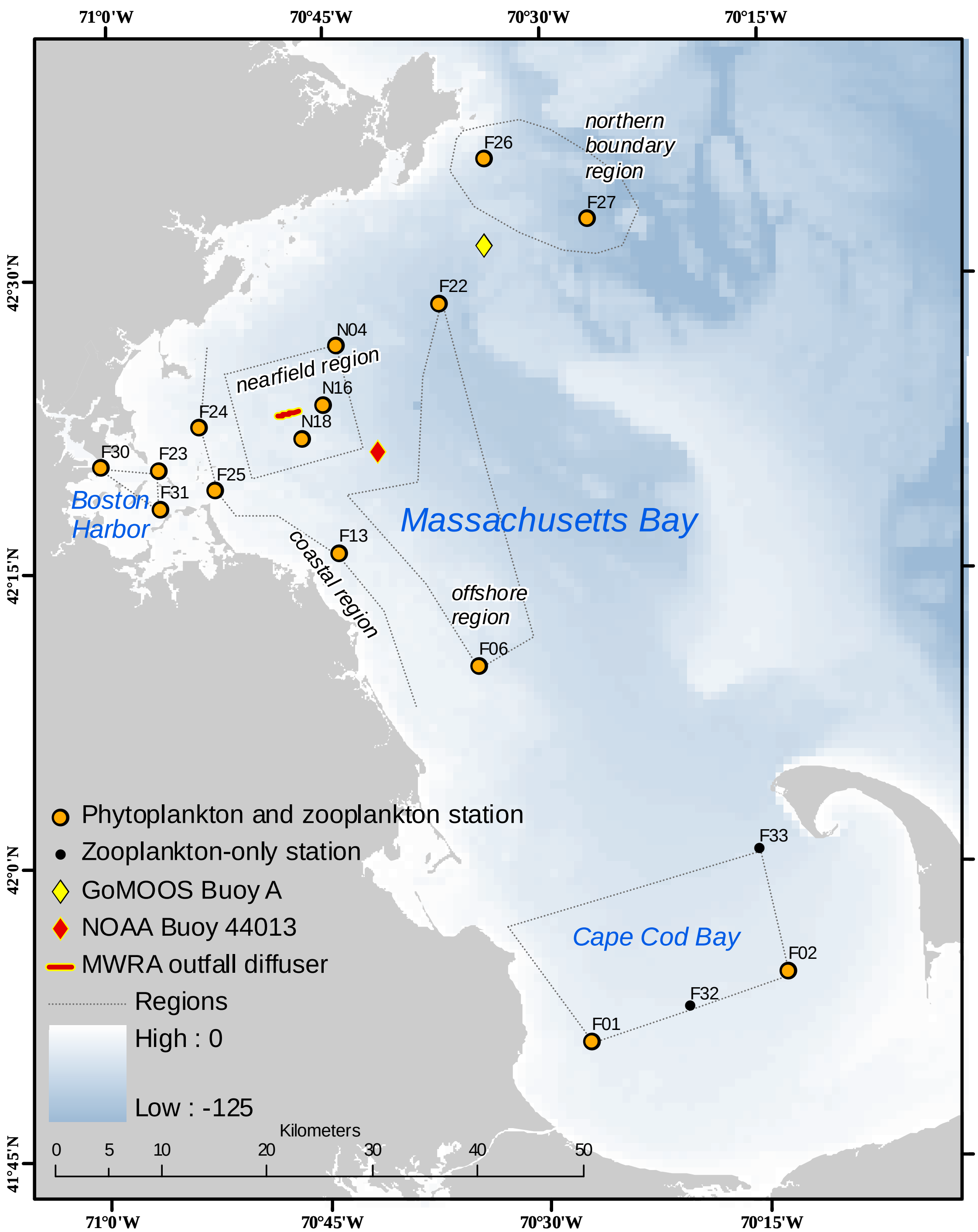

Figure 3-3. MWRA plankton stations included in water-column monitoring. The stations are a subset of those monitored for water quality. Regional groupings, the instrumented buoys, and the MWRA outfall are also shown.

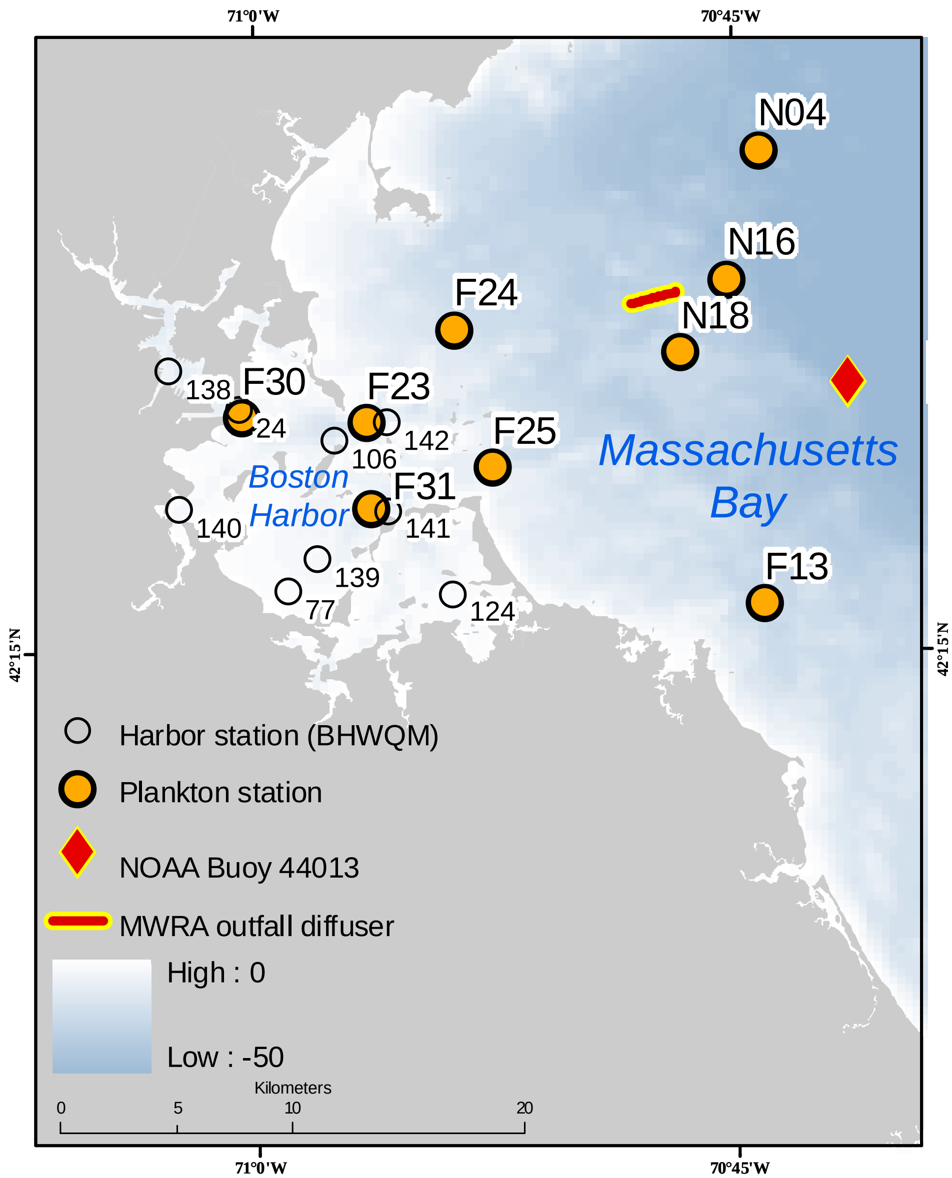

Figure 3-4. MWRA Boston Harbor Water Quality Monitoring (BHWQM) stations and nearby BWQM plankton stations. Primary productivity is measured at Stations F23, N18, and N04.

Table 3-3. Nearfield water-column monitoring parameters.

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

Table 3-4. Farfield water-column monitoring parameters.

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

Contingency Plan Thresholds

Threshold parameters for water-column monitoring include minimum dissolved oxygen concentrations and percent saturation in nearfield and Stellwagen Bank bottom waters, dissolved oxygen depletion rate in nearfield bottom waters, chlorophyll levels, abundance of nuisance algal species, geographic extent of PSP toxin, and initial dilution (Table 3-5). Oxygen concentrations and percent saturation are compared to background levels rather than to the caution and warning levels.

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

Location/ Parameter	Specific Parameter	Baseline	Caution Level	Warning Level
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
	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
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
	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
Bottom water nearfield	DO depletion rate (June-October)	0.024 mg/L/day	0.037 mg/L/day	0.049 mg/L/day
Chlorophyll nearfield	Annual	79 mg/m^2	118 mg/m^2	158 mg/m^2
	Winter/spring	62 mgml^2	238 mg/m^2	None
	Summer	51 mg/m^2	93 mg/m^2	None
	Autumn	97 mg/m^2	212 mg/m^2	None
Nuisance algae nearfield *Phaeocystis pouchetii*	Winter/spring	468,000 cells/L	2,020,000 cells/L	None
	Summer	72 cells/L	357 cells/L	None
	Autumn	317 cells/L	2,540 cells/L	None
Nuisance algae nearfield *Pseudo-nitzschia*	Winter/spring	6,200 cells/L	21,000 cells/L	None
	Summer	14,600 cells/L	43,100 cells/L	None
	Autumn	9,940 cells/L	24,700 cells/L	None
Nuisance algae nearfield *Alexandrium fundyense*	Any nearfield sample	Baseline maximum = 163 cells/L	100 cells/L	None
Farfield	PSP toxin extent	Not applicable	New incidence	None

4. Sea Floor

Background

Bottom Characteristics and Sediment Transport

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

Modeling and long-term monitoring have confirmed that sediment transport in the region occurs primarily during storms (Butman *et al.* 2005). Typically, waves during storms with winds from the northeast resuspend sediments, which are transported by shallow currents from western Massachusetts Bay toward Cape Cod Bay and by deeper currents to Stellwagen Basin. Cape Cod Bay is partially sheltered from large waves by the arm of Cape Cod, and storm waves are rarely large enough to resuspend sediments in Stellwagen Basin, which is the deepest feature in the region. Tidal currents, wind-driven currents, and currents associated with spring runoff are too weak or too shallow to resuspend sediments.

Environmental Concerns

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

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

Are natural/living resources protected?

Will benthic enrichment contribute to changes in community structure of soft-bottom and hard-bottom macrofauna, possibly affecting fisheries?

Will benthic macrofauna near the outfall mixing zone be exposed to some contaminants, potentially contributing to changes in the community?

Will the benthos near the outfall mixing zone and in depositional areas farther away accumulate some contaminants?

- What is the level of sewage contamination and its spatial distribution in Massachusetts and Cape Cod bays sediments before discharge through the new outfall?
- Has the level of sewage contamination or its spatial distribution in Massachusetts or Cape Cod bays sediments changed after discharge through the new outfall?
- Have the concentrations of contaminants in sediments changed?
- Has the soft-bottom community changed?
- Are any benthic community changes correlated with changes in levels of toxic contaminants (or sewage tracers) in sediments?
- Has the hard-bottomed community changed?

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

- Have the sediments become more anoxic; that is, has the thickness of the sediment oxic layer decreased?

If diversion of the nutrient loads to offshore were to cause eutrophication, the depressed levels of dissolved oxygen that were also a concern in water-column monitoring could adversely affect bottom-dwelling animals. An increase in the amounts of particles and organic matter to the bottom could disrupt normal benthic community structure in the vicinity of the discharge. Although source control and treatment plant performance are designed to keep effluent contaminant concentrations too low to affect the sediments, the location of the outfall in an area of sediment transport caused concern about increased accumulation of toxic contaminants in Cape Cod Bay and Stellwagen Basin. Similarly, concentrations of particulate matter were expected to be low, but there remained some concern that bottom communities near the outfall could be affected by deposition.

Monitoring Design

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

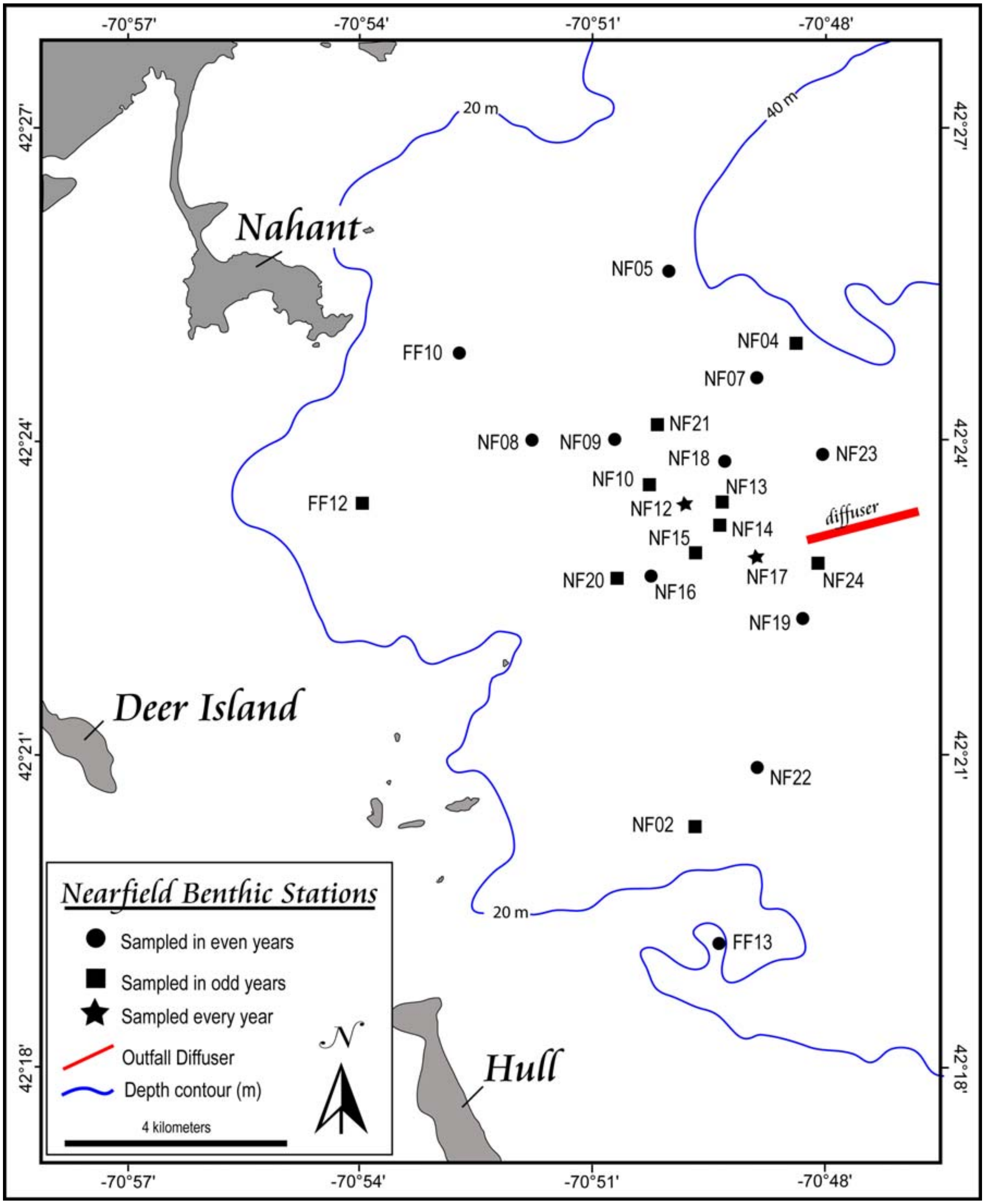

Figure 4-1. Locations of nearfield soft-bottom stations.

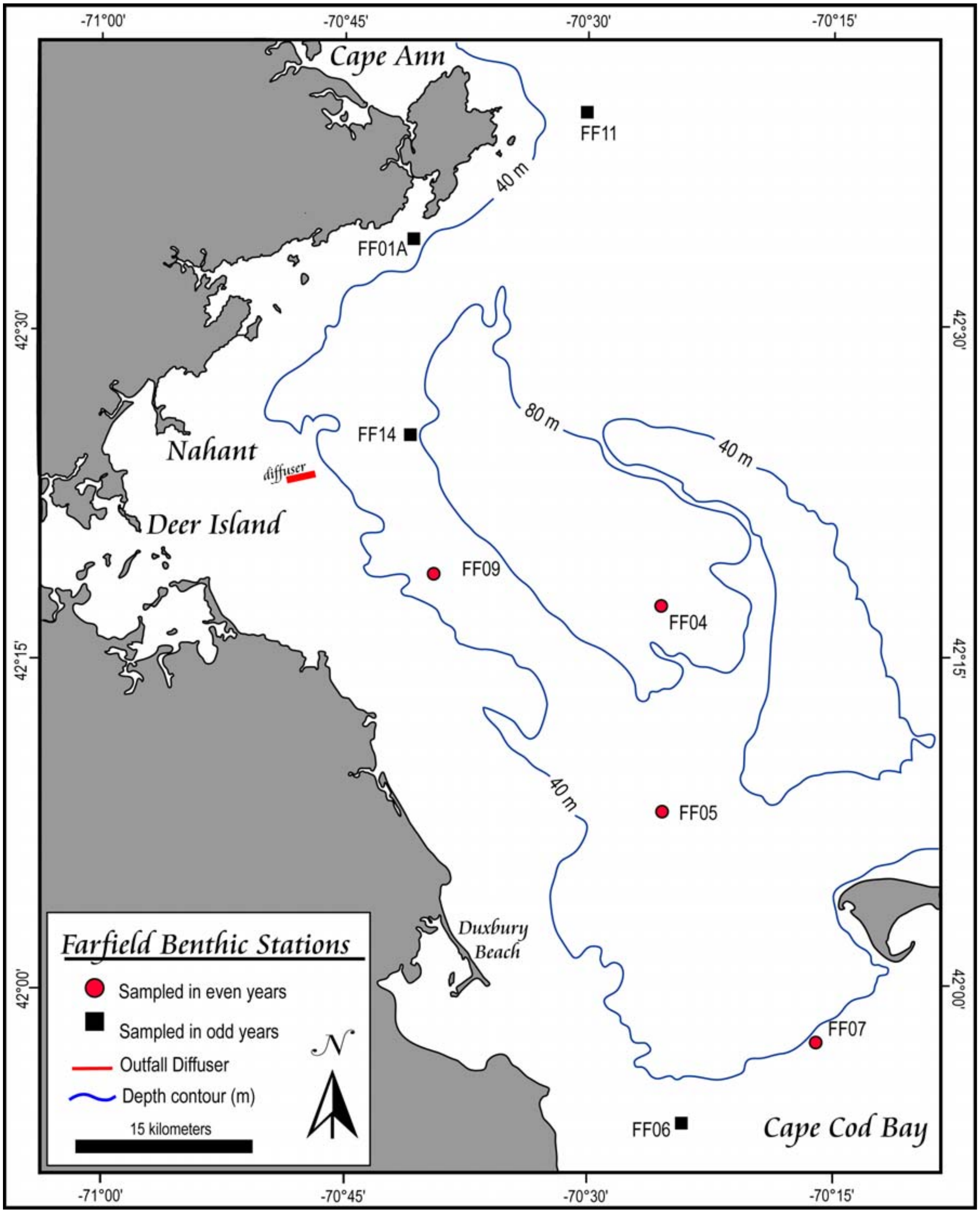

Figure 4-2. Locations of farfield soft-bottom stations.

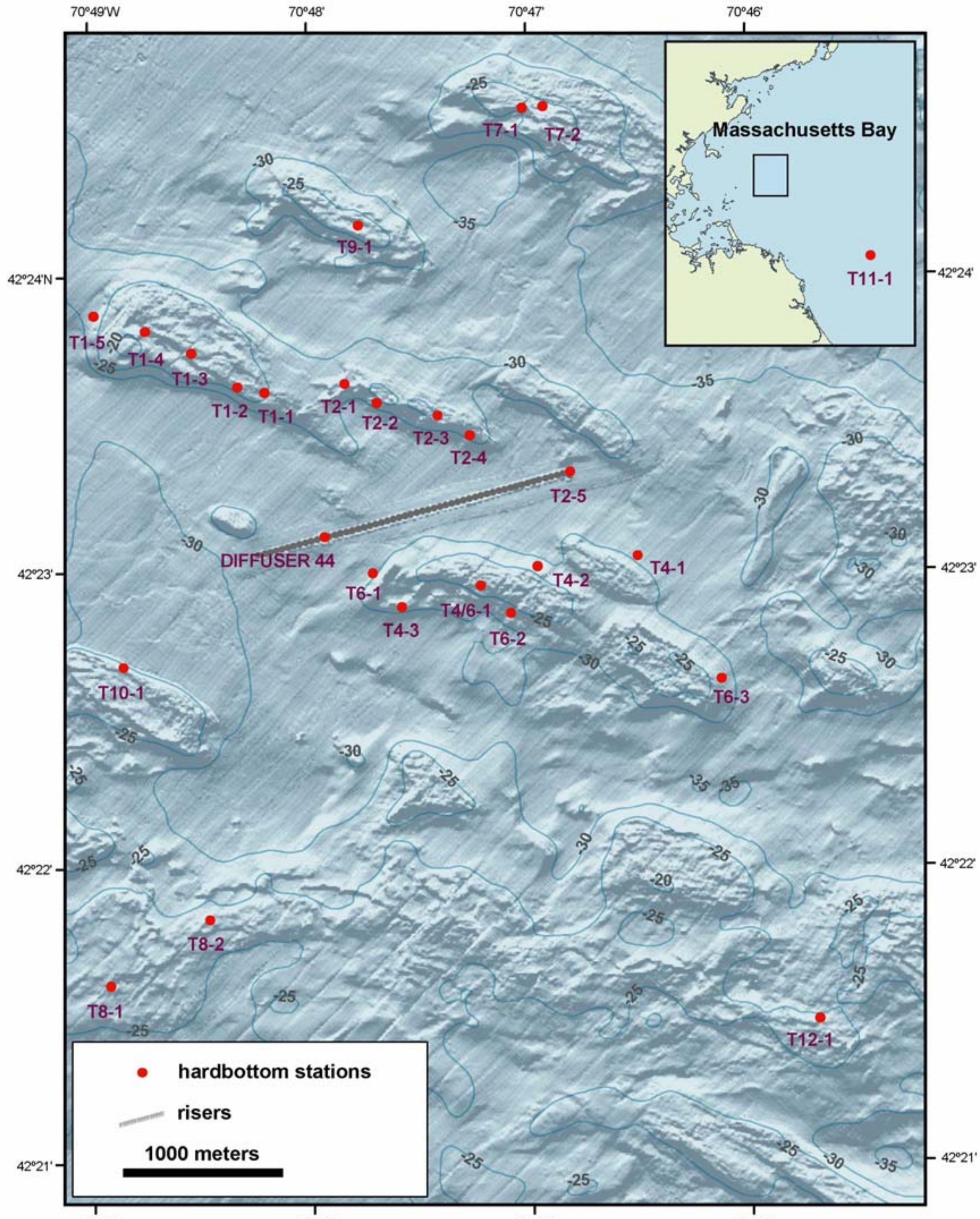

Figure 4-3. Locations of hard-bottom stations.

Measurements of sediment characteristics, tracers, and contaminants include analyses of grain size, total organic carbon (TOC), *Clostridium perfringens* spores, PAHs, PCBs, chlorinated pesticides, and metals. Sediment-contaminant monitoring has been complemented by special studies, primarily in association with USGS (for example, Bothner and Butman 2007).

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

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

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

Beginning in 2003 and 2004, the existing 23 nearfield and 8 farfield soft-bottom stations were split into two subgroups. This division was made randomly after accounting for regional representation and level of replication, with two stations (NF12 and NF17, which are also sampled by USGS) being included in both groups. The program includes the following:

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

Contingency Plan Thresholds

The Contingency Plan sets caution levels for RPD depth and benthic community parameters and warning levels for toxic contaminants in sediments (Figure 4-2). Because different stations are sampled in even and odd years, benthic-diversity parameters have separate Contingency Plan caution levels for those subsets of stations. Caution and warning levels exist for benthic opportunists, which are species that could be indicative of pollution.

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

Location	Parameter	Caution Level	Warning Level
Sediments, nearfield	RPD depth	1.18 cm	None
Sediment toxic contaminants, nearfield	Acenaphthene	None	500 ppb dry
	Acenaphylene	None	640 ppb dry
	Anthracene	None	1100 ppb dry
	Benzo(a)anthracene	None	1600 ppb dry
	Benzo(a)pyrene	None	1600 ppb dry
	Cadmium	None	9.6 ppm dry
	Chromium	None	370 ppm dry
	Chrysene	None	2800 ppb dry
	Copper	None	270 ppm dry
	Dibenzo(a,h)anthracene	None	260 ppb dry
	Fluoranthene	None	5100 ppb dry
	Fluorene	None	540 ppb dry
	Lead	None	218 ppm dry
	Mercury	None	0.71 ppm dry
	Naphthalene	None	2100 ppb dry
	Nickel	None	51.6 ppb dry
	p,p'-DDE	None	27 ppm dry
	Phenanthrene	None	1500 ppb dry
	Pyrene	None	2600 ppb dry
	Silver	None	3.7 ppm dry
	Total DDTs	None	46.1 ppb dry
	Total HMW PAH	None	9600 ppb dry
	Total LMW PAH	None	3160 ppb dry
	Total PAHs	None	44792 ppb dry
	Total PCBs	None	180 ppb dry
	Zinc	None	410 ppm dry
Even years: benthic diversity, nearfield	Species per sample	<48.41 or >82.00	None
	Fisher's log-series alpha	<9.99 or >16.47	None
	Shannon diversity	<3.37 or >4.14	None
	Pielou's evenness	<0.58 or >0.68	None
Odd years: benthic diversity, nearfield	Species per sample	<46.52 or >79.95	None
	Fisher's log-series alpha	<9.95 or >15.17	None
	Shannon diversity	<3.30 or >3.91	None
	Pielou's evenness	<0.56 or >0.66	None
Benthic opportunists	Percent opportunists	>10%	>25%

5. Fish and Shellfish

Background

MWRA monitors fish and shellfish because of concerns for public health and because some fish and shellfish species are good indicators of effects of pollutants on overall marine health (Table 5-1). The fish and shellfish industry is an important part of the regional identity and economy of Massachusetts.

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

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

The two main concerns for fish and shellfish were that the discharge of sewage effluent into the relatively clean waters of Massachusetts Bay could result in chemical contamination of the fisheries and that contaminants in the effluent could cause direct damage to health of the fishery stocks. Because many toxic contaminants adhere to particles, which settle, animals that live on the bottom, in contact with sediments and those that eat bottom-dwelling organisms were considered to be the most likely species to be affected. Exposure to contaminated sediments could result in fin erosion, disease, or other, subtler, abnormalities in flounder, lobster, or other bottom-dwelling animals. Shellfish that feed by filtering suspended matter from large volumes of water are also potential bioaccumulators of toxic contaminants. Consumption of filter-feeding animals by predators could result in transferring contaminants up the food chain and ultimately to humans.

Monitoring Design

The monitoring program focuses on three indicator species: winter flounder (*Pseudopleuronectes americanus*), lobster (*Homarus americanus*), and blue mussel (*Mytilus edulis*). Winter flounder and lobster are important resource species in the region. Like all flatfish, winter flounder live and feed on the bottom, often lying partially buried in the sediments. Lobsters live on a variety of surfaces within the region, including mud, sand, gravel, and rock outcrops. Blue mussels are also resource species. Like other filter feeders, mussels process large volumes of water and can concentrate toxic metals and organic compounds in their tissues. They can be readily maintained in fixed cages, so they are convenient monitoring tools.

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

Winter Flounder

Flounder are collected annually. Whole fish are examined for external lesions or other abnormalities, and flounder livers are examined to quantify disease, including three types of vacuolation (centrotubular (CHV), tubular, and focal, representing increasing severity), microphage aggregation, biliary-duct proliferation, and neoplasia or tumors. Vacuolation and neoplasia have been associated with chronic exposure to contaminants.

Since 2004, chemical analyses for flounder are completed every third year, including 2006, to determine tissue burdens and to evaluate whether contaminant burdens approach human health consumption limits. Chemical analyses (Table 5-2) of composite samples of fillets and livers include PCBs, pesticides, mercury, and lipids. Liver samples are also analyzed for PAHs, lead, silver, cadmium, chromium, copper, nickel, and zinc.

Lobster

Commercial lobstermen collect lobsters for the monitoring program. Since 2004, lobsters have been studied every third year, including 2006. All lobsters are examined for external conditions, and chemical analyses are performed on composite samples. Meat (from the tail and claw) and hepatopancreas are analyzed for lipids, PCBs, pesticides, and mercury.

Hepatopancreas samples are also analyzed for PAHs, lead, silver, cadmium, chromium, copper, nickel, and zinc.

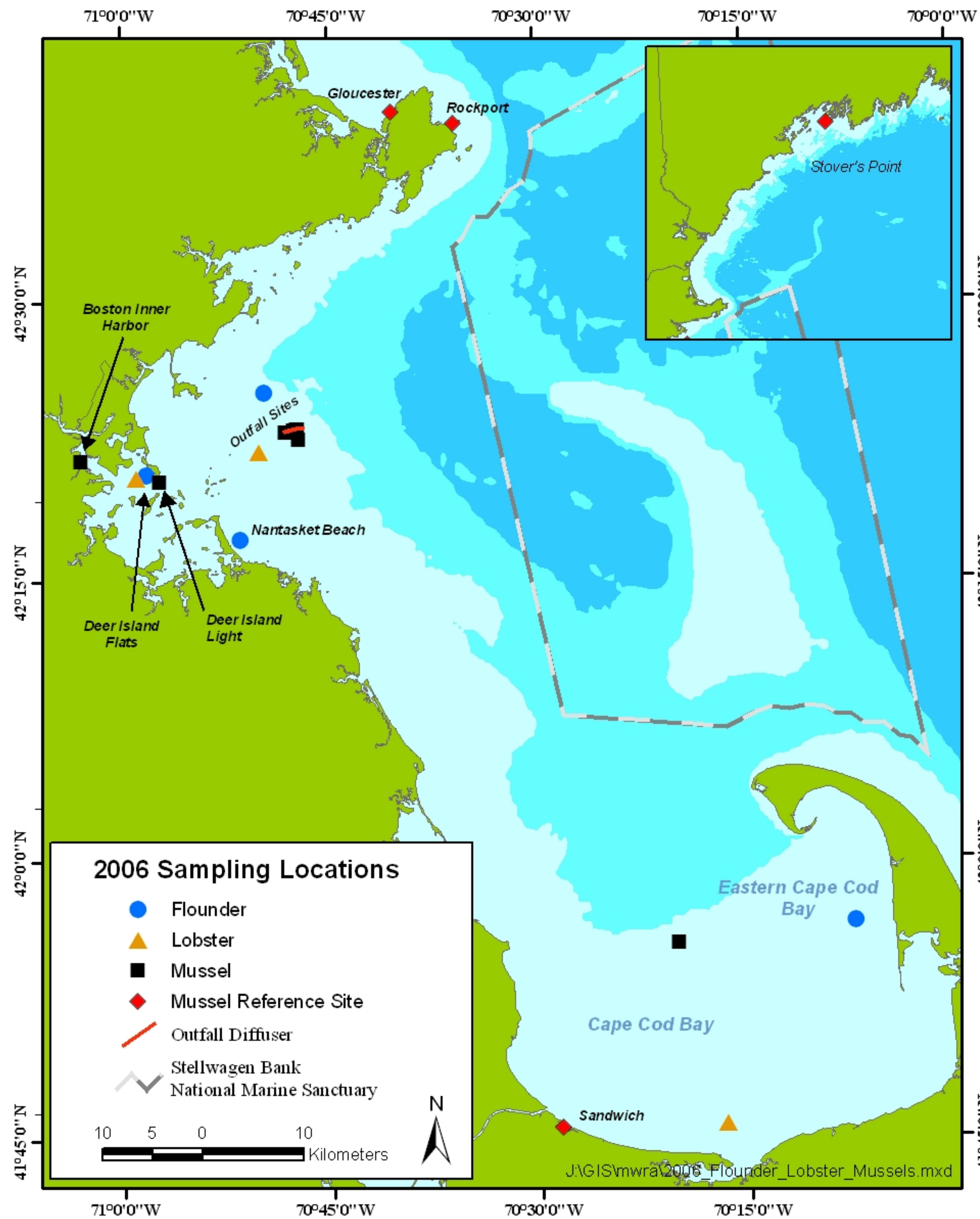

Figure 5-1. Sampling areas and reference sites for fish-and-shellfish monitoring.

Blue Mussel

Mussels are collected from clean reference sites (which have included Rockport, Gloucester, and Sandwich, Massachusetts, and Stover's Point, Maine; see Figure 5-1). They are placed in cages and deployed in replicate arrays. Since 2004, mussel deployments and analyses have been carried out every third year, including 2006.

After a minimum deployment of 40 days or a preferred deployment of 60 days, chemical analyses are performed on composite samples of mussel tissue. Tissues are analyzed for PCBs, pesticides, PAHs, lipids, mercury, and lead.

Table 5-2. Chemical analyses of fish and shellfish.

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

Contingency Plan Thresholds

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

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

Parameter Type/ Location	Parameter	Baseline	Caution Level	Warning Level
Flounder tissue nearfield	PCB	0.033 ppm	1 ppm wet weight	1.6 ppm wet weight
	Mercury	0.074 ppm	0.5 ppm wet weight	0.8 ppm wet weight
Flounder tissue, lipid normalized, nearfield	Chlordane	242 ppb	484 ppb	None
	Dieldrin	63.7 ppb	127 ppb	None
	DDT	775.9 ppb	1552 ppb	None
Flounder nearfield	Liver disease (CHV)	24.4%	44.9%	None
Lobster tissue nearfield	PCB	0.015 ppm	1 ppm wet weight	1.6 ppm wet weight
	Mercury	0.148 ppm	0.5 ppm wet weight	0.8 ppm wet weight
Lobster tissue, lipid normalized, nearfield	Chlordane	75 ppb	150 ppb	None
	Dieldrin	161 ppb	322 ppb	None
	DDT	341.3 ppb	683 ppb	None
Mussel tissue nearfield	PCB	0.011 ppm	1 ppm wet weight	1.6 ppm wet weight
	Lead	0.415 ppm	2 ppm wet weight	3 ppm wet weight
	Mercury	0.019 ppm	0.5 ppm wet weight	0.8 ppm wet weight
Mussel tissue, lipid normalized, nearfield	Chlordane	102.3 ppb	205 ppb	None
	Dieldrin	25 ppb	50 ppb	None
	DDT	241.7 ppb	483 ppb	None
	PAH	1080 ppb	2160 ppb	None

6. Special Studies

Background

Besides monitoring the effluent and the water column, sea floor, and fish and shellfish in Massachusetts Bay and the surrounding area, MWRA conducts special studies in response to specific permit requirements, scientific questions, and public concerns.

Some studies have been reported during each year of the monitoring program. For example, studies of nutrient flux at the sediment-water interface have been conducted each year in response to a concern that increased loads of organic matter might enhance benthic respiration and nutrient fluxes between the sediments and the water column in the nearfield. The resulting higher rates of benthic respiration or sediment oxygen demand might lead to lower levels of oxygen in both the sediments and the water column.

Since 1995, MWRA has included endangered species observers on monitoring surveys. 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.

A major special study carried out by the US Geological Survey began in 1989 and was completed in 2007. This cooperative research project investigated processes influencing the transport and fate of contaminated sediments in Boston Harbor and Massachusetts Bay (Bothner and Butman 2007).

Other special studies have included reviews of nutrient and toxic-contaminant issues, additional analyses of the effluent, evaluations of the Bays Eutrophication Model, floatables monitoring, and red-tide monitoring and analyses.

7. Stellwagen Bank National Marine Sanctuary

Background

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

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

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

Although these positive findings were anticipated, MWRA’s discharge permit requires an annual assessment of possible outfall effects.

Monitoring Design

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

During 2001–2006, the sanctuary managers, in conjunction with MWRA's contractor Battelle, conducted a supplemental water-quality monitoring program which added four stations to the August and October MWRA surveys (Figure 7-1). These sites were selected to provide a more comprehensive evaluation of water quality across the sanctuary.

Two MWRA sea-floor stations are within the sanctuary, one at the southern boundary and one within Stellwagen Basin (FF04 and FF05, Figure 7-2). A third sea-floor station (FF11) is just north of the sanctuary boundary and a fourth station (FF14) is located outside the sanctuary, but within Stellwagen Basin. These four stations are the deepest of those included in the MWRA monitoring program and have similar properties, with muddy sediments and moderate concentrations of total organic carbon. The stations are east or northeast of the outfall, outside the general circulation pattern that transports diluted effluent south and southeastward in Massachusetts Bay. During 1992–2003, these stations were sampled annually in August. Changes to the benthic monitoring program implemented in 2004 call for sampling approximately half the stations each year.

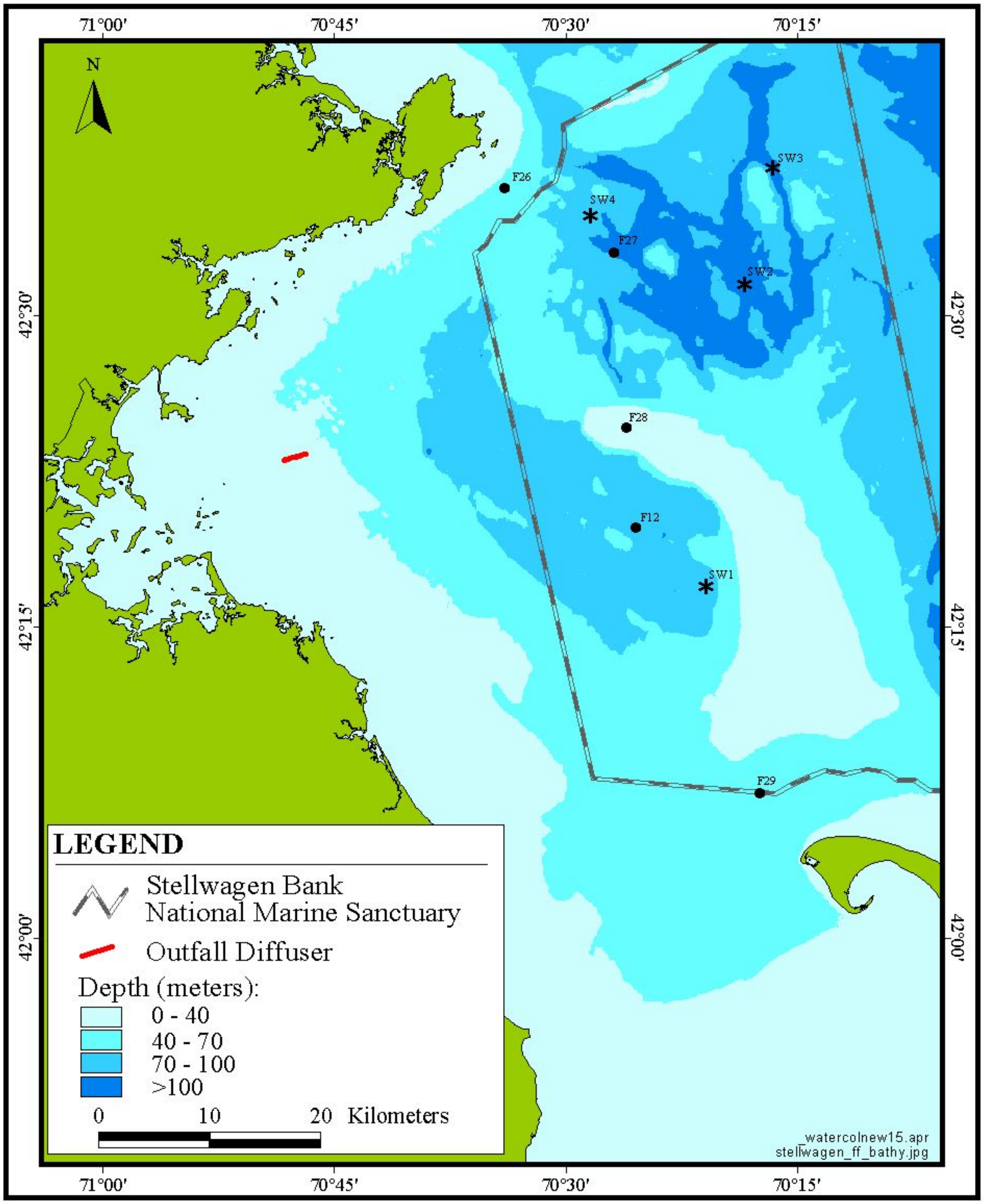

Figure 7-1. MWRA and supplemental water-column stations in and near the Stellwagen Bank National Marine Sanctuary. MWRA stations within the sanctuary are F27, F28, F12. Supplemental stations are indicated by ∗.

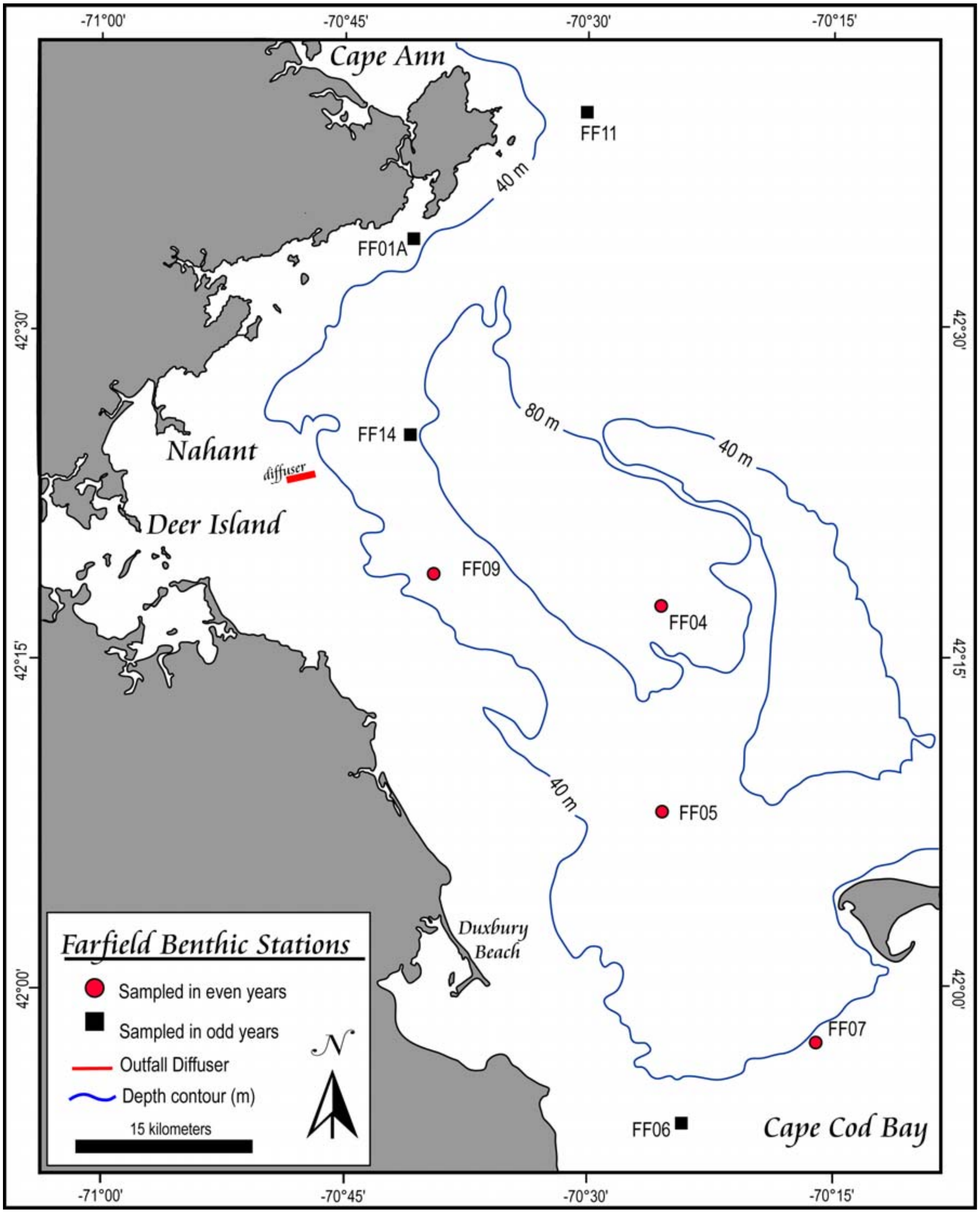

Figure 7-2. Farfield benthic stations.

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List of Acronyms

BHWQM	Boston Harbor Water Quality Monitoring
BOD	Biochemical oxygen demand
BWQM	Bay Water Quality Monitoring
cBOD	Carbonaceous biochemical oxygen demand
CHV	Centrotubular hydropic vacuolation
C-NOEC	Chronic test, no observable effect concentration
DDT	Dichlorodiphenyltrichloroethane
DITP	Deer Island Treatment Plant
DO	Dissolved oxygen
EPA	U.S. Environmental Protection Agency
FA	Foul Area
GoMOOS	Gulf of Maine Ocean Observation System
HMW	High molecular weight
IAAC	Inter-agency Advisory Committee
IWS	Industrial Waste Site
LC50	50% mortality concentration
LMW	Low molecular weight
MADEP	Massachusetts Department of Environmental Protection
MBDS	Massachusetts Bay Disposal Site
MGD	Million gallons per day
MWRA	Massachusetts Water Resources Authority
NCCOS	National Centers for Coastal Ocean Science
NDBC	National Data Buoy Center
NOAA	National Oceanic and Atmospheric Administration
NOEC	No observable effect concentration
NPDES	National Pollutant Discharge Elimination System
OMSAP	Outfall Monitoring Science Advisory Panel
OMTF	Outfall Monitoring Task Force
PAH	Polycyclic aromatic hydrocarbon
PCB	Polychlorinated biphenyl
PIAC	Public Interest Advisory Committee
RPD	Redox potential discontinuity
PSP	Paralytic shellfish poisoning
SEIS	Supplemental Environmental Impact Statement
TOC	Total organic carbon
TRAC	Toxic Reduction and Control Program
TSS	Total suspended solids
USGS	U.S. Geological Survey

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