# Ambient Monitoring Plan for the Massachusetts Water Resources Authority Effluent Outfall

Revision 2.1
August 2021

Massachusetts Water Resources Authority
Environmental Quality Department
Report 2021-08

**Citation:**

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Note: This report supersedes Report 2010-04, Revision 2.

# Ambient Monitoring Plan Revision 2.1

**Note:** This revision (# 2.1) to MWRA's permit-attached Ambient Monitoring Plan incorporates changes that were discussed with regulatory agencies, their Outfall Monitoring Science Advisory Panel (OMSAP), and representatives of the public during 2019. The changes were proposed by MWRA in 2020 and approved by regulatory agencies on January 28, 2021. More details on the process can be found at https://www.mwra.com/harbor/pdf/20201113_amp.pdf.

Revision 2.1 to the Ambient Monitoring Plan incorporates only those modifications to monitoring study design language from Revision 2 (available at http://www.mwra.state.ma.us/harbor/enquad/pdf/2010-04.pdf) necessary to capture the approved changes. Deleted text in Sections 4 and 5 is ~~lined~~ out, and new text is highlighted. Except for updating the OMSAP, PIAC, and IAAC lists, all other text, tables and figures from Revision 2 are unchanged.

OMSAP and regulatory agencies' review of MWRA's monitoring and of the scientific questions the monitoring addresses is ongoing, and additional changes are possible. MWRA anticipates preparing a more extensive revision (#3) of the Ambient Monitoring Plan when that process is complete.

## REVISION HISTORY

| Revision Number | Affected Section(s) | Effective Date | Summary of Changes |
|---|---|---|---|
| 1 | All | 03/04/2004 | Rewrite of entire Plan, reviewed and approved by regulatory agencies |
| 2 | All | 12/06/2010 | Rewrite of entire Plan, reviewed and approved by regulatory agencies |
| 2.1 | Acknowledgments | 01/28/2021 | OMSAP, PIAC, and IAAC lists updated |
| | 4.3.1 | | Text describing monitoring of sediments for sediment profile imaging and legacy contaminants has been lined out. |
| | Figure 4.14 | | Text added to figure caption noting that sediment profile image monitoring ended after 2019. |
| | 5.3.1 | | Text identifying Nantasket and East Cape Cod Bay sites has been lined out. |
| | Figure 5.1 | | Text added to figure caption noting that flounder monitoring at Nantasket and East Cape Cod Bay ended after 2020. |
| | Table 5.1 | | Number of stations for flounder study changed to "2 (after 2020)". |
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# ACKNOWLEDGMENTS

## Outfall Monitoring Science Advisory Panel

The U.S. Environmental Protection Agency and the Massachusetts Executive Office of Environmental Affairs organized an Outfall Monitoring Science Advisory Panel (OMSAP) to provide advice, guidance, and oversight for monitoring of the MWRA effluent outfall in Massachusetts Bay. Membership of OMSAP and organizations represented on its subcommittees (as of March 2021):

| | |
|---|---|
| Judith Pederson (Chair) | Massachusetts Institute of Technology |
| Robert Beardsley | Woods Hole Oceanographic Institution (retired) |
| Peter Burn | Suffolk University |
| Virginia P. Edgcomb | Woods Hole Oceanographic Institution |
| Loretta Fernandez | Northeastern University |
| Robert Kenney | University of Rhode Island |
| Mark R. Patterson | Northeastern University |
| Jeffrey Rosen | Corona Environmental Consulting |
| Juliet C. Simpson | Massachusetts Institute of Technology |
| Juanita Urban-Rich | University of Massachusetts, Boston |

**Public Interest Advisory Committee** is advisory to OMSAP

Save the Harbor/Save the Bay

Association to Preserve Cape Cod

Boston Harbor Now

Cape Cod Commission

Center for Coastal Studies

Conservation Law Foundation

Massachusetts Bays Partnership

MWRA Advisory Board

MWRA Wastewater Advisory Committee

Safer Waters in Massachusetts

**Inter-Agency Advisory Committee** is advisory to OMSAP

Mass. Coastal Zone Management

Mass. Department of Environmental Protection

Mass. Division of Marine Fisheries

Stellwagen Bank National Marine Sanctuary

United States Army Corps of Engineers

United States Environmental Protection Agency

United States Geological Survey

# FOREWORD

## Genesis of the plan

When regulatory agencies approved the plan by Massachusetts Water Resources Authority (MWRA) to move its municipal wastewater discharge from Boston Harbor into the deeper waters of Massachusetts Bay, they also required that MWRA monitor for effects of the new outfall. The MWRA outfall monitoring program was originally designed in 1990-1991 by the Outfall Monitoring Task Force (OMTF), advising the U.S. Environmental Protection Agency (USEPA) and the Massachusetts Executive Office of Environmental Affairs. The focus was on basic concerns about potential outfall environmental impacts. These concerns, from National Research Council guidance (NRC 1990), were that it would be safe to swim, safe to eat the fish, whether there would be aesthetic problems, and whether the ecosystem would be degraded. OMTF translated these concerns into monitoring questions that guided the design of the comprehensive monitoring program (MWRA 1991, 1997, 2004). OMTF and MWRA qualitatively assessed each ecosystem component for its likely utility as an indicator of an outfall-related perturbation, considering potential influence, spatial scales, and the level of scientific understanding. Components that showed the highest likelihood of indicating a change due to the outfall formed the basis of the measurements chosen in the 1991 plan. Monitoring was concentrated around the outfall—the most likely location of an effect—with farfield sites serving primarily as reference locations to identify regional ecosystem events (such as a Bay-wide plankton bloom). The plan also included "special studies;" these include the U.S. Geological Survey-MWRA study of sediment transport (Bothner and Butman 2007), and the benthic nutrient flux study.

The monitoring program was comprehensive; there was concern about the effects of a primary-treated discharge on bottom water dissolved oxygen, organic loading to the seafloor, and accumulation of toxic contaminants. The original construction schedule anticipated that primary-treated effluent would be discharged to Massachusetts Bay for five years until the new secondary treatment plant could be finished. Due to outfall construction delays, however, secondary treatment began in 1998, well before offshore discharge started in 2000.

Advancements in chemistry technology have shown that the actual toxic contaminant concentrations in secondary effluent are considerably lower than the imprecise estimates assumed in outfall siting studies (USEPA 1988).

## Evolution of the monitoring plan

The transfer of the outfall discharge into Massachusetts Bay was planned for 1995 but was delayed until September 2000. This allowed collection of over eight years of baseline data, from February 1992 to August 2000, rather than the minimum three years required by regulators. The discharge monitoring program contains essentially the same environmental measurements as the pre-discharge program, since its purpose is to measure differences from baseline.

The permit (MA0103284) for the new treatment plant and outfall was issued in August 2000, and incorporates the monitoring plan by reference as Attachment N. In August 2005, the permit expired, and has been administratively continued while a permit renewal is being developed by regulatory agencies.

In 2004, MWRA and the Outfall Monitoring Science Advisory Panel (OMSAP) revised the 1997 (MWRA 1997) Ambient Monitoring Plan as recommended by the National Research Council (NRC 1990) based on two years of post-diversion monitoring to compare with baseline conditions (OMSAP 2003 a,b,c,d,e). The revision refocused the monitoring program on the potential for long-term chronic effects, with ongoing effluent monitoring remaining the core of the monitoring program (MWRA 2004).

Now, there are nine years of post-diversion ambient monitoring data. These data support the understanding that the outfall has had only limited effects on Massachusetts Bay while the ecosystem of  Boston Harbor continues to dramatically improve. This proposed monitoring plan, Revision 2, builds on the scientific understanding gained to appropriately shift the focus and scale of the monitoring.

Previous versions of the plans are available at MWRA in Charlestown, Massachusetts,  and at a repository library on Cape Cod, or by request from MWRA, and may be retrieved from MWRA's web site http://www.mwra.state.ma.us/harbor/enquad/trlist.html
as required by the NPDES permit. For easy reference, the sampling design for the monitoring plan as implemented beginning in 2004 is appended to this proposed monitoring plan.

## Changes from 2004 Ambient Monitoring Plan

Changes to the plan are based on data collected and technical reports written since the monitoring began, including seventeen years of environmental monitoring (eight years of baseline and nine years of discharge monitoring). The monitoring plan revisions reflect that the original monitoring questions have been answered.  The focus of the monitoring program now appropriately shifts to a less intensive, less geographically dispersed, but more synoptic and consistent program.  The updates and changes from the 2004 plan in this revision are summarized below.

## Updates to the monitoring plan

The results sections have been updated to reflect the findings since the outfall went online. A brief summary of observed pre- versus post-diversion differences in the ambient environment is given. Exhaustive technical analyses, synthesis reports, and issues reports comprise more complete descriptions of results to date and are found in MWRA's library of technical reports on-line at http://www.mwra.state.ma.us/harbor/enquad/trlist.html

Completed studies have been removed from the plan, e.g. plume tracking, sediment transport. Results of these studies are summarized here; more detail can be found in MWRA technical reports. The listing and description of other special studies has been updated.

## Changes to monitoring activities

This revised Ambient Monitoring Plan incorporates changes recommended by MWRA and was reviewed by the Outfall Monitoring Science Advisory Panel (OMSAP), regulatory agencies, and the public in 2009. In December 2009 OMSAP voted to recommend that the changes be accepted. Changes are summarized below.

Effluent

1. Discontinue effluent floatables monitoring.
2. Change special study metals and organic chemicals sampling frequency from "weekly" to "4 times per month."

Water column

1. Reduce the total number of outfall monitoring stations sampled from 33 to 14, focusing the monitoring on the geographic area now known to have the possibility of being affected by the discharge. Reference stations are included, but most of the farther stations are removed.
2. Monitor in Cape Cod Bay and Stellwagen Bank NMS at 3 stations, two depths, including *in situ* water quality parameters, water column chemistry, and plankton measurements. These stations will be sampled synoptically with the nearfield stations and reference stations (*i.e.* target the sampling to occur within 48 hours of sampling at the nearfield and reference stations)[1].
3. Change survey schedule from 12 nearfield station surveys and 6 farfield station surveys annually to 9 surveys annually of 5 nearfield stations, 6 reference stations and 3 Cape Cod Bay-Stellwagen Bank National Marine Sanctuary stations. This design will enable MWRA to sample all stations during every survey, and to measure physical, chemical, and plankton parameters at all stations.[2] This will provide a synoptic picture of a broader area than was

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[1] If it is logistically infeasible to sample within 48 hours of the targeted day, MWRA will provide EPA a courtesy notification. MWRA will provide further information in its annual outfall monitoring overview report including the actual dates monitoring was conducted and rationale for any monitoring which exceeded the 48 hours of the targeted day.

[2] Plankton will not be measured at station N21 at the edge of the mixing zone because the other 4 nearfield stations will provide sufficient characterization of plankton in the nearfield.

previously possible, facilitating data interpretation. While the nearfield stations will be sampled less often than they are currently, reference stations will be visited more often than in the existing design.

4. Discontinue costly productivity measurements which have not found a substantial increase in outfall-related productivity.
5. Discontinue some water chemistry tests which have been rarely used in interpretive reporting.
6. Reduce frequency of net tow surveys for floatables, but do visual monitoring for floatables at the outfall site on each survey.Carry out two net tow surveys annually following blending events at Deer Island Treatment Plant.
7. MWRA has augmented the Gulf of Maine Ocean Observing System mooring off Cape Ann with instrumentation for continuous chlorophyll measurements. In addition, MWRA has added water quality instrumentation to the NOAA weather buoy 44013 southeast of the outfall. Thus, continuous water quality data is available in real time on the internet.

Seafloor

1. Reduce the number of soft-bottom community monitoring stations sampled annually from 16 or 17 (depending on if it is an even or odd year) to 13, and change the present design which samples alternating sets of stations each year to one in which a consistent group of stations is sampled every year. Nearfield, reference, and Stellwagen locations are included in the soft-bottom community surveys. (Continue the cost-effective sediment profile imaging at the current 23 nearfield soft bottom stations.)
2. Reduce the sediment contaminant monitoring stations to the same 13 stations used for soft bottom community monitoring. Continue the existing schedule of sampling every third year.
3. Discontinue the annual sediment contaminant sampling at two nearfield stations. These stations will now be sampled every third year with the rest of the stations.
4. Modify the sampling frequency for the hard bottom study to every third year, with samples collected the same year as sediment contaminant studies. A hard bottom survey in a year when none is planned would be triggered if the 7-day mass loading for total suspended solids exceeds 180,000 pounds/day.
5. End the nutrient flux study which has answered its monitoring questions.

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# 1 INTRODUCTION

## 1.1 Background

The Massachusetts Water Resources Authority (MWRA) is responsible for maintenance of, and improvements to, greater Boston's municipal wastewater system, including the operation of an ocean outfall from the Deer Island Wastewater Treatment Plant (DITP) that began discharging on September 6, 2000. The outfall is located in Massachusetts Bay approximately 15 km from DITP in a water depth of 32 m (Figure 1-1). Improved effluent treatment, cessation of sludge discharge, and moving the wastewater discharge from within the confines of Boston Harbor were intended to provide significant improvement in water and sediment quality within the harbor area without causing harm to the environment of Massachusetts and Cape Cod bays (USEPA 1988). Table 1-1 gives the timeline for treatment and disposal improvements and development of the monitoring.

**Table 1-1 Timeline of treatment upgrades and ambient monitoring**

| YEAR | BOSTON HARBOR PROJECT MILESTONES | MONITORING ACTIVITIES |
|---|---|---|
| 1991 | Interim repairs to existing treatment plants completed, pumping capacity increased. Sludge discharge into Boston Harbor ceased in December. | Outfall Monitoring Task Force designs Phase I Outfall Monitoring Plan, which formulated monitoring hypotheses to be tested. |
| 1992 | | MWRA initiates Baseline (Phase I) monitoring. |
| 1995 | New primary treatment facility at DITP became operational in January. | |
| 1997 | Secondary treatment Battery A at DITP start-up in July. | MWRA issues Contingency Plan in February and Phase II Outfall [Ambient] Monitoring Plan in December. |
| 1998 | Secondary Battery B start-up in March. South system flows diverted from Nut Island Treatment Plant to DITP via the inter-island tunnel in July. | |
| 2000 | Outfall is relocated to Massachusetts Bay, 9.5 miles from DITP, in September. | Regulatory agencies issue NPDES permit in August which incorporates Ambient Monitoring Plan and Contingency Plan by reference.<br>Monitoring changes from baseline to discharge (monitoring design remains consistent). |
| 2001 | Secondary Battery C start-up in March. | Contingency Plan revised to reflect new information since 1997. |
| 2004 | Inter-island tunnel transport for sludge and improvements to secondary treatment facilities completed. | MWRA completes four years of discharge monitoring, implements Revision 1 of Ambient Monitoring Plan. |
| 2009 | | MWRA completes nine years of discharge monitoring, proposes Revision 2 of Ambient Monitoring Plan. |

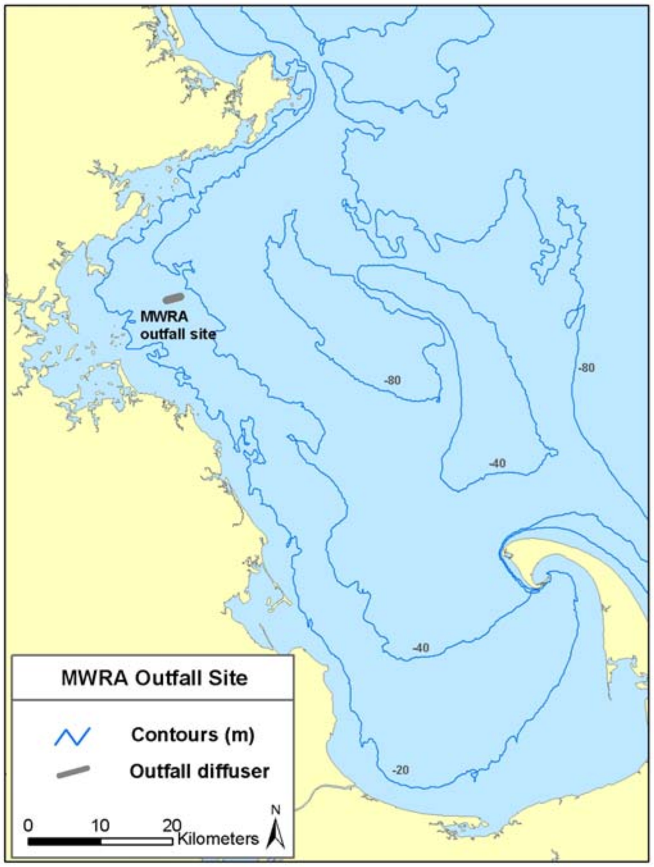

**Figure 1-1 Map of Massachusetts and Cape Cod bays showing MWRA outfall location 9.5 miles from Deer Island in 30 meters of water.**

The outfall is regulated through a permit issued by the U.S. Environmental Protection Agency and the Massachusetts Department of Environmental Protection under the National Pollutant Discharge Elimination System (NPDES). The ambient monitoring plan is incorporated by reference into the August 2000 NPDES permit for the new plant and outfall, which expired August 9, 2005 but remains in effect while a follow-on permit is developed. MWRA applied for permit renewal in February, 2005.

The major emphasis in the ambient monitoring has been in the vicinity of the outfall, called the nearfield, with additional effort in Cape Cod and Massachusetts Bay (farfield stations). This proposed plan re-focuses the monitoring within the area now known to be potentially affected by the discharge, with reference stations outside that area. Improvements in Boston Harbor are also monitored by MWRA but most of that monitoring is not covered by this plan. The Contingency Plan lists thresholds (Caution and Warning Levels), which were developed to protect the environment and public health. The Contingency Plan also describes the various management actions that MWRA could undertake when thresholds are exceeded. Examples of management actions include additional monitoring, development of response plans and performance of engineering feasibility studies.

Special studies have addressed particular questions; for example, sediments around the outfall were sampled three times per year before and after outfall start-up to see if there would be rapid accumulation of contaminants there. A jointly funded US Geological Survey-MWRA study that examined transport of sediments and contaminants from the outfall in Massachusetts Bay was completed (Bothner and Butman 2007). MWRA has participated in a number of projects monitoring and modeling red tide in Massachusetts Bay (Anderson *et al.* 2007), and a special study focused on the occurrence of skin lesions that were discovered on flounder during the monitoring (Moore 2006).

Other special projects provide contextual information that assists in the interpretation of outfall monitoring data. For example, MWRA participates in opportunities for regional monitoring such as the Gulf of Maine Ocean Observing System (GoMOOS 2003 www.neracoos.org/gomoos), and uses satellite imagery from the Ocean Biology Processing Group http://oceancolor.gsfc.nasa.gov/ (NASA 2008) to understand large-scale patterns in the ocean.

Results of monitoring are described in many technical reports, see MWRA's website http://www.mwra.state.ma.us/harbor/Boston: Massachusetts Water Resources Authority/trlist.html (e.g. Libby *et al.* 2008, 2009; Tucker *et al.* 2008, 2009; Maciolek *et al.* 2008, 2009; Kane-Driscoll *et al.* 2008) and in an annual Outfall Monitoring Overview (e.g. Werme *et al.* 2009). Details of the field and analytical program are provided in a series of Combined Work/Quality Assurance Project Plans (e.g. Libby *et al.* 2008, Tucker *et al.* 2008, Maciolek *et al.* 2008). In addition, many papers on the results of the monitoring have been published in the peer-reviewed literature; many of these papers are listed on MWRA's website http://www.mwra.state.ma.us/harbor/html/litlist.html .

## 1.2 Monitoring objectives

The primary objectives of the Monitoring Plan are to:

1. Test for compliance with NPDES permit requirements.
2. Test whether the impact of the discharge on the environment is within the bounds projected by the SEIS (USEPA 1988).
3. Test whether change within the system exceeds the Contingency Plan thresholds (MWRA 2001).

MWRA is required to monitor effluent regularly to test for compliance with its NPDES permit requirements. For example, the permit specifies allowable limits of carbonaceous Biochemical Oxygen Demand (cBOD) and Total Suspended Solids (TSS) in the effluent based on expected performance. Monitoring for these parameters allows MWRA to check treatment performance, pinpoint areas of concern, and correct for problems if they exist. MWRA submits monthly Discharge Monitoring Reports and immediately reports violations of permit limits if they occur.

The USEPA Environmental Impact Statement (SEIS) on the outfall (USEPA 1988) with concurrent opinion from the Massachusetts Executive Office of Environmental Affairs (EOEA) determined that there would not be significant water quality or biological impacts associated with the outfall. The monitoring plan tests for water quality, sedimentary, and biological parameters to ensure that impacts from the discharge are within the bounds projected by the SEIS.

The Contingency Plan is part of a Memorandum of Agreement among the National Marine Fisheries Service, USEPA, and MWRA, and is one of the "Conservation Recommendations" issued by NMFS (1993) to further protect endangered species. The Contingency Plan specifies numerical or qualitative thresholds that would suggest that effluent quality or environmental conditions may be changing or might be likely to change in the future. In the event that one of these thresholds is exceeded, MWRA's discharge permit sets into motion a process to confirm the threshold exceedance, to determine the causes and significance of the exceedance, and identify MWRA's response if the analysis indicates a change attributable to the effluent outfall. There is some overlap of Objective 3 with Objectives 1 and 2. The NPDES permit effluent limits are echoed in the Contingency Plan as warning level thresholds.

EOEA and USEPA established the Outfall Monitoring Science Advisory Panel (OMSAP) to oversee and make recommendations on the Monitoring Plan, as well as to provide guidance in interpretation and evaluation of collected data. OMSAP is comprised of scientists from a variety of disciplines. The Public Interest Advisory Committee and the Interagency Advisory Committee advise OMSAP on public and regulatory concerns. OMSAP builds upon the work of its predecessor, the Outfall Monitoring Task Force that operated between 1991 and June 1998. These groups have provided the oversight necessary for an effective monitoring program (Schubel 2003).

## 1.3 Components of the monitoring plan

The outfall ambient monitoring was designed to address the environmental concerns for impacts that might reasonably be expected to be caused by effluent constituents. The monitoring plan is designed to address four basic questions:

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

Possible environmental responses to the effects of constituents in effluent are translated into specific monitoring questions. The Ambient Monitoring Plan (AMP) is organized around the general subject headings of effluent, water column, sediment, and fish and shellfish monitoring. Each of these subjects are discussed in more detail in subsequent sections, organized as follows:

1 Purpose of the monitoring
2 Monitoring questions and results
3 Proposed revised monitoring plan
4 Data evaluation
5 Rationale for monitoring redesign

## 1.4 Relationship to Contingency Plan

Pre-discharge data collected as part of the AMP were used to calculate some of the threshold values for the Contingency Plan. Monitoring data collected after the outfall began operating are used to compare to the Contingency Plan thresholds. Thresholds listed in the Contingency Plan (MWRA 2001) are based on effluent limits, observations from the baseline monitoring, national water quality criteria and state standards, and in some cases, best professional judgment. Most values for threshold parameters are calculated from data collected in the outfall nearfield. There are reference stations in the AMP to help determine if changes in the nearfield are likely due to the discharge or due to more broad-scale environmental changes in Massachusetts Bay. The proposed changes to the AMP will retain the existing contingency plan thresholds, however the calculations of the threshold values (based on baseline data) and tests (based on current sampling data) may change as a result of the changes to the number of stations and frequency of sampling. As was done for the previous 2004 modification, the baseline threshold values would be recalculated based on the modified sampling design.

# 2 EFFLUENT MONITORING

## 2.1 Purpose of Effluent Monitoring

The most important part of protecting Massachusetts Bay from pollution is ensuring that the final treated effluent is as clean as possible. MWRA accomplishes this with a vigorous pretreatment program and pollution prevention initiatives that minimize toxic contaminants entering the waste stream, and by maintaining and operating the treatment plant well. The MWRA toxic reduction and control program sets and enforces limits on the types and amounts of pollutants that industries can discharge into the sewer system. This has minimized contaminants in effluent and in the sludge that is removed during primary and secondary treatment, enabling beneficial re-use of treated sludge. Details of MWRA's pollution prevention program are in MWRA's Industrial Waste Report (MWRA October 2008).

The contaminants of concern in wastewater fall into the general categories of nutrients, toxic contaminants, organic material, human pathogens, solids, and floatables. Secondary treatment reduces the concentrations of contaminants of concern (except nutrients) that are in the effluent that is ultimately discharged to Massachusetts Bay. The treatment plant removes approximately 95% of the mercury and lead, 85% of the cadmium and copper, 80% of the chromium and zinc, and 45% of the nickel from the effluent. Solids discharges from MWRA sources, including Deer Island and Nut Island treatment plants and sludge, have decreased by 87% since the beginning of the Boston Harbor project. The effluent consistently meets permit limits for solids and organic material in both wet and dry weather conditions.

Results of the extensive effluent monitoring required in MWRA's stringent discharge permit, and the additional effluent monitoring required in this Ambient Monitoring Plan and the Contingency Plan demonstrate how well the flow is treated. The plant is performing as well or better than anticipated in initial environmental impact studies during the treatment plant's design phase (Wu 2008, Delaney and Rex 2007, Delaney 2009).

### 2.1.1 Contingency Plan thresholds

All NPDES permit effluent limits (Table 2-1) are also Contingency Plan warning level thresholds. The Contingency Plan (MWRA 2001) contains additional effluent thresholds for overall plant performance, total nitrogen load, and oil and grease. Effluent floatables are monitored under the Contingency Plan.

## 2.2 Effluent Monitoring Questions and Results

This section summarizes results from all the types of effluent monitoring done by MWRA, including the more "routine" effluent monitoring, and more specialized testing required in the Contingency Plan and AMP. A detailed description of effluent monitoring results for the first five years of discharge through the Massachusetts Bay outfall is in Delaney and Rex (2007), and an addendum to that report shows results from 2005-2008 (Delaney 2009).

### 2.2.1 Effluent monitoring questions

The effluent monitoring program is intended to answer the following questions (MWRA 1991):

→ *Do effluent pathogens exceed permit limits?*

→ *Does acute or chronic toxicity of effluent exceed permit limits?*

→ *Do effluent contaminant concentrations exceed permit limits?*

→ *Do conventional pollutants in the effluent exceed permit limits?*

→ *What are the concentrations of contaminants and characteristic tracers of sewage in the influent and effluent and their associated variability?*

### 2.2.2 Permit discharge monitoring results

The treatment plant reliably meets its permit requirements. Discharges of conventional pollutants (Figures 2-1, 2-2) and toxic contaminants (Figure 2-3) decreased dramatically over the past decade as treatment improvements came on-line. One of the most encouraging success stories is the decline in mercury discharges as a result of efforts by MWRA and the New England states to reduce use and disposal of mercury (Figure 2-4).

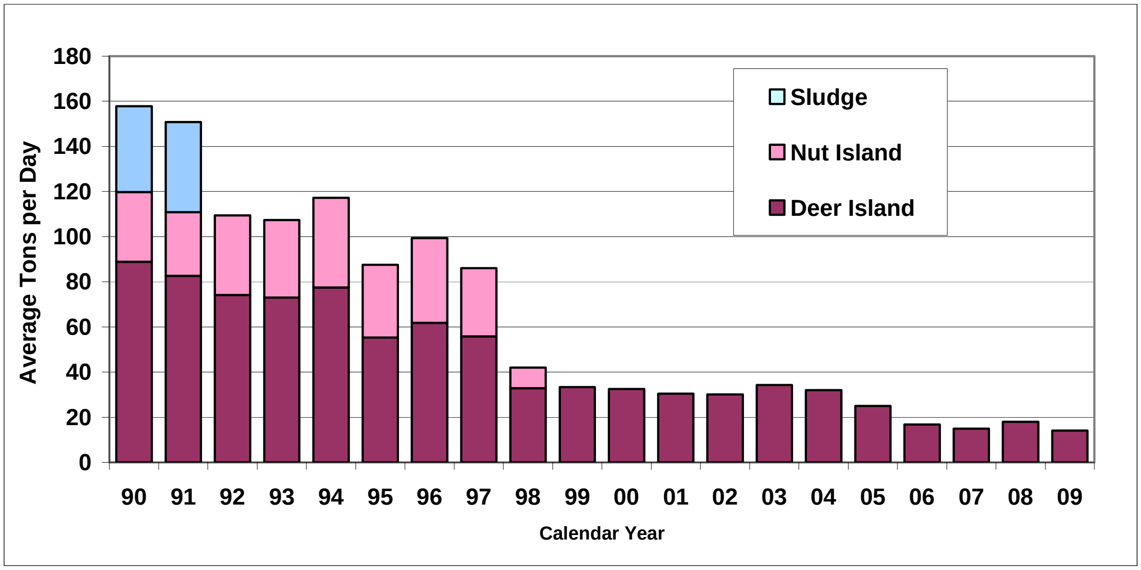

**Figure 2-1 Solids in MWRA effluent have dropped dramatically since 1990.**

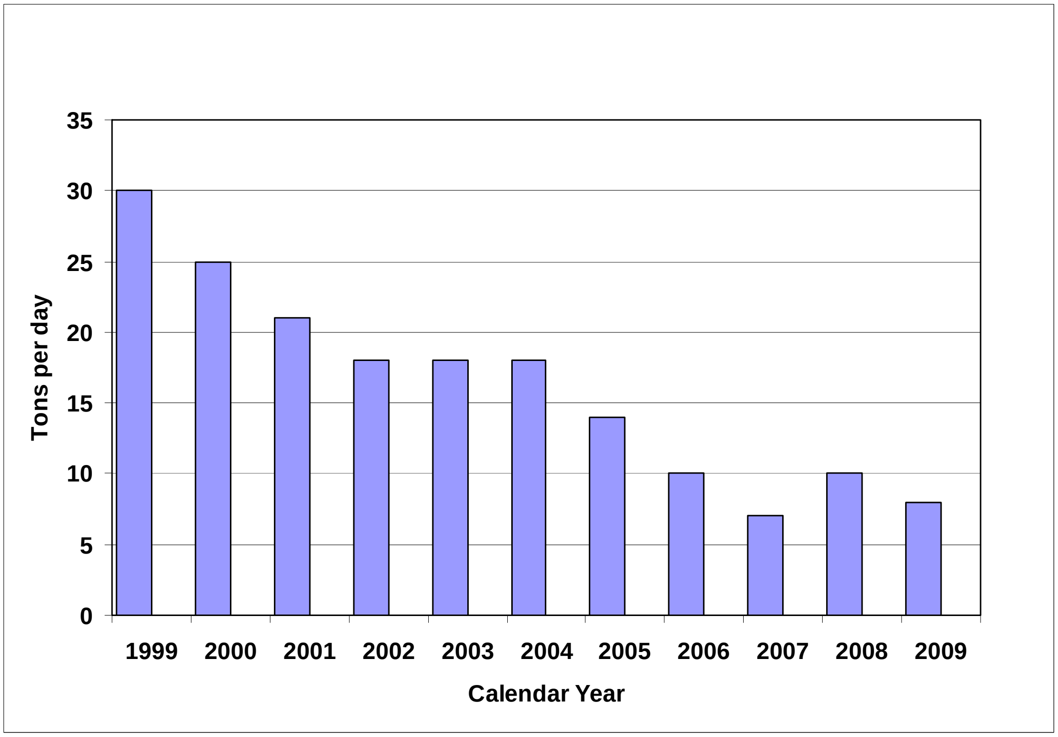

**Figure 2-2 Discharge of carbonaceous biochemical oxygen demand (cBOD) has dropped substantially.**

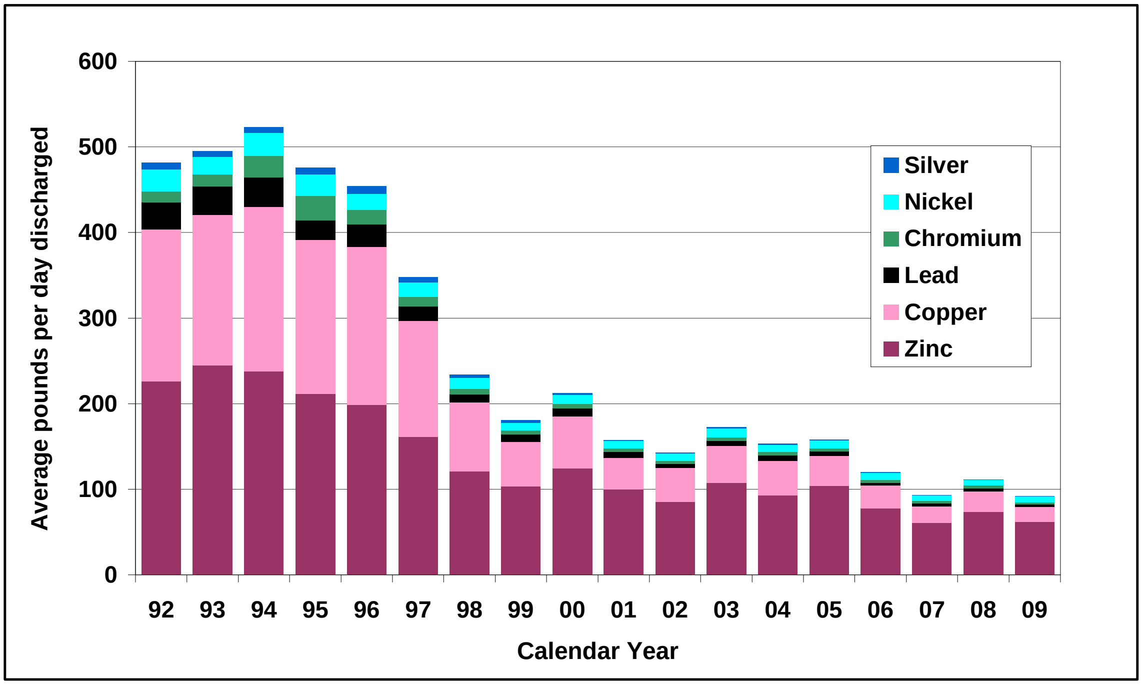

**Figure 2-3 Metals discharges in MWRA effluent have dropped due to pre-treatment and secondary treatment.**

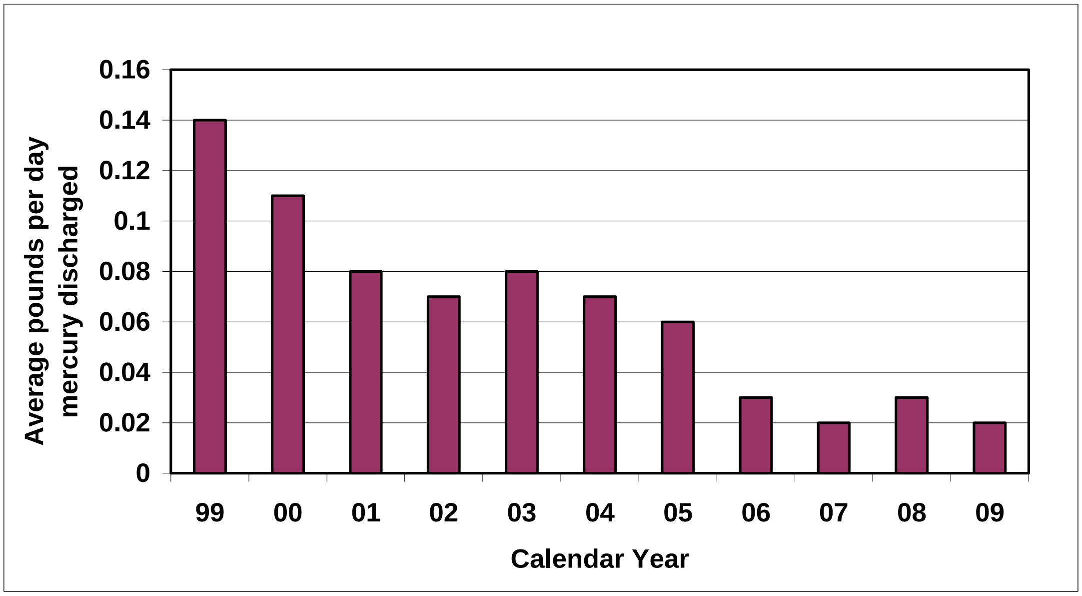

**Figure 2-4 Mercury discharged in effluent (and in sludge, data not shown) has declined, largely due to pollution prevention efforts.**

From the time that the outfall went online in 2000, through 2009, there were only a few violations of permit limits (Table 2-1). Out of tens of thousands of tests performed on MWRA effluent since the outfall went on-line, there have been eleven violations (which are also Contingency Plan threshold exceedances). The failures comprise several toxicity tests (none of those failures were clearly attributable to toxic contaminants in effluent); exceedances of the total suspended solids limits after an industrial discharge caused an upset of secondary treatment; and brief fecal coliform violations associated with extreme high flows during severe storms.

**Table 2-1 Effluent violations and Contingency Plan exceedances have been rare over the past 9 years.**

| DATE OF EXCEEDANCE | EFFLUENT PERMIT VIOLATIONS | CAUSE | NUMBER TESTS SEPT 6, 2000-DEC 2009 |
|---|---|---|---|
| August 2002 | Suspended solids (monthly limit) | Upset of secondary process by industrial discharge | 595 |
| August 24, 2002 | Suspended solids | | |
| August 17, 2002 | Suspended solids | | |
| April 2, 2004 | Fecal coliform | Storm-related | 3,399 |
| December 18, 2001 | Fecal coliform | Storm-related | |
| August 21, 2006 | Toxicity (*Menidia*) | Unknown | 560 |
| September 15, 2005 | Toxicity (*Arbacia*) | Unknown, repeat passed | |
| April 2001 | Toxicity (*Menidia* growth) | Unknown, probably natural variability of test organisms | |
| January 2001 | Toxicity (*Arbacia*) | Unknown | |
| December 14, 2000 | Chlorine | Prior to completion of automated dechlorination monitoring | 10,297 |
| December 7, 2000 | pH | Measurement technique was biased low for pH | 3,399 |

There was some public concern that the discharge would contain significant amounts of sewage-related plastics (tampon applicators, condoms) that would be an aesthetic nuisance or harm marine life. Therefore, MWRA designed an automatic floatables sampler that screened solid material from final effluent, and developed methods for measuring floatables weight and volume. Floatables discharges were minimal (Figure 2-5) (Rex *et al.* 2008), which supports ending the effluent floatables monitoring.

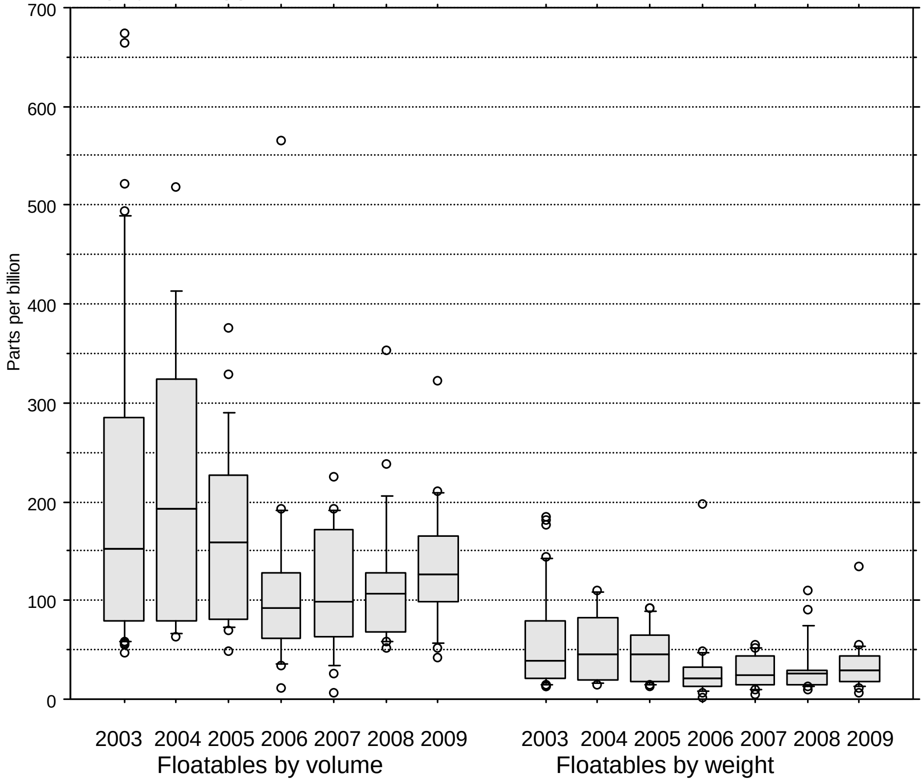

**Figure 2-5 Floatables in DITP effluent by weight and volume 2003-2009.**

### 2.2.3 Contingency Plan results

None of the Contingency Plan (MWRA 2001) thresholds for overall plant performance, total nitrogen load, or oil and grease have been exceeded. Effluent floatables are at parts per billion levels (Rex *et al.* 2008).

### 2.2.4 Special studies

**Detailed effluent characterization of toxic contaminants.** MWRA prepared a detailed report on priority pollutant data in DITP effluent (Delaney and Rex 2007). The report has been updated with an addendum for data collected from August 2005 through December 2009 (Delaney 2010). The maximum and average values measured for all metals except copper, meet marine receiving water quality criteria in effluent *before dilution* (Table 2-2). Detected organic contaminants from August 2005 through December 2009 were at low concentrations, and none of these contaminants would exceed any applicable marine water quality criteria after dilution (Table 2-3).

**Table 2-2 Metals detections and concentrations in DITP effluent August 2005-December 2009**

| Metal | Method* | Samples | Non-Detects | Detects (%) | Range (µg/L) | Median (µg/L) | Upper 95% Percentile (µg/L) | Lowest EPA Water Quality Criterion (µg/L)** |
|---|---|---|---|---|---|---|---|---|
| Aluminum | ICP | 420 | 200 | 220 (52%) | <15 - 230 | 90 | 99 | None |
| Antimony | ICP | 109 | 109 | 0 (0%) | <25 | <25 | <25 | 5.6 (HHC) |
| Arsenic | GFAA | 108 | 104 | 4 (4%) | <0.8 – 1.0 | <0.8 | <0.8 | 0.018 (HHC) |
| Beryllium | ICP | 109 | 109 | 0 (0%) | <0.5 | | | None |
| Boron | ICP | 109 | 67 | 42 (38%) | <250 – 352 | <250 | 328 | None |
| Cadmium | GFAA | 393 | 138 | 255 (65%) | <0.03 – 0.34 | 0.049 | 0.116 | 8.8 (CCC) |
| Chromium | GFAA | 394 | 111 | 283 (72%) | <0.70 – 3.4 | 0.87 | 1.69 | 50 (CCC) as $Cr^{+6}$ |
| Copper | GFAA | 332 | 0 | 332 (100%) | 2.5 – 12 | 6.2 | 9.0 | 3.1 (CCC) |
| | ICP | 393 | 328 | 65 (16%) | <10 – 71 | <10 | 12.6 | 3.1 (CCC) |
| | ICP/MS | 53 | 0 | 53 (100%) | 4.5 – 26 | 7.4 | 15.6 | 3.1 (CCC) |
| Iron | ICP | 109 | 0 | 109 (100%) | 97 – 630 | 183 | 459 | None |
| Lead | GFAA | 392 | 381 | 11 (3%) | <2.4 – 7.0 | <2.4 | <2.4 | 8.1 (CCC) |
| | ICP/MS | 52 | 0 | 52 (100%) | 0.43 – 7.2 | 0.96 | 2.5 | 8.1 (CCC) |
| Mercury | CVAA | 413 | 315 | 98 (24%) | <0.01 – 0.072 | <0.01 | 0.017 | 0.94 (CCC) |
| | CVAF | 52 | 0 | 52 (100%) | 0.0029 – 0.072 | 0.0068 | 0.024 | 0.94 (CCC) |
| Molybdenum | GFAA | 282 | 0 | 282 (100%) | 1.5 – 17 | 4.3 | 7.7 | None |
| Nickel | GFAA | 392 | 0 | 392 (100%) | 0.80 – 5.6 | 2.3 | 3.4 | 8.2 (CCC) |
| Selenium | GFAA | 109 | 109 | 0 (0%) | <0.9 | <0.9 | <0.9 | 71 (CCC) |
| Silver | GFAA | 392 | 192 | 200 (51%) | <0.09 – 1.3 | 0.09 | 0.30 | 1.9 (CMC) |
| Thallium | GFAA | 109 | 109 | 0 (0%) | <1 | <1 | <1 | 0.24 (HHC) |
| Zinc | ICP | 392 | 0 | 392 (100%) | 7.2 – 85 | 19.2 | 35.6 | 81 (CCC) |

* Metals Methods Acronyms
ICP: Inductively Coupled Plasma Optical Emission Spectrometry
GFAA: Graphite Furnace Atomic Emission Spectrometry
CVAA: Cold Vapor Atomic Emission Spectrometry
CVAA: Cold Vapor Atomic Fluorescence Spectrometry
ICP/MS: Inductively Coupled Plasma Mass Spectrometry

** From EPA, 2006. Based on Saltwater or Human Health Criteria.
CCC: Criterion Continuous Concentration is an estimate of the highest concentration of a material in surface water to which an aquatic community can be exposed indefinitely without resulting in an unacceptable effect.
CMC: Criteria Maximum Concentration is an estimate of the highest concentration of a material in surface water to which an aquatic community can exposed briefly without resulting in an unacceptable effect.
HHC: Human Health Criterion is based on a carcinogenicity of $10^{-6}$ risk

## Table 2-3 Pesticides, PAHs, and PCB detections and concentrations in DITP effluent August 2005-December 2009

| Compound* | Samples | Non-Detects | Detects (%) | Range (ng/L) | Median (ng/L) | Upper 95% Percentile (ng/L) | Lowest EPA Water Quality Criterion (ng/L)** |
|---|---|---|---|---|---|---|---|
| Total Chlordane (SIM only) | 510 | 0 | 510 (100%) | 0.16 – 5.7 | 0.78 | 2.2 | 0.80 (HHC) for Chlordane only |
| Alpha-Chlordane (SIM only) | 510 | 0 | 510 (100%) | 0.14 – 3.7 | 0.55 | 1.62 | 0.80 (HHC) for Chlordane only |
| Total DDT | 510 | 60 | 450 (88%) | 0.084 – 14.6 | 0.61 | 2.35 | 0.22 (HHC) for 4,4'-DDT only |
| 4,4'-DDE (SIM only) | 510 | 131 | 379 (74%) | 0.096 – 1.58 | 0.31 | 1.3 | 0.22 (HHC) |
| 4,4'-DDT (SIM only) | 510 | 344 | 166 (32%) | 0.176 – 2.93 | 1.05 | 2.1 | 0.22 (HHC) |
| Gamma-BHC (Lindane) (ECD only) | 106 | 106 | 0 (0%) | <10 – <28 | | | 160 (CMC) |
| Gamma-BHC (Lindane) (SIM only)[+] | 510 | 394 | 116 (23%) | 0.18 – 21.5 | 0.66 | 1.45 | 160 (CMC) |
| Hexachlorobenzene (HCB) (ECD only) | 106 | 106 | 0 (0%) | <10 – <28 | | | 0.28 (HHC) |
| Hexachlorobenzene (HCB) (SIM only)[+ #] | 503 | 78 | 425 (84%) | 0.025 – 7.81 | 0.081 | 0.24 | 0.28 (HHC) |
| Total PCB | 564 | 8 | 556 (99%) | 0.10 – 6.12 | 0.86 | 2.48 | 0.064 (HHC) |
| Chrysene | 488 | 2 | 526 (100%) | 1.16 – 138 | 6.77 | 23 | 3.8 (HHC) |
| Fluorene | 488 | 18 | 470 (96%) | 1.00 – 113 | 3.38 | 11 | 1,100,000 (HHC) |
| Total NOAA PAH | 260 | 0 | 260 (100%) | 29 – 2340 | 110 | 349 | N/A |

*Method Acronyms

ECD: Gas Chromatography with Electronic Capture Detector
SIM: Selected Ion Monitoring Gas Chromatography / Mass Spectrometry

** From EPA, 2006. Based on Saltwater or Human Health Criteria.
CCC: Criterion Continuous Concentration is an estimate of the highest concentration of a material in surface water to which an aquatic community can be exposed indefinitely without resulting in an unacceptable effect.
CMC: Criteria Maximum Concentration is an estimate of the highest concentration of a material in surface water to which an aquatic community can exposed briefly without resulting in an unacceptable effect.
HHC: Human Health Criterion is based on a carcinogenicity of $10^{-6}$ risk

NOTE: Total NOAA PAH is based on the average of duplicate pairs of samples. It is computed as the sum of the detected concentrations for the 24 individual PAH compounds.

**Nutrients**. Although the permit requires monthly nutrient sampling, MWRA carries out weekly sampling to better characterize effluent variability. Figure 2-6 shows that annual average loadings of total nitrogen in effluent have shown no trend for the period 1996 through 2009. During the same period, average loadings of the dissolved inorganic nitrogen fraction, largely as ammonium, have increased as a proportion of the total discharge, as a result of the upgrade to secondary treatment. Levels of annual nitrogen loadings are well below the threshold.

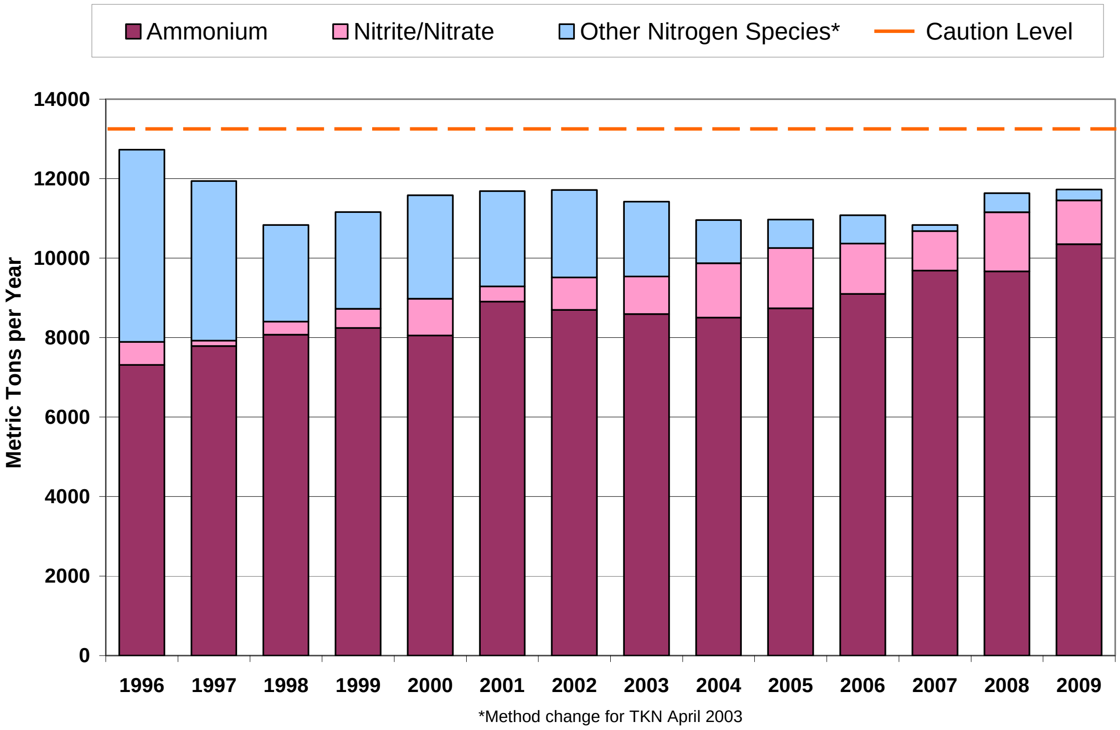

**Figure 2-6 Nitrogen loadings from DITP 1996-2009**

**Emerging contaminants.** In 2007, MWRA did a pilot study on two sets of dry-weather Deer Island Treatment Plant samples to test for pharmaceuticals and personal care products (MWRA, unpublished data). Thirty-one chemicals (a list developed by USGS) were tested for; 23 chemicals were detected at least once at parts-per-trillion to parts-per-billion concentrations. Eleven chemicals showed substantial removal during the treatment process, generally above 80%. There are no EPA recommended water quality criteria for any of the chemicals that were detected.

### 2.2.5 Comparison with planning projections

In 1988, USEPA's Supplemental Environmental Impact Statement (SEIS) projected loadings from DITP with secondary treatment for selected metals and organic contaminants after secondary treatment. Table 2-4 shows that actual loadings are substantially lower than projected (Delaney and Rex 2007, Delaney 2010).

**Table 2-4 Projected and measured mean annual contaminant loadings from DITP**

| Parameter | Projected for Secondary (Kg/yr) (SEIS) | Mean Loading Kg/yr (August 2005 – December 2009) |
|---|---|---|
| **Cadmium** | 697 | 29 |
| **Chromium** | 3,517 | 481 |
| **Copper** | 11,945 | 3,253 |
| **Lead** | 4,961 | 674 |
| **Mercury** | 216 | 5.1 |
| **Molybdenum** | | 2,223 |
| **Nickel** | 8,926 | 1,150 |
| **Silver** | 299 | 67 |
| **Zinc** | | 11,182 |
| **Total PCB** | 50 | 0.52 |
| **Total PAH**[+] | | 84.3 |
| **Total DDT** | | 0.43 |
| **4,4'-DDT (only)** | 28 | 0.31 |
| **Total Chlordanes** | | 0.54 |
| **Heptachlor (only)**[#] | 10 | 0.54 |

Empty cell indicates that no projection was made for that parameter

[+] Total NOAA PAH, 24 compounds

[#] All Heptachlor results were non-detect, so the median "less than" value (<1.06 ng/L) was used to estimate the mean loading.

## 2.3 Effluent Monitoring Plan

MWRA's effluent monitoring requirements include standard discharge monitoring requirements reported to regulatory agencies monthly in the National Pollutant Discharge Elimination Program (NPDES) Discharge Monitoring Reports (DMRs), and additional requirements in the outfall Contingency Plan. Effluent special studies address emerging issues, for example nutrient loading, newer pathogen indicators, and low-detection methods for effluent contaminants. There are two changes to the effluent monitoring:

1. End the effluent floatables study, which has shown very small (parts per billion) levels of floatables (Rex *et al.* 2008, see Figure 2-5). There are no standards for effluent floatables.

2. For the detailed effluent characterization (see Table 2-6), change the sampling frequency from the existing "weekly" to "4 times per month." The NPDES permit requires monthly sampling; this change in the special detailed study schedule will eliminate the present replication that occurs due to variations in schedules while retaining detailed information.

### 2.3.1 NPDES Permit discharge monitoring requirements

Table 2-5 lists DITP's NPDES permit requirements, which are typical for wastewater treatment permits, and would be changed only with a permit modification. Some of the parameters have limits (i.e. maximum or minimum allowed levels) and some are "report only."

**Table 2-5 Permit-required DMR monitoring for Deer Island Treatment Plant effluent**

| PARAMETER | LIMIT | SAMPLE TYPE | FREQUENCY |
|---|---|---|---|
| Flow | report only | Flow meter | Continuous |
| Flow dry day | 436 MGD annual average | Flow meter | Continuous |
| cBOD | 40 mg/L weekly, 25 mg/L monthly | 24-hr composite | 1/day |
| TSS | 45 mg/L weekly, 30 mg/l monthly | 24-hr composite | 1/day |
| pH | not <6 or >9 | Grab | 1/day |
| Fecal coliform bacteria | 14,000 col/100ml | Grab | 3/day |
| Total residual chlorine | 631µg/L daily, 456 µg/L monthly | Grab | 3/day |
| PCB, Aroclors | 0.045 ng/L | 24-hr composite | 1/month |
| Toxicity LC50 | 50% | 24-hr composite | 2/month |
| Toxicity C-NOEC | 1.5% | 24-hr composite | 2/month |
| Settleable solids | Report | Grab | 1/day |
| Chlorides (influent only) | | Grab | 1/day |
| Mercury | | 24-hr composite | 1/month |
| Chlordane | | 24-hr composite | 1/month |
| 4,4' – DDT | | 24-hr composite | 1/month |
| Dieldrin | | 24-hr composite | 1/month |
| Heptachlor | | 24-hr composite | 1/month |
| Ammonia-nitrogen | | 24-hr composite | 1/month |
| Total Kjeldahl nitrogen | | 24-hr composite | 1/month |
| Total nitrate | | 24-hr composite | 1/month |
| Total nitrite | | 24-hr composite | 1/month |
| Cyanide, total | | Grab | 1/month |
| Copper, total | | 24-hr composite | 1/month |
| Total arsenic | | 24-hr composite | 1/month |
| Hexachlorobenzene | | 24-hr composite | 1/month |
| Aldrin | | 24-hr composite | 1/month |
| Heptachlor epoxide | | 24-hr composite | 1/month |
| Total PCBs | | 24-hr composite | 1/month |
| Volatile organics | | Grab | 1/month |

### 2.3.2 Monitoring in support of the Contingency Plan

All of the permit limits are echoed in the Contingency Plan (MWRA 2001) as Warning Level thresholds. Weekly additional monitoring is done for oil and grease. (MWRA is proposing to end monitoring for floatables).

### 2.3.3 Special studies

Tables 2-6 and 2-7 summarize effluent special studies of toxic contaminants and nutrients.

***Detailed effluent characterization of toxic contaminants.*** Effluent monitoring can warn of increases in loads of toxic contaminants, but only if methods are sensitive enough to detect the very low levels of these pollutants. MWRA has found that the ability to detect trace levels of contaminants in its effluent aids in the interpretation of other ambient monitoring data, especially for evaluation of fish and shellfish data and toxicity testing. The pattern of certain organic contaminants can help determine whether MWRA effluent might be a source of contamination found in the environment. The effluent data provide valuable feedback to the treatment plant operators and the pollution prevention team. The parameters measured and sampling schedule are shown in Table 2-6.

**Table 2-6 Special study: detailed effluent characterization of toxic contaminants**

| PARAMETER | SAMPLE TYPE | FREQUENCY |
|---|---|---|
| Acid base neutrals | 24-hr composite | bimonthly |
| Volatile Organic Compounds | Grab | |
| Low detection limit analyses | | |
| Cadmium | 24-hr composite | 4 times/month |
| Copper | | |
| Chromium | | |
| Mercury | | |
| Lead | | |
| Molybdenum | | |
| Nickel | | |
| Silver | | |
| Zinc | | |
| 17 chlorinated pesticides | | |
| Extended list of PAHs | | |
| 20 PCB congeners | | |

***Nutrients.*** To interpret the Massachusetts Bay water column monitoring data, it is helpful to make more frequent and additional nutrient measurements than those included in ordinary discharge monitoring. For example, effluent phosphorus measurements are not required by the NPDES permit, but phosphorus is important to algal growth. Weekly nutrient measurements provide more precise load estimates. The parameters measured and the sampling schedule are shown in Table 2-7.

**Table 2-7 Special study: effluent nutrient monitoring**

| PARAMETER | SAMPLE TYPE | FREQUENCY |
|---|---|---|
| Total Kjeldahl nitrogen | 24-hr composite | Weekly |
| Ammonia | | |
| Nitrate | | |
| Nitrite | | |
| Total phosphorus | | |
| Total phosphate | | |

## 2.4 Data evaluation

MWRA uses effluent monitoring data to quickly identify any problems with treatment that could lead to environmental impacts. In the case of a permit violation, the additional monitoring data can help interpret the routine discharge monitoring data and predict whether the violation might result in an adverse effect in the environment. Annual reports summarize trends in concentrations and loads (Wu 2009, Werme and Hunt 2008, Werme *et al.* 2009), and periodic reports summarize the special sampling data (*e.g.* Delaney and Rex 2007, Delaney 2010).

## 2.5 Rationale for proposed changes

MWRA is proposing little change to the effluent monitoring. MWRA proposes to end the study of floatables because the effluent has been well-characterized and floatables of concern are rarely found. The minor change in schedule for metals sampling will eliminate some redundant sampling.

# 3 WATER COLUMN MONITORING

## 3.1 Purpose of Water Column Monitoring

### 3.1.1 Environmental concerns

The components of wastewater that are of concern in the water column are nutrients, organic material, pathogens, and floatables; these may impact the ecosystem, human health, and aesthetics. DITP effectively removes suspended solids, oxygen-consuming organic material, pathogens, and floatables from wastewater, but removes only about 20% of the nitrogen. Secondary treatment increases the proportion of effluent nitrogen that can be readily taken up by marine algae. Therefore although monitoring in the water column addresses aesthetic and human health concerns, the monitoring focuses on nutrients and their possible eutrophication impacts such as low dissolved oxygen, nuisance algal blooms, and altered plankton communities.

### 3.1.2 Contingency Plan thresholds

Water column monitoring provides the data required for testing of the thresholds in the Contingency Plan (MWRA 2001):

- dissolved oxygen (DO) concentration, percent saturation, and rate of summertime decline
- seasonal and annual chlorophyll
- nuisance algae

Details are given in the Contingency Plan (MWRA 2001). The Outfall Monitoring Overview reports (e.g. Werme *et al.* 2009) summarize the comparison of monitoring results with Contingency Plan thresholds.

## 3.2 Water Column Monitoring Questions and Monitoring Results

MWRA has been monitoring water quality in Massachusetts and Cape Cod Bays for 17 years, documenting the findings in numerous detailed technical reports and broader overviews. These reports can be retrieved from http://www.mwra.state.ma.us/harbor/Boston: Massachusetts Water Resources Authority/trlist.html .

In 2002, MWRA and OMSAP reviewed the monitoring questions relative to water column impacts (OMSAP 2002). It was agreed that most of the questions had been answered with respect to acute impacts on the environment (none or minimal), but that the potential for more long-term effects still existed, and therefore MWRA continued monitoring to evaluate whether the outfall may yet have unanticipated impacts. Seven years later, in 2010, MWRA believes that the original acute monitoring questions are answered. The data support implementation of changes in the monitoring to tighten the focus on parameters, locations, and sampling schedule that are most likely to show outfall effects. MWRA believes that the revisions will more efficiently and effectively use public resources that fund the monitoring work and, furthermore, that the changes improve the ability to interpret monitoring data because of synoptic sampling.

### 3.2.1 Monitoring questions: Dilution

→ *Are the model estimates of short-term (less than 1 day) effluent dilution and transport accurate?*

***Results: Yes.*** The outfall performs as designed. During summer 2001, a dye study of effluent dilution was conducted (Hunt, Mansfield *et al.* 2002). Field results agreed well with physical and computer model predictions for initial dilution (about 100:1 in the summer study), plume thickness and height, and lateral spreading. This question is answered and was removed from the monitoring plan in 2004.

→ *Do levels of contaminants outside the mixing zone exceed State Water Quality Standards?*

***Results: No.*** After the dilution provided by the outfall, effluent contaminant concentrations are low enough so that water quality standards are met in the receiving water. To confirm this, selected contaminants were measured during the dye study of effluent dilution (Hunt, Mansfield *et al.* 2002). Bacterial indicators were at or below the detection limits on both surveys; copper concentrations, while higher than background values, were well below applicable standards. Other parameters such as nutrients and total suspended solids showed elevated concentration in the plume, as expected. However, measured concentrations were consistent with the initial dilution measured by the dye. The subsequent dilution as the plume is transported through the far field brings the concentrations of these parameters to background levels in less than a day.

### 3.2.2 Monitoring questions: Pathogens

→ *Are pathogens transported to shellfish beds at levels that might affect shellfish consumer health?*

→ *Are pathogens transported to beaches at levels that might affect swimmer health?*

***Results: No***. Sampling results and the measured dilution show that shellfish beds and beaches are not impacted by the outfall discharge (Hunt, Mansfield *et al.* 2002).

**Other monitoring results:** Ongoing sampling for bacteria in the water column near the outfall is not part of this monitoring plan, rather, that sampling is governed by a permit-required (Part I.1.a. Footnote 15) Memorandum of Understanding with the MA Division of Marine Fisheries. Bacteria sampling is carried out monthly for fecal coliform and *Enterococcus*.

Monitoring has detected a slight increase in bacteria counts after the outfall began. The highest counts are typically at stations directly over the diffuser line, but even these are well below the most stringent water quality standards. More than 900 samples have been collected at the 6 outfall nearfield stations since the outfall went on-line. The nearfield geometric mean *Enterococcus* is 2 colonies/100 ml, well below the standard of 35 colonies/100 ml.; most of the samples are non-detects. Only one sample (in 2003) exceeded the “single sample maximum” of

104 col/100 ml. (MWRA 2008, retrieved from http://www.mwra.state.ma.us/harbor/html/mb_bacteria.htm).

### 3.2.3 Monitoring questions: Aesthetics

→ *Has the clarity and/or color around the outfall changed?*

→ *Has the amount of floatable debris around the outfall changed?*

***Results:*** Floatables have been sampled by a surface net tow near the outfall and at a control site during each nearfield survey. The nets collect varying amounts of natural debris (seaweed and larger plankton) at both sites and occasionally collect refuse typical of land-runoff, but no more than before the outfall began discharging. The net tow at the outfall site captures small fat particles characteristic of treated effluent. There are some slight changes in aesthetics around the outfall observable in certain weather conditions but no increase in plastics of concern have been observed (Rex *et al.* 2008). In some surveys, bits of fat are collected in the net. In the summer stratified season, the outfall discharge is not visible at the surface. The plume reaches the surface in winter but is visible only on calm days when the sea is flat; then the plume sometimes appears as a subtle 30-m diameter circle of calmer water over each diffuser riser.

### 3.2.4 Monitoring questions: Transport and fate

→ *What are the nearfield and farfield water circulation patterns?*

→ *What is the farfield fate of dissolved, conservative, or long-lived effluent constituents?*

***Results:*** Understanding of the physical oceanographic conditions in the bays has been detailed in Libby *et al.* 2009, and earlier water column reports (*e.g.* Libby *et al*. 2003, 2004, 2006a, 2006b, 2007), and in numerous peer-reviewed papers in the scientific primary literature (*e.g.* Butman 1975, Geyer *et al.* 1992, Signell *et al.* 1996, Anderson *et al.* 2005).

On a regional scale, circulation in the bays is often affected by the larger pattern of water flow in the Gulf of Maine. The western Maine coastal current usually flows southwestward along the coast of Maine and New Hampshire and depending on prevailing oceanographic and meteorological conditions may enter Massachusetts Bay south of Cape Ann (Geyer *et al.* 1992). Optimal conditions for inflow usually occur during the spring when winds out of the northeast bring significant freshwater inflow from the gulf into the bays and transport generally follows a counterclockwise path along the coast to Cape Cod Bay. Inflow from the gulf is the major source of nutrients to the bay. The inflow also helps to flush the bay, and gives the bay its water quality characteristics including dissolved oxygen levels and plankton communities (including nuisance blooms such as *Alexandrium*). During the summer, winds are generally from the south; this impedes surface water inflow from the gulf, but causes upwelling along the coast and entry of deep waters from the gulf into the bay.

The combination of the general circulation within Massachusetts Bay and local conditions and mixing determine the fate and transport of effluent discharged from the outfall. Vertical rise of the effluent plume from the sea-floor diffuser is stopped at mid-depth by the density gradients that prevail from April through October. Tides and wind-driven flow displace the plume horizontally 5-10 km in a day over a contorted path. Although there is no prevailing net direction at the outfall site (Butman *et al.* 1992), this motion helps mix the plume with surrounding water such that effluent contaminants are diluted to background levels within 20 km of the outfall (Hunt, Mansfield *et al.* 2002, Libby 2003).

The substantial and seasonal influence of the Gulf of Maine has been observed on circulation, nutrient loading, DO, and nuisance algal species in the bays.

### 3.2.5 Monitoring questions: Water chemistry (nutrients and dissolved oxygen)

→ *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?*

***Results:*** The observed changes in the nutrient regime following diversion are unambiguous: ammonium ($NH_4$) has dramatically decreased in Boston Harbor and nearby coastal waters while increasing moderately in the nearfield. The signature levels of $NH_4$ in the plume are generally confined to an area within 10-20 km of the outfall. The change in $NH_4$ concentrations observed is consistent with model simulations which predicted that the transfer of effluent from Boston Harbor to Massachusetts Bay would greatly reduce nutrients in the harbor and increase them locally in the nearfield (Signell *et al*. 1996). This change was predicted to have little impact on concentrations in the rest of Massachusetts and Cape Cod Bays.

The spatial patterns in $NH_4$ concentrations in the harbor, nearfield and bays since the diversion in September 2000 have consistently confirmed this (Taylor 2006; Libby *et al*. 2003, 2004, 2006a, 2006b, 2007, 2009). The changes in $NH_4$ are clearly seen in annual mean concentrations for these areas (Figure 3-1). The annual mean $NH_4$ concentration in Boston Harbor dropped sharply from 2000 to 2001. A sharp decrease was also seen at the coastal stations which are strongly influenced by water quality conditions in Boston Harbor. In contrast, the increase in annual mean $NH_4$ in the nearfield was much less dramatic than the harbor and coastal water decrease. Compared to 1999, the last full year before the bay outfall came online, annual mean $NH_4$ levels in the nearfield almost doubled in 2001. After 2001 $NH_4$ has shown a system-wide decrease. Even in the nearfield, $NH_4$ concentrations are again comparable to the pre-diversion, 1999 levels. This decline in $NH_4$ over the last several years can be seen in all of the survey regions and current annual concentrations are comparable to 1992-1999 across the bays.

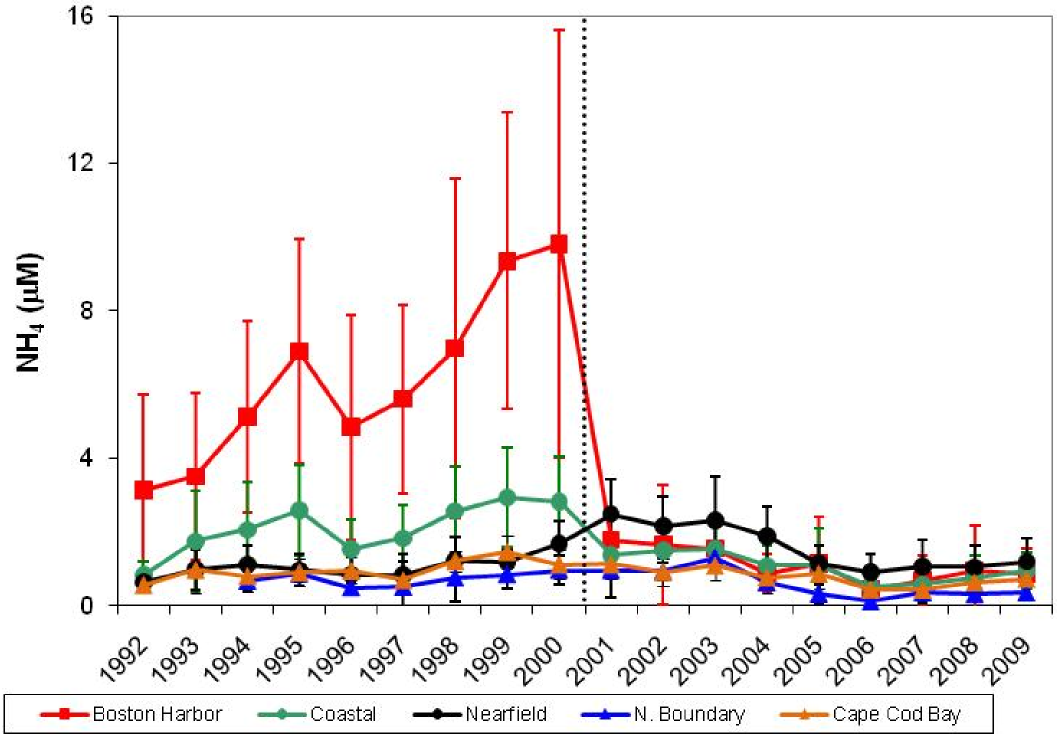

**Figure 3-1 Annual mean ammonium by area 1992-2009**

The trends in annual mean concentration for other inorganic nutrients are more variable. For example, $NO_3$, has actually increased slightly over much of the bays (except Boston Harbor) over the course of the monitoring program.

The overall shift in $NH_4$ and $NO_3$ from pre- to post-diversion years in the nearfield and Boston Harbor can be seen over the annual cycle on a survey-by-survey basis. The reduction in Boston Harbor $NH_4$ concentrations has been significant and can be clearly seen over all six survey periods. There has been an increase in survey mean $NH_4$ concentrations in the nearfield of about 1 µM during the stratified period from May to October. Ammonium concentrations are also elevated above baseline during the other surveys, but to a lesser degree. Boston Harbor $NO_3$ concentrations have decreased by approximately the same extent in the winter and fall. For $NO_3$, there has been a slight increase in the nearfield of about 1-2 µM.

**Statistical analyses.** Regression analysis of nearfield data showed the moderate increase in $NH_4$ concentrations was most apparent in summer and also particulate organic carbon (POC) increased in the nearfield in the summer (Libby *et al.* 2009). However, Before-After, Control-Impact (BACI) statistical analyses put the changes in POC and $NH_4$ in context. BACI analysis found that only $NH_4$ concentrations changed between the impact (inner nearfield) and control (outer nearfield, Massachusetts Bay offshore, and Cape Cod Bay) areas. $NH_4$ was higher in the inner nearfield. The analyses did not find statistically significant changes in chlorophyll or POC in this “impact” area compared to “control” regions of the bays that are 5 to >50 km distant, supporting the understanding that observed changes in phytoplankton biomass are associated with regional processes.

→ *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?*

***Results:*** The state standard allows for natural variability, and oxygen levels in bottom waters of the nearfield and Stellwagen Basin have not yet fallen below natural background values (Libby *et al.* 2009, Werme *et al.* 2008). For example, Figure 3-2 shows DO concentrations in the nearfield.

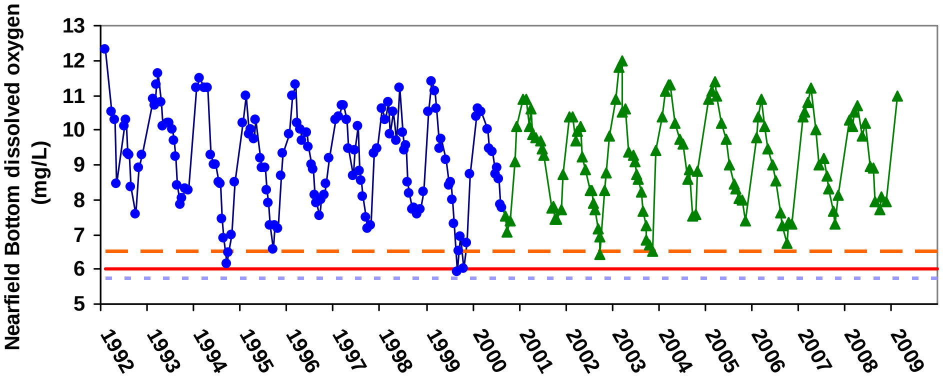

**Figure 3-2 Nearfield bottom water dissolved oxygen concentration results**

**Blue line represents baseline data, green line is post-diversion data. Caution, Warning and Background levels are indicated by orange dashed, red, and blue dotted lines respectively.**

→ *Have the concentrations (or percent saturation) of dissolved oxygen in the vicinity of the outfall or at selected farfield stations in Massachusetts Bay or Cape Cod Bay changed relative to predischarge baseline or a reference area? If so, can changes be correlated with effluent or ambient water nutrient concentrations, or can farfield changes be correlated with nearfield changes?*

***Results.*** There have been limited or no changes noted between baseline and post-diversion DO levels or patterns as documented in Libby *et al.* (2004, 2006a, 2006b, 2007, 2009). Furthermore, modeling and statistical analyses indicate that bottom water DO levels in Massachusetts Bay are highly correlated with conditions along the bay/Gulf of Maine boundary and that regional processes and advection are the primary factors governing bottom water DO concentrations in the bay (HydroQual 2001, Geyer *et al.* 2002, Jiang *et al.* 2007).

### 3.2.6 Monitoring questions: Biology (chlorophyll, productivity, and plankton)

→ *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 or Boston Harbor 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?*

***Results:***

**Phytoplankton biomass:** The data are summarized in the most recent water column annual report, Libby *et al.* (2009). The higher nearfield $NH_4$ concentrations since the outfall went on-line have not translated directly into changes in biomass, whether measured as chlorophyll, POC, or phytoplankton abundance, although there has been a significant increase in winter/spring biomass in the nearfield and most of Massachusetts Bay due to larger scale regional trends in phytoplankton bloom dynamics. In Boston Harbor, the dramatic decrease in $NH_4$ has been concomitant with significant decreases in other nutrients (Taylor 2006). However, throughout most areas of the bays significant changes in levels and temporal patterns have also occurred for other parameters. Many of these changes were noted on both a station-by-station and grouped-station basis. There were some regional patterns evident in the nutrient data such as the increase in $NO_3$ concentrations in the winter/spring and fall.

Before-After, Control-Impact statistical analyses examined if the changes that have been observed within the nearfield and throughout the bays are significantly different from one another. The only differences were seen for $NH_4$ concentrations, which were higher in the inner nearfield compared to the outer nearfield, Massachusetts Bay offshore, and Cape Cod Bay during all three seasons ($P<0.002$). None of the other tested changes were significant. This indicates that even though there has been an increase in $NH_4$ at these stations close to the bay outfall, there have not been any significant changes in chlorophyll or particulate organic carbon (POC) in this "impacted" area compared to "control" regions of the bays that are 5 to >50 km distant. There certainly have been significant changes in these parameters post-diversion, but they have changed in both impact and control areas and thus appear to be associated with regional processes.

In Boston Harbor, there have been decreases in seasonal chlorophyll and POC commensurate with the decreases in dissolved inorganic nutrients. The harbor has also exhibited patterns in these parameters (and productivity) that are comparable to those observed in the nearfield and other temperate coastal waters. The spatial pattern of summer decreases in chlorophyll and POC in Boston Harbor is as predicted based on the removal of the source of the surface water nutrients that supported the high biomass during the baseline (Signell *et al.* 1996).

Although there appears to be a direct relationship between decreases in nutrients and biomass in Boston Harbor, for the bay the association between observed changes is not as clear. In the nearfield, there have been increases in $NH_4$ during all three seasonal periods, and in $NO_3$ during winter/spring and fall, while for the rest of Massachusetts Bay $NH_4$ levels have decreased in winter/spring and fall and $NO_3$ concentrations have increased in winter/spring. These changes in nutrients have been coincident with increases in winter/spring areal chlorophyll throughout Massachusetts Bay, increases in winter/spring nearfield POC, and a decrease in fall chlorophyll in the southern region of Massachusetts Bay.

**Productivity:** Post-diversion production data indicate there has been a decrease in Boston Harbor ($P<0.05$), while there have been no significant changes in nearfield production since September 2000. Reduced productivity at the harbor mouth is correlated with reduced nutrients due to outfall relocation. An increase in February production, combined with a large decrease in April-August production and a proportionally lower reduction for fall production has modified the seasonal pattern for harbor productivity. Rather than increasing over the course of the spring and peaking in the summer, as observed when the discharge was located in Boston Harbor, the harbor station is exhibiting a pattern of productivity more similar to the nearfield stations.

Changes in nutrient concentrations in the nearfield during the spring bloom period appear to be correlated with increased biological utilization and increased peak bloom chlorophyll biomass even though no statistically significant changes in spring productivity have been observed and levels have in fact decreased compared to baseline. The trends observed in productivity for the pre- versus post-diversion comparisons appear to be driven by, or confounded by, more regional processes. The annual productivity data suggest that there has been a decrease in production since 2003 and an evaluation confirms that significant decreases in nearfield production have occurred from 1995-2002 versus 2003-2007 for annual, as well as fall time periods. This makes it difficult to rule out a small local difference in productivity in the nearfield (compared to the rest of the region, where productivity is not measured) since diversion. But the data do show that the outfall has not caused detrimental or anomalous increases in production. Annual nearfield productivity correlates with winds (summer average and gusts) and degree of stratification, suggesting that the observed decreases in annual productivity at the harbor and nearfield stations in recent years are, at least in part, a result of decreased wind speed and increased stratification.

**Nuisance algae:** Major red tides occurred in 2005 and 2006 off the Maine coast and in Massachusetts Bay. *Alexandrium* abundance had been low (0-100 cells $l^{-1}$) from 1992-2004 and was low again in Massachusetts Bay in 2007 even though there was a large bloom observed offshore in the Gulf of Maine. There are no indications of a regional outfall effect on the 2005 and 2006 *A. fundyense* blooms; a modeling analysis estimated that if a local outfall effect had occurred, it would have been minor (Anderson *et al.* 2007). A red tide originating off the coast of Maine entered Massachusetts Bay in 2008, causing shellfish bed closures including in Boston Harbor. This red tide event was briefer and over a smaller geographic area than the previous blooms in 2005 and 2006.

The occurrence of large April *Phaeocystis* blooms since 2000 in Massachusetts Bay appears to be influenced by copepod abundance and salinity in February and March. The lower the copepod abundance and the higher the salinity, the more likely there will be a large *Phaeocystis* bloom. These results are consistent with long-term trend analyses, which show post-2000 declining copepod abundance simultaneous with increasing *Phaeocystis* abundance. The duration of these *Phaeocystis* blooms is closely related to surface water temperature. *Phaeocystis pouchetii* is a cold water species that has a physiological upper temperature tolerance of 14°C. A significant linear relationship was found between the day 14°C is reached and *Phaeocystis* bloom duration, which explains 70% of the variance in Massachusetts Bay *Phaeocystis* bloom duration during 2000-2007.

**Phytoplankton communities:** Analyses of long-term phytoplankton trends indicate that there have been shifts within the phytoplankton community assemblage since 2000. Diatoms (with the exception of *Dactyliosolen fragilissimus*) and dinoflagellates have generally declined, while microflagellates and *Phaeocystis* have had relative increases. There is no outfall-related direct link or causality associated with these shifts as many of the changes are occurring over larger spatial scales and, as with the changes in *Phaeocystis* (regional blooms) or *Ceratium* (related to stratification), appear to be related to more regional ecosystem dynamics in the Gulf of Maine.

**Zooplankton communities:** Long-term trend analyses and pre-/post-diversion comparisons indicate a general decline in zooplankton abundance (with the exception of *Calanus finmarchicus*) from 2001 to 2006 before increasing again in 2007. The timing of this decline coincides with the diversion of the outfall, but there are no plausible linkages between the diversion and apparent decline, which is region-wide. The changes in zooplankton abundance could also be related to a variety of factors from top-down controls due to grazing by ctenophores or other predators, to bottom-up control via *Phaeocystis* blooms in the spring (poor food source) or lack of substantial fall phytoplankton blooms (reduced food source), to physical hemispheric climatic processes for example the North Atlantic Oscillation, or freshening of the Northwest Atlantic due to Arctic melting. Alternatively, different oceanographic regimes (i.e., variable influence of nearshore vs. offshore water masses) having different fauna (*Calanus*-dominated vs. *Oithona*-dominated) may be operative in and co-varying with *Phaeocystis* vs. non-*Phaeocystis* bloom years.

A special study using sensitive nitrogen isotope tracers to follow the uptake of nitrogen from sewage in zooplankton, sponsored by the Provincetown Center for Coastal Studies (PCCS) (Moore, CR *et al*. 2005, based on Montoya *et al*. 2003) showed that

> "after one year there was no appreciable change to the sources of nitrogen to the food web. That is, when archived (pre-outfall) zooplankton were compared with post outfall zooplankton, $\delta\ ^{15}N$ values were not significantly different at the depths sampled. The PCCS-sponsored study concluded that zooplankton in Massachusetts Bay continues to

> reflect the isotopic composition of marine sources of nitrogen. In general, summer sampling results within Cape Cod Bay are correlated with the MWRA results, showing an incremental return to expected $\delta^{15}$N ratios within 20-40 km, just entering Cape Cod Bay. In cooler winter months however, migration of sewage-N as far as 80 km was reported by the PCCS-Georgia Tech study, presumably when uptake by phytoplankton is significantly reduced."

The MWRA ambient water quality monitoring program has collected an exceptional dataset to examine the Massachusetts and Cape Cod Bays ecosystem. The diversion of the discharge from Boston Harbor to the bay outfall provided a unique situation in which to examine the relative effects of local perturbations to both relatively small (Boston Harbor) and large (Massachusetts and Cape Cod Bays) systems. The predictive models and post-diversion results indicate that the impact of the diversion is local in scale – primarily observed as lower nutrient and chlorophyll concentrations in Boston Harbor and higher $NH_4$ concentrations in the inner nearfield within 5 km of the outfall. Other pre- vs. post-diversion changes have been noted, but they appear to be associated with long-term trends unrelated to the outfall diversion.

## 3.3 Water Column Monitoring Plan

The previous design scheduled nearfield sampling surveys 12 times annually and farfield surveys 6 times annually, with farfield samples located throughout Massachusetts and Cape Cod Bays. The design was very complex with respect to which analyses were carried out where. The revised design described here aims for synoptic sampling of locations that previous studies show either are, or have the potential to be, affected by the effluent. In addition, reference locations in Boston Harbor and offshore of the outfall are included for a total of 11 stations (three additional stations will be included in a monitoring study of Cape Cod Bay and Stellwagen Bank National Marine Sanctuary as described below). All tests will be done at all locations. The rationale for these changes is below, after the description of the plan.

**Sampling schedule.**
Nine synoptic surveys.

**Table 3-1 Water column survey schedule**

| WHEN | TARGET WEEK | ORIGINAL SURVEY NUMBER | PURPOSE |
|---|---|---|---|
| Early February | 6 | 1 | Nutrient conditions near start of spring bloom |
| March | 12 | 3 | Spring bloom |
| Early April | 15 | 4 | Capture *Phaeocystis* bloom. Late winter/spring bloom nutrients |
| Mid-May | 20 | 6 | Nutrient/water column conditions at end of winter-spring, *Alexandrium* |
| Mid-June | 25 | 7 | Early summer stratification and nutrients. Mid-late red tide season. |
| Mid-July | 30 | 9 | Mid-summer stratification and nutrients |
| Mid-August | 34 | 11 | Mid-summer stratification and nutrients |
| September | 36 | 12 | Nutrients, etc. prior to overturn. |
| Late October | 43 | 14 | Mid-fall bloom nutrients, DO minima, etc. |

**Sampling locations.**
Sampling locations are shown in Figure 3-3. There are five nearfield stations to characterize the area near the discharge, six reference stations, and three stations in Cape Cod Bay-Stellwagen Basin National Marine Sanctuary. Five depths will be sampled at all stations, except Cape Cod Bay and Stellwagen Basin National Marine Sanctuary will be sampled at two depths. Table 3-2 summarizes the stations and their purpose in monitoring

**Figure 3-3 Map of MWRA outfall ambient water column monitoring stations**

**Table 3-2 List of water column monitoring stations**

| STATION ID | WATER DEPTH (M) | LOCATION DESCRIPTION RELATIVE TO OUTFALL | PURPOSE |
|---|---|---|---|
| F22 | 80 | 17 km NE | Northern reference station<br>Gulf of Maine influence<br>Regional physical forcing relates to nearfield DO<br>Link between buoy and sampling data<br>“Upstream” sentinel station in winter-spring |
| N04 | 50 | 7.1 km NE | Evaluate extent of plume northeast |
| N01 | 31 | 6.3 km NW | Evaluate extent of plume northwest |
| N21 | 35 | 60 m | Evaluate water quality at ZID<br>Close to outfall<br>Ammonium signature<br>Primary “impact” station for comparison to other stations |
| N18 | 27 | 2.5 km S | Close to outfall<br>Ammonium signature<br>Primary “impact” station for comparison to other stations |
| N07 | 50 | 7 km SE | Near NOAA buoy MWRA instruments-data comparison |
| F23 | 25 | 12 km E | Boston Harbor |
| F15 | 38 | 9 km S | Evaluate southward extent of plume |
| F13 | 25 | 14 km S | Near coastal (model, *Alexandrium*) |
| F10 | 33 | 20 km S | Furthest expected southern expression of effluent plume |
| F06 | 33 | 29 km SE | Southern reference station |

**Parameters.** Table 3-3 lists the parameters to be measured. The *in-situ* sensors attached to the water sampler electronically measure the parameters. As the water sampler descends the sensors provide data at half-meter resolution from surface to within five meters of the bottom at each station. On the ascent the sensors provide data during collection of discrete water samples. An appropriate number of water samples will also be collected for laboratory analysis of dissolved oxygen and fluorescence sufficient to calibrate the field instruments.

Gene probe measurements for *Alexandrium* are added, because this method is the fastest and most accurate method to measure red tide.

The design is consistent, enabling more direct comparisons among stations. The goal will be to sample each station for the same parameters on the same day.

**Table 3-3 Water column parameters**

| ANALYTE | DEPTH | PARAMETER |
|---|---|---|
| Hydro profile | Downcast data continuous, with upcast data at any sampled depths | Temperature<br>Salinity<br>Dissolved oxygen<br>Chlorophyll fluorescence<br>Transmissometry<br>Irradiance<br>Depth of sensors |
| Water chemistry | Five depths.  Surface, bottom, and three intermediate depths which includes the chlorophyll maximum | Ammonium<br>Nitrate<br>Nitrite<br>Total dissolved nitrogen<br>Particulate nitrogen<br>Phosphate<br>Total dissolved phosphorus<br>Particulate phosphorus<br>Silicate<br>Particulate carbon |
| *Alexandrium* | Two depths. | Gene probe |
| Phytoplankton<br>Zooplankton | Near surface<br>Net tow for zooplankton.<br>Plankton will not be measured at station N21 because nearfield plankton is adequately characterized by data collected at the other four nearfield stations. | Identification, enumeration |

**Cape Cod Bay-Stellwagen Bank National Marine Sanctuary.** Two stations (Figure 3-3 and Table 3-4) in Cape Cod Bay and one station at the southern boundary of Stellwagen Bank National Marine Sanctuary (SBNMS) will be monitored for *in situ* parameters, water column chemistry and plankton (Table 3-5) nine times annually. Monitoring will focus on two depths rather than five. Sampling will be coordinated with outfall monitoring to be synoptic (within 48 hours) with the outfall monitoring surveys.[3] Stations F01 and F02 are the two locations within Cape Cod Bay that MWRA has historically sampled for all parameters including plankton.

**Table 3-4 Sampling locations for Cape Cod Bay-Stellwagen Bank National Marine Sanctuary**

| STATION ID | WATER DEPTH (M) | LOCATION DESCRIPTION RELATIVE TO OUTFALL | PURPOSE |
|---|---|---|---|
| F29 | 65 | 50 km SE | Evaluate nutrients and plankton in Stellwagen Bank National Marine Sanctuary |
| F02 | 32 | 70 km SE | Evaluate nutrients and plankton in Cape Cod Bay |
| F01 | 26 | 66 km SE | |

**Table 3-5 Water column parameters in Cape Cod Bay and Stellwagen NMS[4]**

| ANALYTE | DEPTH | PARAMETER |
|---|---|---|
| Hydro profile | Continuous downcast data from within 1m of surface to within 5m of bottom. | Temperature<br>Salinity<br>Dissolved oxygen<br>Depth of sensor<br>Chl fluorescence<br>PAR |
| Water chemistry | Two depths<br>Near-surface and<br>Near-bottom | Nitrate + nitrite<br>Ammonium<br>Phosphate<br>Total nitrogen<br>Total phosphorus<br>Extracted chl |
| Phytoplankton | Near-surface | Identification and Enumeration |
| Zooplankton | Net tow | |

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[3] If it is logistically infeasible to sample within 48 hours of the targeted day, the MWRA will provide EPA a courtesy notification. MWRA will provide further information in its annual outfall monitoring overview report including the actual dates monitoring was conducted and rationale for any monitoring which exceeded the 48 hours of the targeted day.

[4] Testing at these locations is slightly different from the nearfield/reference stations in order to be consistent with ongoing monitoring at other stations in the area carried out by the Provincetown Center for Coastal Studies.

**Continuous measurement of biological parameters.** MWRA tracks data from the Gulf of Maine Ocean Observing System (GoMOOS 2008) monitoring buoy off Cape Ann, and has added chlorophyll measurements to that buoy. In addition, a suite of water quality instrumentation has been placed on the NOAA weather buoy 44013 just south of the outfall site. Data from both buoys are available in real time.

**Remote Sensing.** Remote sensing via satellite imagery offers the opportunity to evaluate spatial variations in the system, and to provide information on changes within the system that occur between monitoring surveys. Parameters available from satellite imagery include sea surface temperature and chlorophyll. The monitoring program accesses this imagery and uses it in the synthesis of water column monitoring results and interpreting unusual events, for example the *Phaeocystis* blooms show up as region-wide events on satellite images.

**Floatables observations.** The purpose of floatables monitoring is to ensure that MWRA discharges continue to meet water quality criteria for aesthetics. During the nine annually conducted water column surveys, monitoring staff will note the presence or absence of visible floating material in the water in the nearfield in its survey reports. In addition, MWRA will carry out two wet weather net tow surveys annually, subsequent to blending events at DITP. [5] Acceptable net tows will be carried out after storms where the duration of blending was more than 3 hours.[6] Net tows will be conducted within 24 hours of the ending of the blending events.[7] The net tows will be carried out as described in previous water column work plans, which include a transect over the outfall and a control transect. The contents of the net will be photographed and observations shall be tabulated as presence/absence data for paper, plastic and/or fat particles in order to be able to compare to previous net tow surveys. A summary of the results of the visual observational surveys and the net tows will be included in the annual water column monitoring report. In addition, MWRA will carry out chemical analyses for PCBs, PAHs, pesticides, and mercury on samples of the fat particles which are collected in the net tows.

**Marine Mammal Observations.** All MWRA monitoring activities are conducted in compliance with state and federal guidelines for vessel operations in areas where endangered right whales might be present. In addition, at the request of NMFS, trained marine mammal observers participate in all surveys and log their observations. The marine mammal observations will be summarized in an annual report.

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[5] After two years of wet-weather floatables monitoring (4 tows), MWRA will analyze and report on the data to determine if it is comparable to previous observations. MWRA may submit a written request, along with the data analysis report, to EPA and DEP requesting an elimination of the net tows. In order to be considered acceptable data for the consideration of elimination of the net tow requirement, tows must be conducted within 24 hours of the end of a blending event of at least 3 hours in duration..

[6] Between July 2006 and December 2009, the 50th percentile for duration of blending events was 3 hours, the mean duration was 6.48 hours, and the 75th percentile was 5.8 hours.

[7] If MWRA finds that it is logistically infeasible, due to weather conditions, to conduct net tows within 24 hours of blending events, it may request that this time limit be reevaluated.

## 3.4 Data evaluation

The suite of measurements provides the necessary information for Contingency Plan threshold comparisons (chlorophyll, dissolved oxygen, and nuisance algae). MWRA also carries out trend analyses and statistical analyses to determine whether conditions are changed with respect to baseline data and between sites affected by the relocation of the discharge and reference areas.The data are also used for input to the Bays Eutrophication Model and to validate the model results.

## 3.5 Rationale for water column monitoring plan redesign

Nine years of discharge monitoring have well characterized the effects of the discharge on the water column and addressed the original monitoring questions. In addition to cost savings and efficiencies, MWRA believes the proposed monitoring changes will improve the ability to discriminate between potential outfall effects and regional phenomena. The disadvantage of the previous design is that it covered such a large spatial area that it has been impractical to sample synoptically. By compressing the spatial coverage, MWRA will be able to increase the frequency of monitoring reference stations without compromising the ability to detect outfall-related changes. As described earlier, there is now ample evidence that the outfall does not impact water quality in Cape Cod Bay, offshore, or in Stellwagen NMS. However, because of the sensitivity of these environments, sampling at three locations is included in the monitoring. Data from the farfield showing trends outside Massachusetts Bay have been useful in showing that for many parameters, water quality in the nearfield is driven by the water quality entering Massachusetts Bay from offshore. MWRA will continue to use data gathered by the Gulf of Maine Ocean Observing System to assess offshore water quality, as well as satellite data.

Within the nearfield, the analyses that follow compare the monitoring results of the existing sampling design to the results that would have been obtained had the proposed design been in place. The results confirm that the proposed design characterizes the nearfield comparably to the existing design for chlorophyll and dissolved oxygen. For nuisance algae, the proposed plan is designed to capture the period when *Phaeocystis* blooms. For *Alexandrium*, MWRA will implement its *Alexandrium* response plan as described in Libby (2006).

### 3.5.1 Chlorophyll

MWRA reports on annual and seasonal nearfield chlorophyll amounts for its Contingency Plan. The proposed sampling design yields similar results to the existing (2004) design for chlorophyll and captures the important events during the year. Using existing data, we plotted the results for areal depth-integrated chlorophyll for the current design and compared it to the results that would have been obtained if the proposed design had been used. The plots below show that the pattern of annual mean chlorophyll values for the two sampling designs over time (Figure 3-4) and the correlations for annual mean chlorophyll (Figure 3-5) are highly similar. Figures 3-6 through Figure 3-9 show plots of patterns over time and correlations for seasonal (winter-spring, summer, and fall) chlorophyll. [8]Overall, the proposed design of 9 surveys annually at 4 stations compared to the existing 12 surveys at 7 stations gives very similar results for nearfield chlorophyll.

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[8] Station N21 is not included in the graphic analyses because it was not included in the 2004 revision of the monitoring plan.

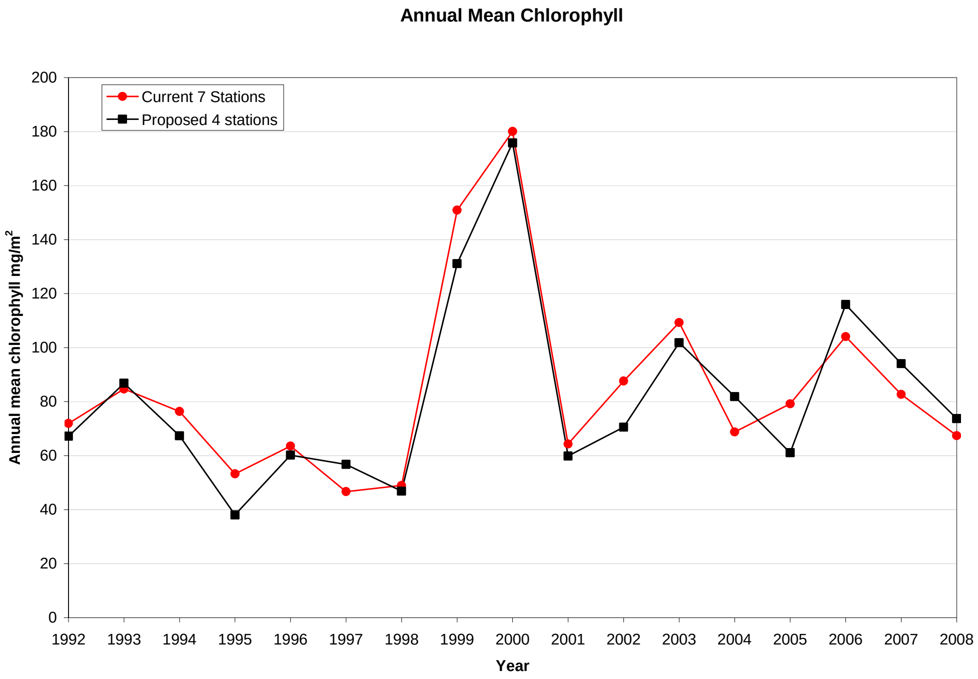

**Figure 3-4 Time-series comparison of annual mean areal nearfield chlorophyll values, current (2004) design with 7 nearfield stations and 12 surveys vs. proposed design with 4 nearfield stations and 9 surveys.**

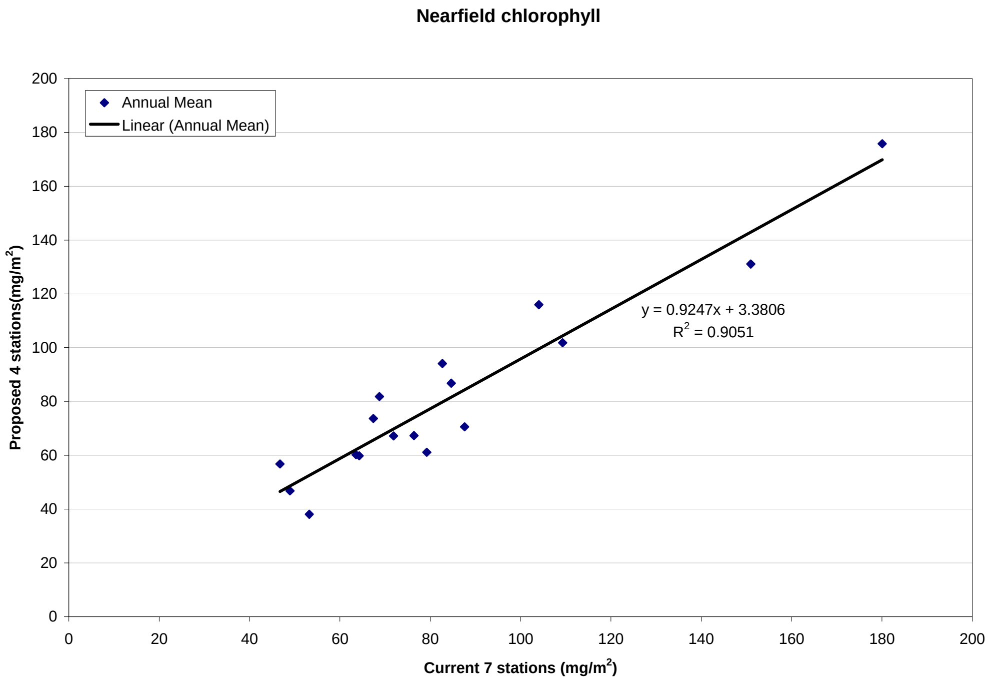

**Figure 3-5 Correlation between current (7 stations, 12 surveys) and proposed (4 stations, 9 surveys) nearfield annual mean chlorophyll.**

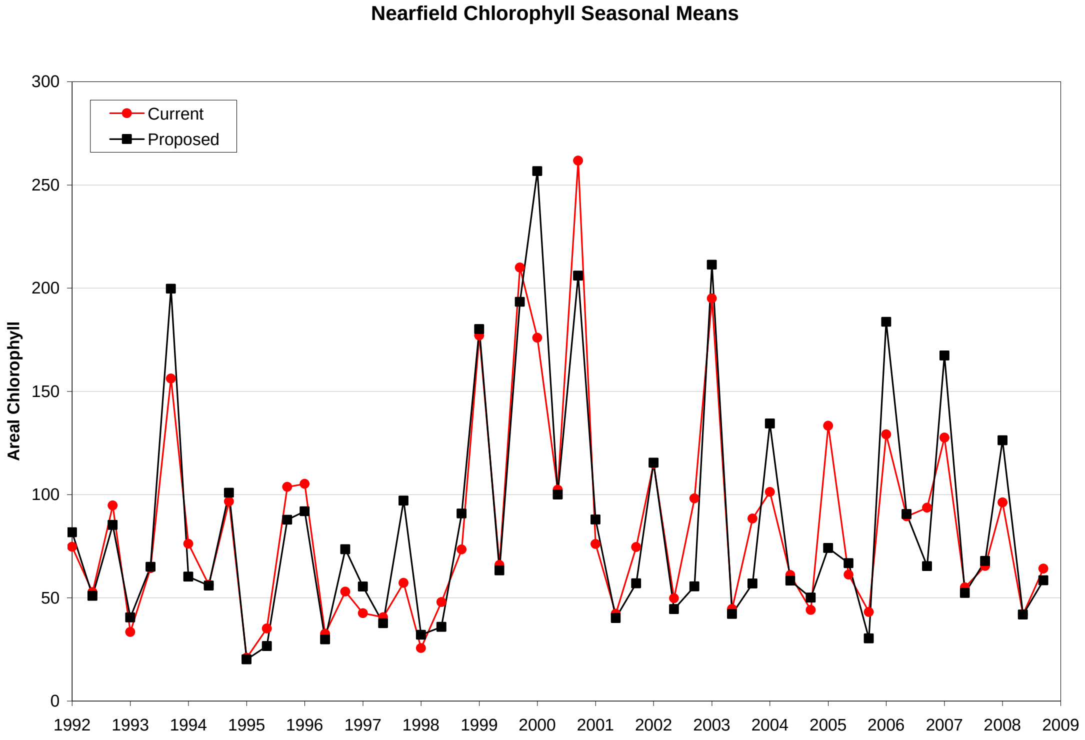

**Figure 3-6 Seasonal (winter-spring, summer, and fall) mean areal chlorophyll for current (7 stations, 12 surveys) and proposed (4 stations, 9 surveys) sampling design.**

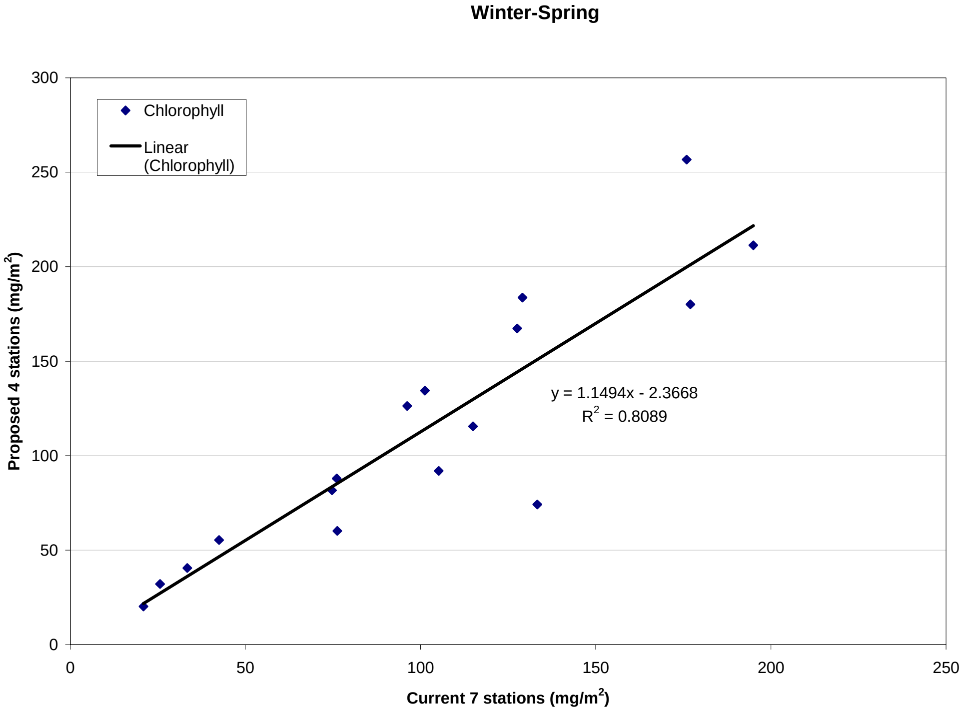

**Figure 3-7 Correlation between current (7 stations, 4 surveys) and proposed (4 stations, 3 surveys) sampling designs for nearfield winter-spring mean chlorophyll.**

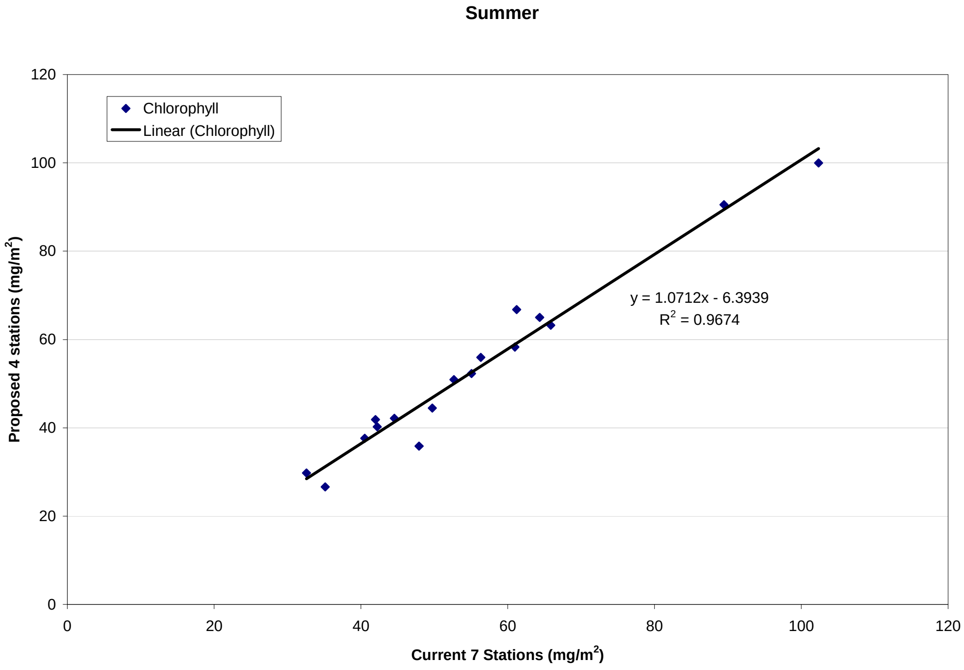

Figure 3-8 Correlation between existing (7 stations, 4 surveys) and proposed (4 stations, 4 surveys) sampling designs for nearfield summer chlorophyll.

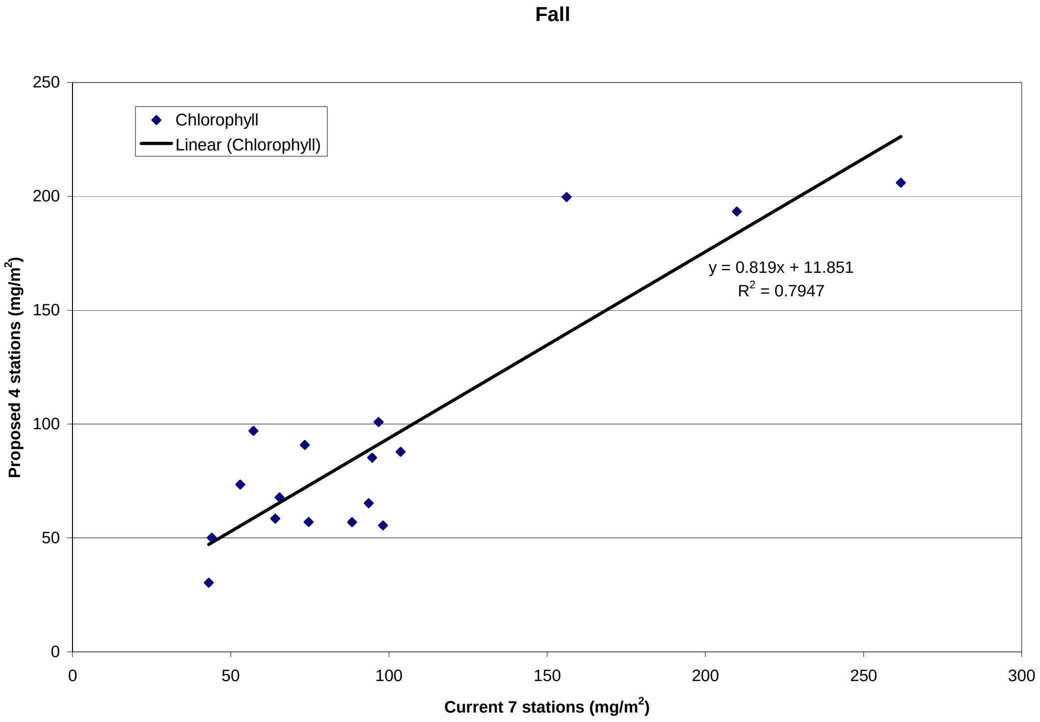

Figure 3-9 Correlation between current (7 stations, 4 surveys) and proposed (4 stations, 2 surveys) sampling designs for nearfield fall chlorophyll.

### 3.5.2 Dissolved Oxygen

For the Contingency Plan, MWRA reports on two types of bottom water dissolved oxygen (DO) thresholds in the nearfield: survey means and summer dissolved oxygen depletion rate. Figure 3-10 plots the survey means for the current (7 stations, 12 surveys) and proposed (4 stations, 9 surveys) nearfield designs. The proposed design captures most of the DO minima that the current design does.

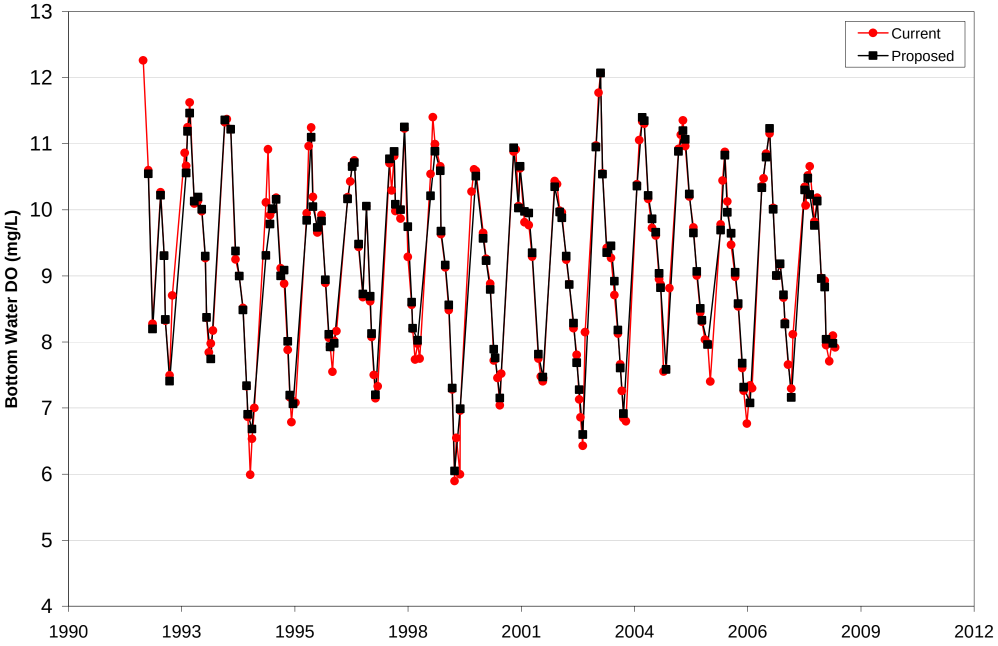

**Figure 3-10 Bottom water dissolved oxygen time-series plots for current (red circles) and proposed (black squares) survey designs.**

**Figure 3-11 Bottom water dissolved oxygen annual minima for current (7 stations) and proposed (4 stations) survey designs.**

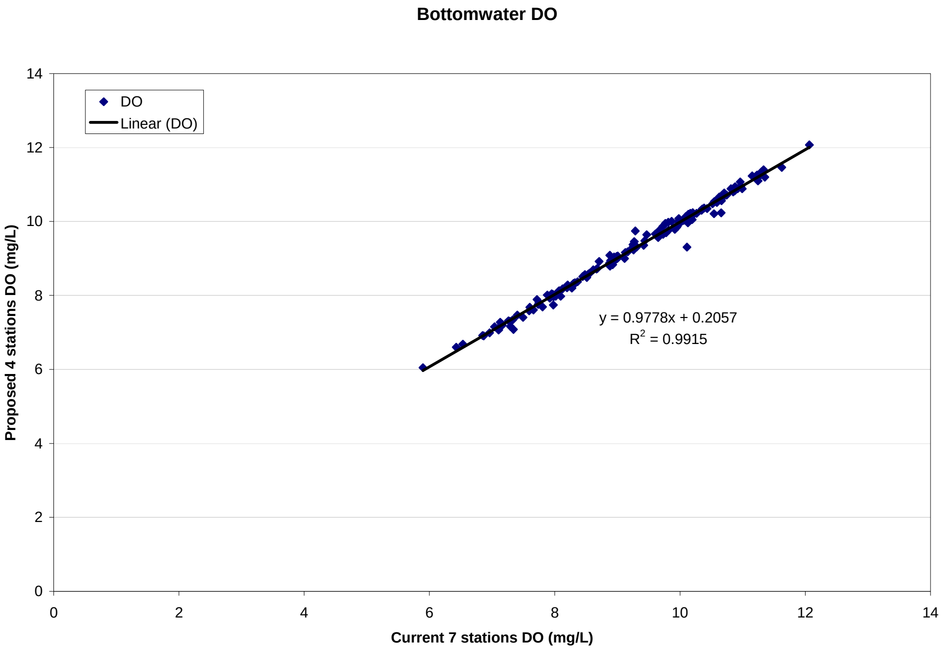

Figure 3-12 Correlation between survey means of bottom water DO for current (7 stations) and proposed (4 stations) designs.

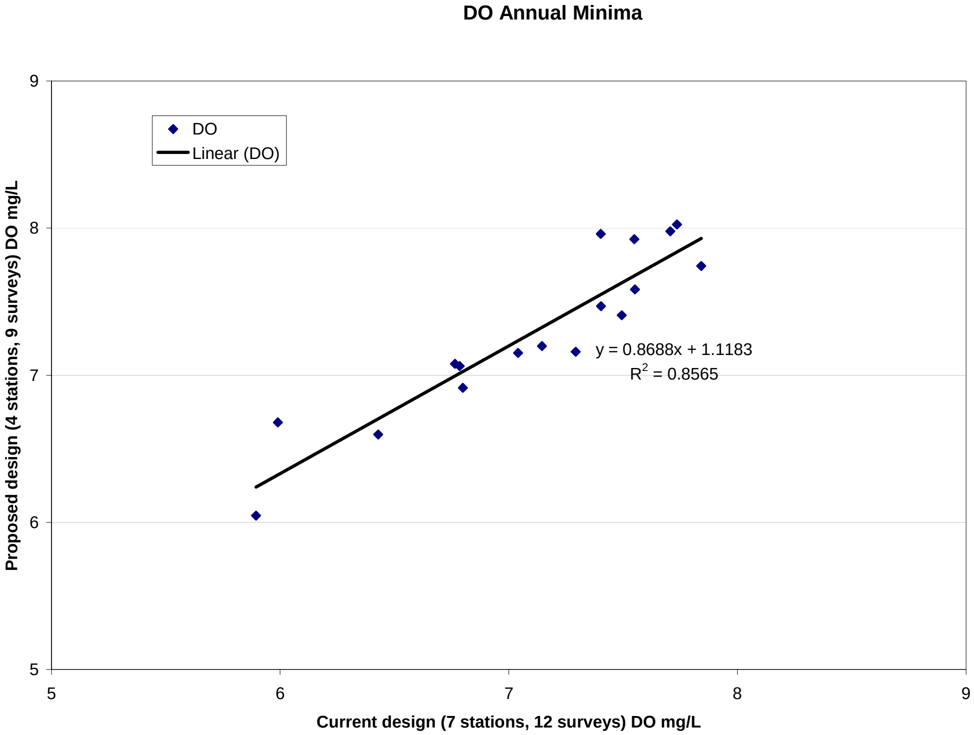

Figure 3-13 Correlation between annual DO minima for current (7 stations, 12 surveys) and proposed (4 stations, 9 surveys) designs.

### 3.5.3 *Alexandrium* method

For the Contingency Plan threshold for the toxic red tide alga *Alexandrium*, MWRA has used data from two[9] methods for enumerating *Alexandrium*— the "screened water method" and the "probe method." Both involve screening through a 20µ mesh in the field to concentrate larger phytoplankton such as *Alexandrium*. The methods differ mainly in relation to preservative, concentration in the laboratory, and staining. The screened water method uses an iodine stain to darken algal starch, while the probe method uses a fluorescent probe called NA-1 that makes ribosomes of *Alexandrium fundyense* glow under fluorescence microscopy.

The methods are comparable for the purpose of testing the *Alexandrium* Contingency Plan threshold of 100 cells/L in any nearfield sample. Figure 3-14 and Table 3-5 compare the results for the 115 samples where both methods have been used. The results are highly correlated. The gene probe results tend to be slightly higher than the screened water results; in that sense the probe method is more protective. Most of the samples were either above the 100 cells/L threshold by both methods or below it by both methods. Nine samples were above the threshold for only the probe method; one sample was above the threshold for only the screened water method (156 cells/L by the screened water method, and 75 cells/L by the probe method).

MWRA has found the probe method to be superior to the screened-water (iodine) method. The iodine method (1) cannot distinguish *A. fundyense* from certain nontoxic *Alexandrium* species, (2) misses some *A. fundyense cells*, mistaking them for related genera, (3) is more time consuming, and (4) gives results more slowly.

MWRA's Contingency Plan threshold for *Alexandrium* was chosen based on data from screened water samples, the method which was available during the baseline period. Nevertheless, discontinuing the screened-water measurements of *Alexandrium* and basing threshold testing on the probe method will not affect Contingency Plan threshold testing. The *Alexandrium* threshold, unlike most others, is tested on single sample results. It is not based on a distributional analysis of the baseline data, but rather was derived by rounding down the highest value seen in the pre-diversion data set (163 cells/l measured in Cape Cod Bay in 1993). Furthermore, the sample size will increase rather than decrease, as *Alexandrium* will be measured at more stations in the nearfield in the revised plan, and no surveys during the spring red tide season will be dropped.

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[9] There is a third method used for enumerating phytoplankton, the "whole water" method which is used to determine the phytoplankton community structure. This method will continue to be used on all routine phytoplankton samples. However, this method is insufficiently precise to quantify *Alexandrium*, which is a tiny component of the total plankton community even during a major red tide, and is not suitable for testing the *Alexandrium* Contingency Plan threshold.

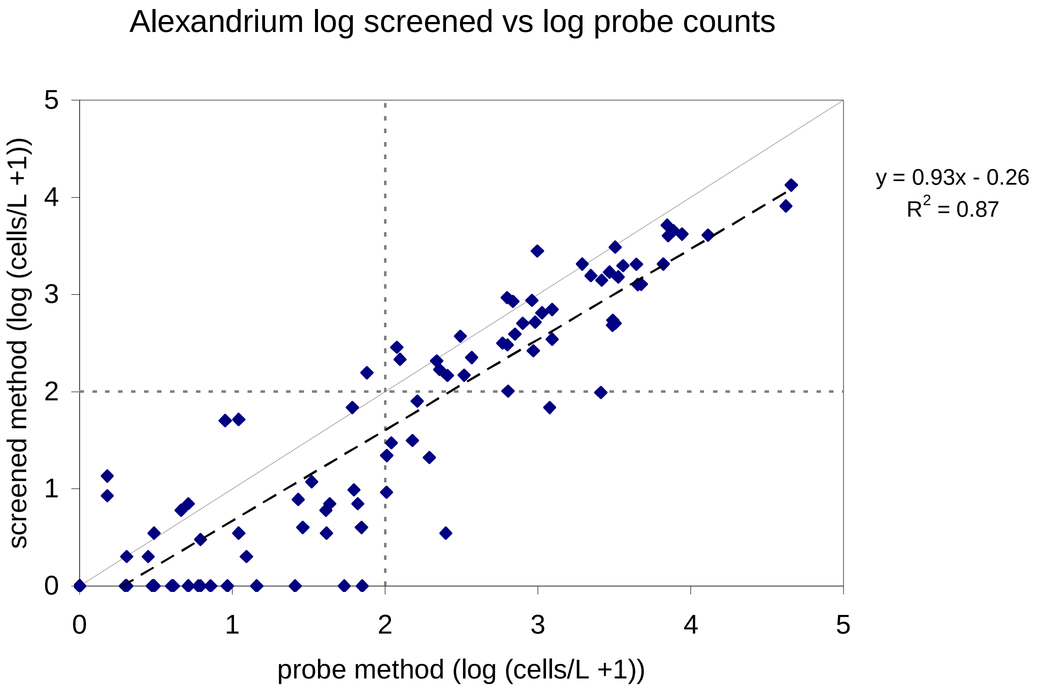

**Figure 3-14** **Correlation between log-transformed individual sample values of *Alexandrium fundyense* (probe) vs. *Alexandrium fundyense* + *Alexandrium* spp. (screened) in 115 samples from 2005-2009 in which both methods were used to enumerate *Alexandrium*.**

**Dotted line shows threshold of 100 cells/l in any sample.**

**Table 3-6 Number of samples below or exceeding per-sample *Alexandrium* threshold of 100 cells/l, in 115 samples from 2005-2009 in which both methods were used to enumerate *Alexandrium*.**

| | **SCREENED WATER COUNTS** | | | |
|---|---|---|---|---|
| | | Below Threshold | Exceeds Threshold | Total |
| **PROBE COUNTS** | Below Threshold | 62 | 1 | 63 |
| | Exceeds Threshold | 9 | 43 | 52 |
| | Total | 71 | 44 | 115 |

### 3.5.4 Estimates of Primary Production

In its August 18, 2009 teleconference reviewing MWRA's proposed changes to the Ambient Monitoring Plan, OMSAP voted to recommend approval of MWRA's proposal to end direct measurements of phytoplankton production, but suggested that MWRA explore ways of estimating (modeling) productivity in addition to staying informed about instrumentation advancements that may eventually provide similar information.[10]

***Water quality modeling of productivity*** MWRA's Bays Eutrophication Model includes modeling of primary productivity throughout the model grid and comparisons of modeled to measured productivity (e.g. Figure 3-7 of Jiang and Zhou, 2008 and Figures 3-17 to 3-19 Jiang and Zhou, 2006). MWRA will compile and report on available model-data comparisons of productivity.

***Light-biomass models*** In addition to making direct measurements of productivity, MWRA has previously evaluated the performance of light-biomass model $BZ_pI_0$ (Cole and Cloern 1987) developed to estimate productivity in estuaries. Comparisons of the modeled $BZ_pI_0$ parameter to measured productivity are in Kelly and Doering (1995, 1997), Cibik *et al.* (1996, 1998a, 1998b), and Libby *et al.* (1999, 2000, 2001). Results of these comparisons have been inconsistent, with measured productivity from some years and stations showing a better fit to the model than others. MWRA will evaluate and report on the $BZ_pI_0$ model and comparisons to measured productivity data.

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[10] For example, an evaluation of the Turner Designs PhytoFlash active fluorometer was included in the late September 2009 water column survey. Results from the active fluorometer will be compared to measurements made as part of MWRA's monitoring.

# 4 BENTHIC MONITORING

## 4.1 Purpose of benthic monitoring

### 4.1.1 Environmental concerns

Within Boston Harbor, studies of the sediments have documented recovery following the cessation of sludge discharge, improvements to CSO systems, and improved sewage effluent treatment (Bothner et al 1998, Bothner and Butman 2007, Durell *et al* 2008, Maciolek, Diaz *et al* 2008 and 2009, Tucker *et al* 2008 and 2009). However, before the outfall went on-line (in 2000), concerns were raised about potential effects of the relocated discharge on the offshore seafloor. These concerns focused on three issues: eutrophication and related low levels of dissolved oxygen, accumulation of toxic contaminants in depositional areas, and smothering of animals by particulate matter. Low effluent concentrations of solids, organic matter, and toxic contaminants as discussed in Section 2, along with effective dilution in Massachusetts Bay, are expected to restrict impacts on the benthos to minor effects in a narrow zone around the diffuser.

### 4.1.2 Contingency Plan thresholds

The Contingency Plan (MWRA 2001) has thresholds for

- sediment redox depth
- toxic contaminant concentrations
- community structure
- abundance of opportunistic species

Details are given in the Contingency Plan (MWRA 2001). The Outfall Monitoring Overview (e.g. Werme and Hunt 2008, Werme *et al*. 2009) summarizes the comparison of monitoring results with Contingency Plan thresholds.

## 4.2 Benthic monitoring questions and results

### 4.2.1 Monitoring questions: Sediment contamination and tracers

→ *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 and Cape Cod bays sediments changed after discharge through the new outfall?*

→ *Have the concentrations of contaminants in sediments changed?*

***Results***

The benthic monitoring program was initiated in 1992 to focus on soft sediments near the site of the new outfall diffuser (the nearfield) as well as selected reference stations in various parts of Massachusetts Bay and Cape Cod Bay (the farfield). Although the Deer Island Treatment Plant was designed to keep effluent contaminant concentrations low, the Environmental Impact Statement for the outfall (USEPA 1988) predicted small increases in contaminant concentrations in nearby sediments, assuming that the outfall would be discharging primary-treated effluent for five years. The relatively intense temporal and spatial scales of the sediment contaminant monitoring in earlier versions of this Ambient Monitoring Plan (MWRA 1991; 1997) were designed to measure impacts from contaminant loadings that turned out to be much lower than projected. It found effects much lower than anticipated, therefore the monitoring program was re-focused on measuring long-term effects. Now, nine years of discharge monitoring data show little if any impact and it is appropriate to re-design the sampling to reflect the increased level of confidence that no deleterious impacts are likely.

The area around the outfall is composed of heterogeneous sediments that have received historic inputs of contaminants from Boston Harbor and other sources. Contaminant concentrations in the nearfield track the silt+clay fraction of the sediments; muddier stations tend to have more organic carbon and higher concentrations of contaminants.

Storm-driven transport of fine sediments and the contaminants they carry is another major factor determining concentrations of contaminants in nearfield sediments (Bothner *et al.* 2002, Butman *et al.* 2002, Bothner and Butman, 2007). USGS research has documented that the regional long-term depositional sinks for fine sediments and their associated contaminants are in Stellwagen Basin and in deeper portions of Cape Cod Bay, with a gradient of highest contaminant concentrations in Boston Harbor; much lower concentrations in western Massachusetts Bay (near MWRA's outfall), in Stellwagen Basin and in Cape Cod Bay; and the lowest concentrations north and east of the bays system (Bothner *et al.* 1993, USGS 1997a, Bothner and Butman, 2007).

Depositional areas in western Massachusetts Bay are characterized by sporadic, storm-induced episodes of sediment transport and mixing. Because of this dynamic environment, contaminant concentrations in nearfield sediments are somewhat variable, both spatially and temporally. Because of the extremely low concentrations of contaminants in MWRA effluent, contaminant buildup, if it occurs at all, is likely to take decades (Coats 1995, Hunt *et al.* 2006).

**Tracers:** Contaminant concentrations in surficial sediments (MWRA 2003a, Maciolek *et al.* 2003, 2008, Bothner *et al.* 2002, Bothner and Butman, 2007) and in sediment traps in the nearfield (Bothner *et al.* 2002, 2007) have not shown rapid increases since outfall startup. An effluent signal was detected in sediment trap samples in the most sensitive sewage tracers measured, silver and *Clostridium perfringens* spores (Bothner *et al.* 2002, Bothner and Butman 2007).

MWRA's monitoring data has detected a "signal" in nearfield sediments of the most sensitive effluent tracer, *Clostridium perfringens* spores, but not of chemical contaminants. These spores of an anaerobic bacterium commonly found in the mammalian gut are abundant in municipal wastewater, and are resistant to disinfection (Bisson and Cabelli 1979). Because they are abundant in wastewater, are attached to the same fine particulates that adsorb contaminants, and can accumulate in sediments, *C. perfringens* spore counts in sediments can serve as sensitive indicators of the presence of effluent-derived solids in sediments (Parmenter and Bothner 1993).

Abundances of *C. perfringens* increased one year after effluent diversion at stations located within 2 km of the outfall (Figure 4-1). This pattern generally held through 2007, although abundances were unusually low in 2006 compared to other post-diversion years. A statistical analysis confirmed the post-diversion increase in *C. perfringens* abundances at nearby sediments is significant. *Clostridium* abundances have decreased in the nearfield area more than 2 km from the outfall and in the farfield regions of Massachusetts and Cape Cod Bays since the mid- to late 1990s (Maciolek *et al*. 2008, 2009).

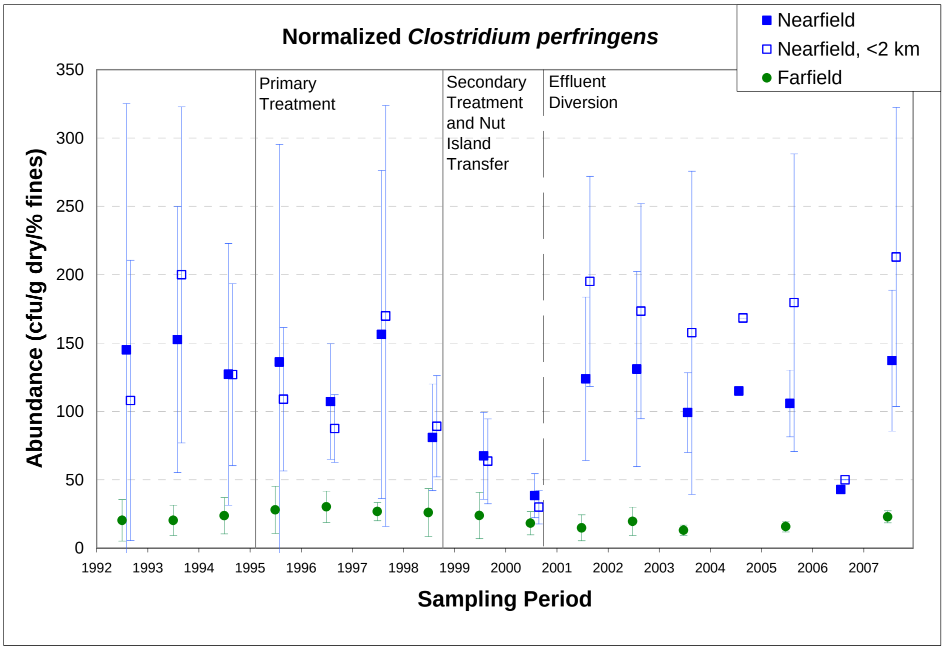

**Figure 4-1 Yearly mean abundance of *Clostridium perfringens*, normalized to percent fines, in nearfield and farfield sediments, 1992 to 2007.**

**The nearfield (filled square symbol) increase is largely associated with stations located within two kilometers of the outfall (open square symbol). Yearly mean abundance is the average of all stations and replicates for a given year, by region. Vertical bars represent one standard deviation.**

*C. perfringens* data clearly trace the diversion of treated effluent discharge from the harbor to the bay evidenced primarily by (1) a decrease ($p<0.05$) between the baseline and post-diversion mean values at the transition area and (2) an increase ($p<0.05$) between the baseline and post-diversion mean values in sediments located nearby the outfall The *C. perfringens* effluent signature appears to be highly localized, as there was no significant difference between the baseline and post-diversion mean values in sediments located further away from the outfall (nearfield >2 km from the outfall and farfield) (Figure 4-2).

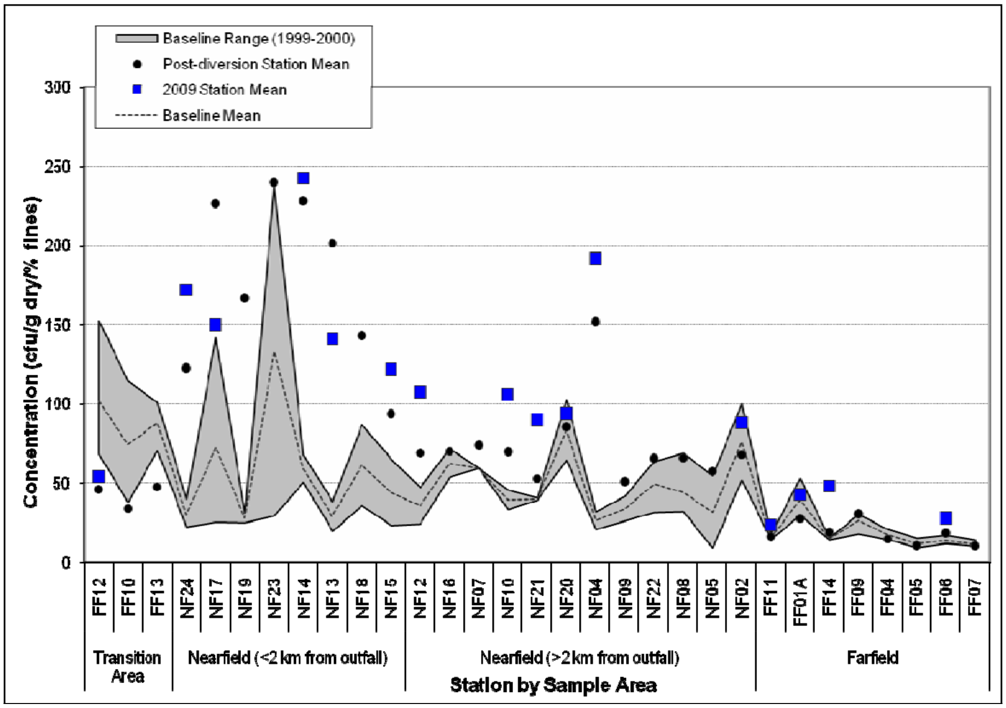

**Figure 4-2 Distribution of *C. perfringens* abundances (normalized to percent fines), by station in surface sediment from Massachusetts and Cape Cod Bays 1999–2009.**

**Station-specific trends: the gray band represents the range of values during baseline (1999–2000), the dashed line represents the baseline mean, and symbols represent the post-diversion data.**

Thus, only within a few kilometers of the discharge can any signature of outfall impact be found in sediments, and then only when using the most sensitive tracers of effluent solids.

**Contaminants:** In contrast to the results of the effluent tracers, MWRA's monitoring data show no evidence that effluent has contributed toxic contaminants to sediments in the Bay. This is consistent with effluent monitoring data showing that priority pollutants are present only at extremely low levels in MWRA's effluent (Delaney and Rex 2007, Delaney 2010). No Contingency Plan thresholds for sediment contaminants have been exceeded since outfall startup in 2000. Table 4-1 shows that results from the most recent sediment contaminant sampling, which was in August 2008, were within or below the baseline range for all contaminants except total DDT, which was marginally above baseline.

**Table 4-1  Sediment contaminant results for 2008, the most recent contaminant survey.**

| | Contaminant | Baseline range | Warning level threshold | 2008 value |
|---|---|---|---|---|
| PAHs (ng/g dry weight) | | | | |
| | Acenaphthene | 23-41.3 | 500 | 27.3 |
| | Acenaphthylene | 38.3-58.4 | 640 | 35.6 |
| | Anthracene | 114-171 | 1,100 | 127.9 |
| | benz(a)anthracene | 221-302 | 1,600 | 236.7 |
| | benzo(a)pyrene | 224-287 | 1,600 | 272.0 |
| | Chrysene | 217-288 | 2,800 | 212.2 |
| | dibenzo(a,h)anthracene | 30.5-42 | 260 | 35.8 |
| | Fluoranthene | 465-592 | 5,100 | 470. |
| | Fluorene | 37.9-60.9 | 540 | 40.3 |
| | Naphthalene | 53.5-83.2 | 2,100 | 56.8 |
| | Phenanthrene | 296-405 | 1,500 | 287.8 |
| | Pyrene | 440-540 | 2,600 | 380.3 |
| | sum HMWPAH | 2,986-3,754 | 9,600 | 3,713 |
| | sum LMWPAH | 1,420-2,004 | 3,160 | 1,580 |
| | total PAH | 4,482-5,726 | 44,792 | 5,292 |
| Other organic contam. (ng/g) | | | | |
| | p,p'-DDE | 0.28-1.25 | 27 | 0.39 |
| | total DDT | 2.59-5.27 | 46.1 | 5.59 |
| | total PCB | 10.4-28.6 | 180 | 7.5 |
| Metals (ug/g dry weight) | | | | |
| | Cadmium | 0.09-0.23 | 9.6 | 0.13 |
| | Chromium | 61.9-86.8 | 370 | 71.9 |
| | Copper | 19.2-27.6 | 270 | 14.7 |
| | Lead | 42.9-47.2 | 218 | 40.2 |
| | Mercury | 0.2-0.29 | 0.71 | 0.13 |
| | Nickel | 15.5-18.5 | 51.6 | 14.9 |
| | Silver | 0.47-0.71 | 3.7 | 0.32 |
| | Zinc | 56.6-69.7 | 410 | 57.8 |

A comprehensive analysis of the long-term monitoring data through 2007 (Maciolek *et al.* 2008) showed that concentrations of anthropogenic contaminants in surface sediments at nearfield and farfield regions of Massachusetts and Cape Cod Bays are spatially and temporally variable and reflect differences in sediment characteristics, such as grain-size distributions and total organic carbon content, rather than an outfall effect.  For example, northeasterly storms in May 2005, likely contributed to a coarsening of sediment grain-size distributions.  With this coarsening of grain size there was a corresponding decrease, in samples collected in the summer of 2005, of concentrations of aluminum, chromium, iron, and nickel, which are primarily crustal in origin.

Post-diversion mean concentrations of total PCB (Figure 4-3), total DDTs, and total chlordanes decreased significantly (at the 95% level of confidence) at farfield regions of Massachusetts and Cape Cod Bays compared to the baseline. Post-diversion mean concentrations of total DDTs, total chlordanes, and total pesticides also decreased significantly at the nearfield. Decreases in total DDTs and total PCB may be associated with the banning of these chemicals in the 1970s and 1980s, which in turn reduced inputs of these chemicals to the system. Decreases in total chlordanes and total pesticides that occurred since the mid-1990s could be associated with remediation activities including source reduction actions and improvements to sewage treatment, which have reduced the loading of contaminants to coastal Massachusetts. Overall, sediment data to date indicate that post-diversion (2001–2007) concentrations of most anthropogenic contaminants have not changed substantively compared to the baseline (1992–2000) (Maciolek *et al*. 2008).

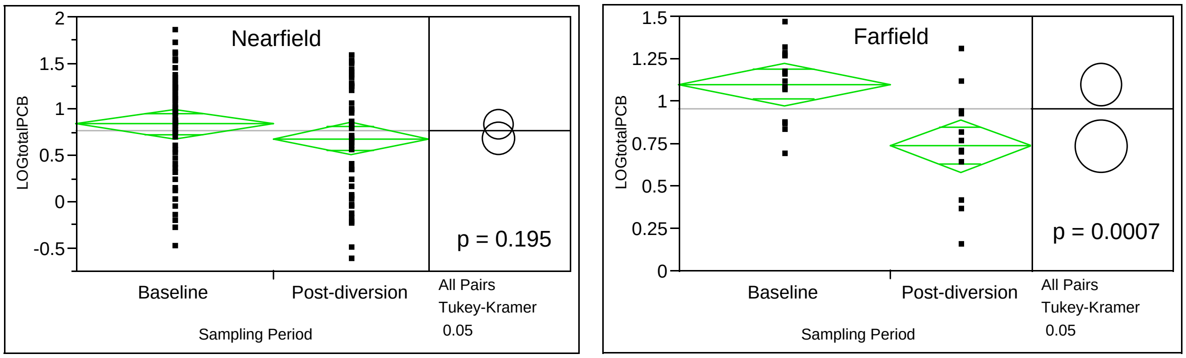

**Figure 4-3 One-way analysis of total PCB (log normalized) by sampling period (baseline and post-diversion) in nearfield and farfield sediments, 1992 – 2007.**

**The means diamond illustrates the sample mean and 95% confidence. The line across each diamond represents the group mean. The vertical span of each diamond represents the 95% confidence interval for each group. Markers represent individual data points. The Tukey-Kramer comparison circles plot is a visual representation of group mean comparisons. Circles for means that are significantly different (at the 95% confidence level) either do not intersect or intersect slightly.**

### 4.2.2 Monitoring questions: Health of soft bottom benthos (sediment oxygenation, infaunal communities)

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

***Results: No.*** For assessing outfall effects, the Contingency Plan threshold for the apparent color Redox Potential Discontinuity (RPD) layer depth is a 50% reduction from baseline, averaged over the study area. This threshold has never been approached during discharge monitoring (Figure 4-4). In fact, the average RPD for 2007 was the deepest yet observed, while the shallowest measurements were made during baseline monitoring in 1997 and 1998.

In 2006, a comparison of baseline to discharge years indicated that the discharge years had significantly deeper RPD layers (baseline to discharge years multiplier 0.202, SE = 0.097, p = 0.038) (Maciolek *et al.* 2007). This is exactly the opposite of what would be expected if effluent solids were adversely impacting the sediments. The color and texture of sediments in the SPI images during discharge monitoring indicate that the amount of deposited organic matter has not changed (Maciolek *et al.* 2008).

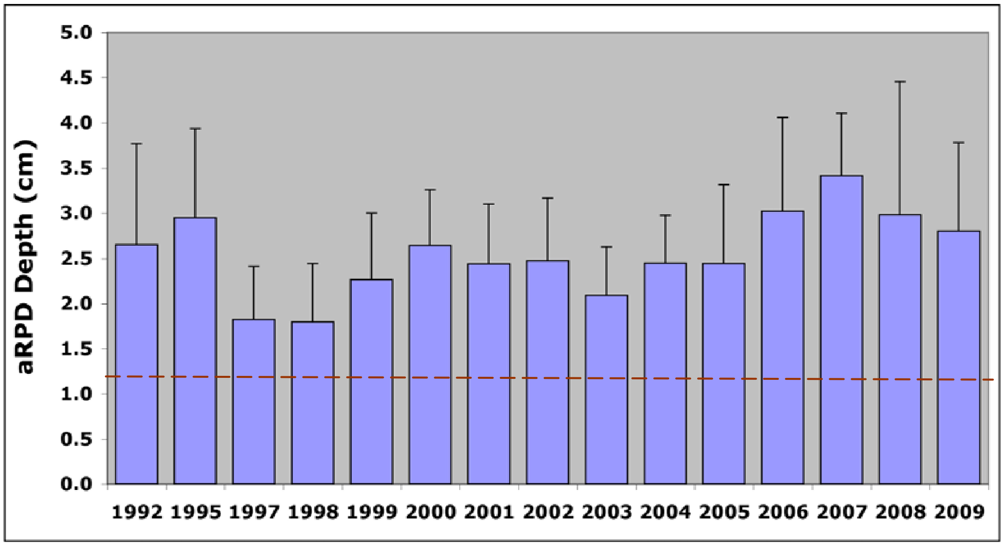

**Figure 4-4 Average nearfield apparent color redox potential discontinuity depth (RPD) 1992-2009. Data collected after the outfall began discharging begins in 2001. The oxygenated layer has remained well above (deeper than) the minimum threshold, indicated by the dashed line.**

→ *Are any benthic community changes correlated with changes in levels of toxic contaminants (or sewage tracers) in sediments?*

→ *Has the soft-bottom community changed?*

***Results:*** A detailed synthesis of the infaunal monitoring results is provided in the most recent outfall benthic monitoring reports (Maciolek *et al.* 2008, 2009) and in previous benthic monitoring reports (e.g. Kropp *et al.* 2002, Maciolek *et al.* 2004, 2007).

Soft-bottom sediments in the nearfield support typical New England coastal infaunal assemblages. Stations with fine sediments have communities dominated by polychaete worms, while sandier stations have distinct assemblages dominated both by polychaetes and by amphipods. Communities in the nearfield through baseline were characteristic of New England shallow subtidal sediments subjected to natural disturbance (Hilbig and Blake 2000), for example sporadic sediment resuspension and transport.

Infaunal benthic communities found at farfield stations share many species with those found in the nearfield, but also support a wider variety of species characteristic of New England coastal habitats. Multivariate analyses of the infaunal species abundance data consistently show the importance of grain size and regional (or depth) differences between samples as important structuring factors for community composition, a pattern that has not changed during discharge monitoring (Figures 4-5, 4-6).

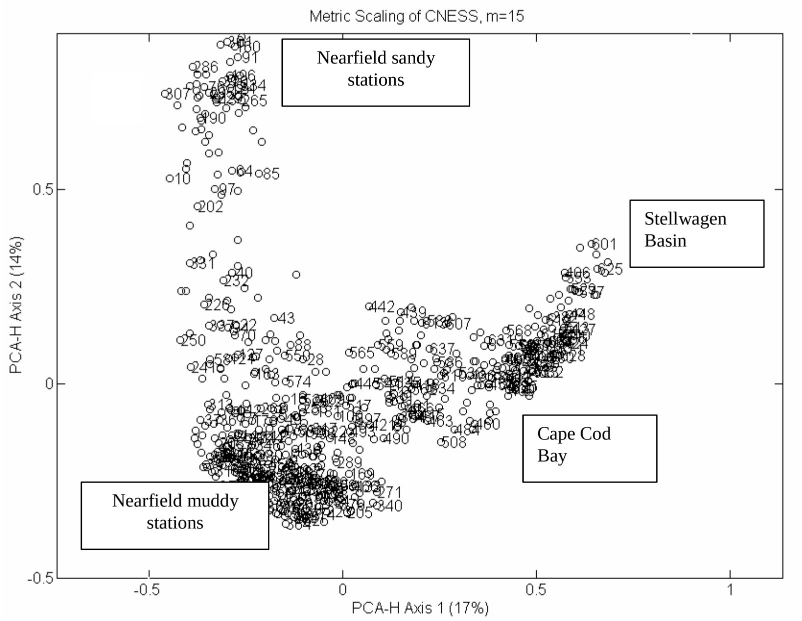

**Figure 4-5 Metric scaling plot of CNESS distance, PCA-H Axis 1 versus Axis 2, among the 640 nearfield and farfield samples collected 1992-2002.**

**Regions where samples consistently plot in that area of the graph are shown in boxes.**

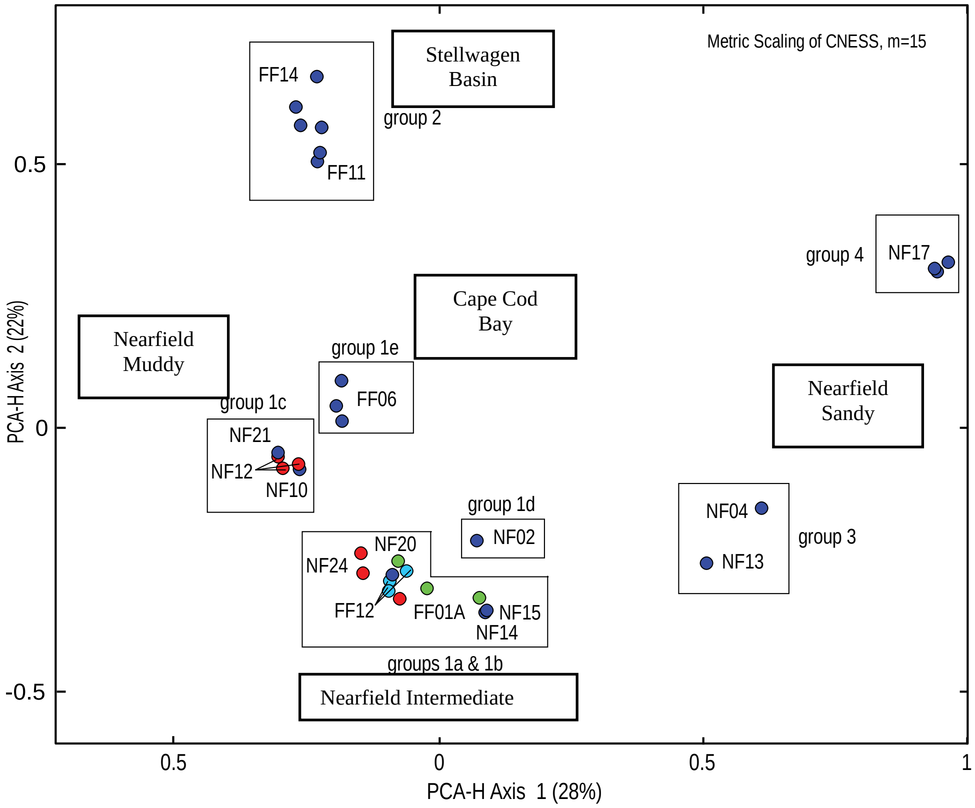

**Figure 4-6 Analysis of the data from 2007 shows a similar grouping of stations to that seen in the 1992-2002 data.**

**(The left-right reversal on the horizontal axis compared to Figure 4-5 is a common artifact of this type of analysis, and has no ecological meaning.)**

Benthic infaunal monitoring data since outfall startup in 2000 show no major departures from the baseline monitoring period for any parameters measured (Figure 4-7). No Contingency Plan thresholds have been exceeded through 2009. Furthermore, “Before-After, Control-Impact” statistical analyses carried out on the results through August 2007 indicate there have been no changes associated with outfall discharge for any benthic community threshold parameters tested under the Contingency Plan (Maciolek *et al.* 2008).

Another Contingency Plan threshold is abundance of opportunistic species. Opportunists remain low in nearfield sediments. After the outfall came online, the highest relative abundance of opportunists was 0.5%, observed in 2005. This is far below the Caution Level threshold of 5% percent opportunists. In 2008, the maximum single-sample percent of opportunists observed in nearfield monitoring was less than 1% (the nearfield average in 2008 was about 0.25%).

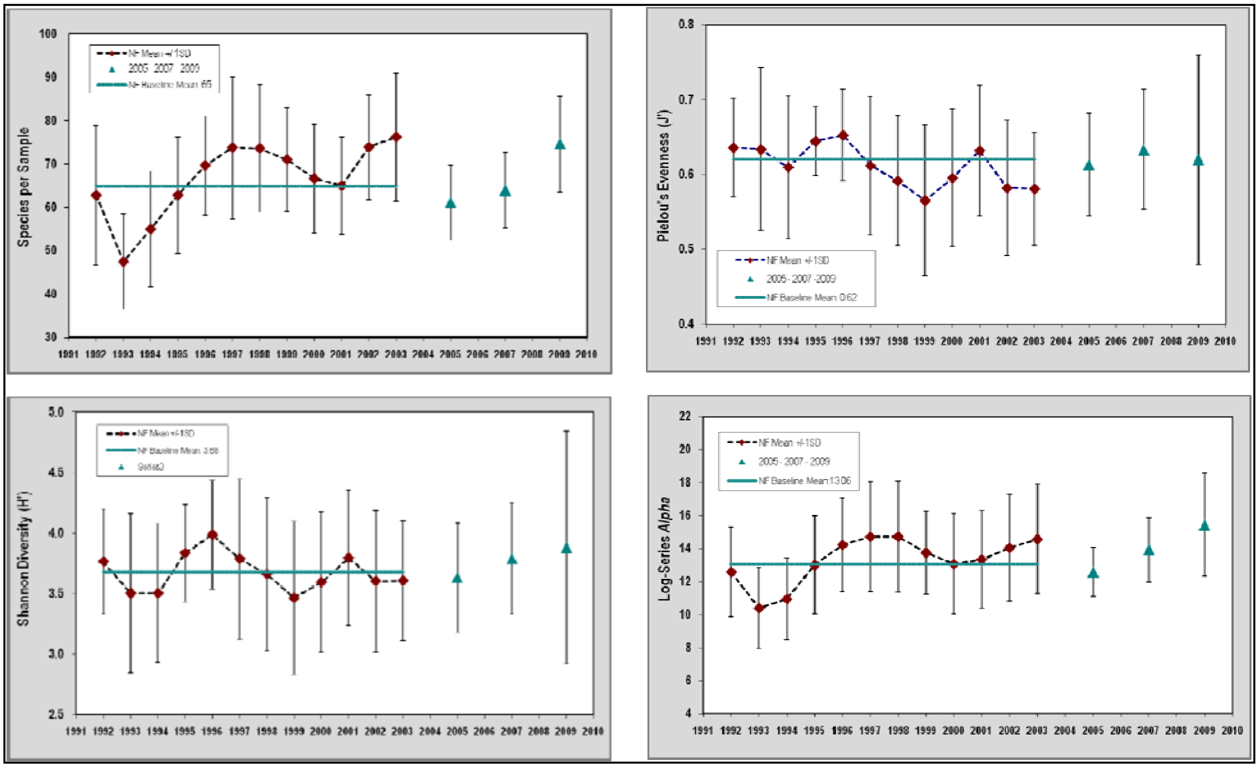

**Figure 4-7 Benthic community parameters 1991-2003 and at "odd-year" stations 2005, 2007, 2009. "Odd-Even" design began in 2004. No Contingency Plan thresholds have been exceeded since the outfall came on-line.**

### 4.2.3 Monitoring questions: Hard bottom community health

→ *Has the hard-bottom community changed?*

***Results***: The hard-bottom benthic communities near the outfall remained relatively stable over the baseline period, and have not changed substantially with activation of the outfall in fall 2000. Major departures from baseline conditions have not occurred during the post-diversion years, however some modest changes have been observed, including decreases in the number of upright algae at some stations and increases in drape and decreases in percent cover of coralline algae at some stations, mainly drumlin top stations north of the outfall (Maciolek *et al*. 2008, 2009).

It is unlikely that the decrease in upright algae was attributable to diversion of the outfall, since abundances of upright algae were quite variable throughout the baseline period, reflecting both temporal and spatial heterogeneity. A general decline in the number of algae had started in the late 1990's and now appears to be reversing at a number of stations. The decline has been most pronounced at the northern reference stations and may, in part, reflect physical disturbance of the seafloor from an increase in anchoring activity of LNG tankers at these locations after 2001. Disturbance of the seafloor in the form of overturned boulders and areas of shell lag has been noted at stations T7-1 and T7-2 in the last several years (Figure 4-8).

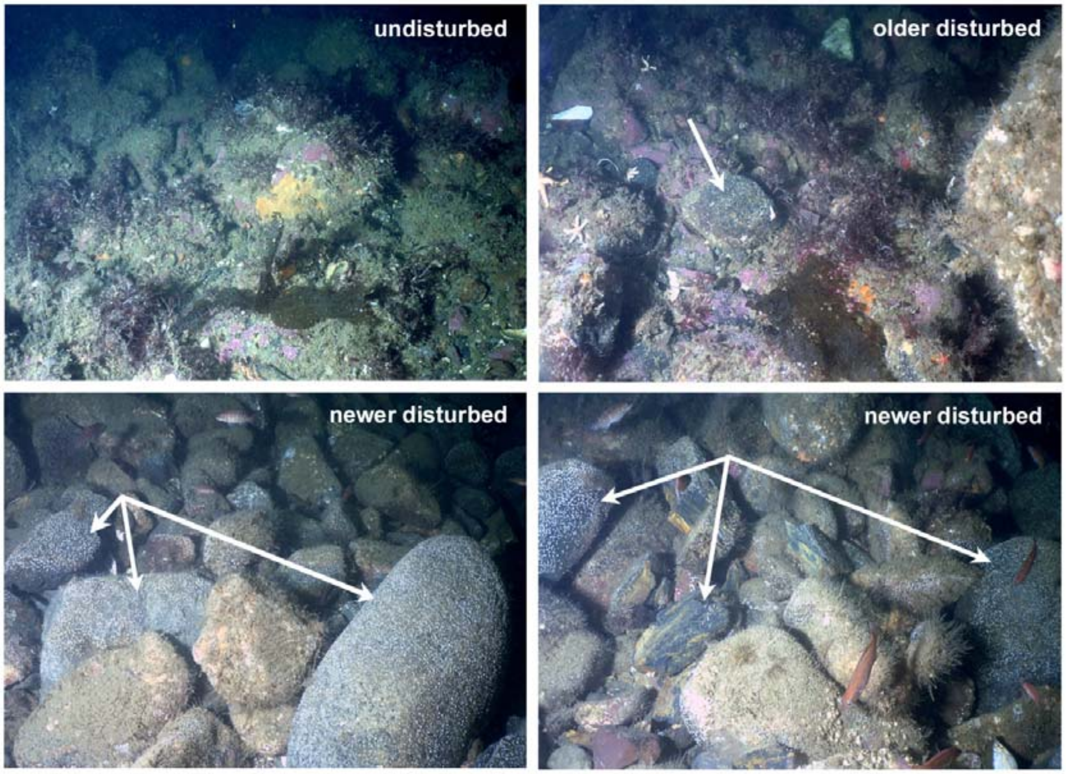

**Figure 4-8 Photographs taken in 2007 of physical disturbance at northern reference station T7-1 possibly caused by the anchoring of LNG tankers.**

**The undisturbed seafloor is characterized by boulders encrusted with coralline algae, moderately-light to moderate drape, and upright algae. An older disturbed area has similar characteristics, but shows some evidence of physical disturbance such as bare rock surfaces. The newer disturbed areas are characterized by boulders that have been turned over exposing bare rock surfaces with little drape, and coralline algae on their lower surfaces. The newly settled barnacles (appear to be a spring set) indicate that the disturbance likely occurred in the winter or early spring. Examples of turned-over rocks are highlighted by arrows.**

The decrease in percent cover of coralline algae has been noticeable at five stations located north of the outfall in all seven post-diversion years. This decrease was particularly pronounced in 2005, and it extended to eight additional stations both north and south of the outfall. Mechanisms relating the decrease in coralline algae to outfall diversion are not clear, since the impact was noted further from the outfall rather than nearby. It is possible that some of the decreases in coralline algae observed at the northern reference stations are related to the physical disturbance of the seafloor observed at these stations, but it does not explain why coralline algae has declined at a number of other stations. It is possible that we are observing long-term changes in sedimentation patterns and hence coralline algae that are completely unrelated to the discharge.

The first seven years of discharge monitoring have shown modest changes suggestive of outfall impact at a subset of five stations, and some other more subtle changes at a number of other stations. Two of the five stations in this subset may have been compromised as “reference” stations by post 9/11 increases in the anchoring frequency of LNG tankers, causing physical disturbance of the seafloor at these sites. Lush epifaunal growth continues to thrive on the diffuser heads surveyed for this study and throughout many of the other stations visited.

### 4.2.4 Monitoring questions: Benthic nutrient flux

→ *How do the sediment oxygen demand, the flux of nutrients from the sediment to the water column, and denitrification influence the levels of oxygen and nitrogen in the water near the outfall?*

→ *Have the rates of these processes changed?*

***Results:*** Sediment processes are integrative, and typically have a slow response time, but the seven years of discharge monitoring address these questions. In addition to the RPD measurements from sediment profile image monitoring discussed above, the sensitive measurements of rates of sediment oxygen demand and nutrient regeneration resulting from the nutrient flux special study confirm that there has been no detectable change in sediment metabolism associated with outfall startup. While changes consistent with recovery from decades of organic enrichment continue to occur in Boston Harbor sediments, rates measured in the nearfield remain low compared to other published measurements (Figure 4-9, 4-10, 4-11) (Tucker *et al.* 2003, Tucker *et al.* 2008, 2009).

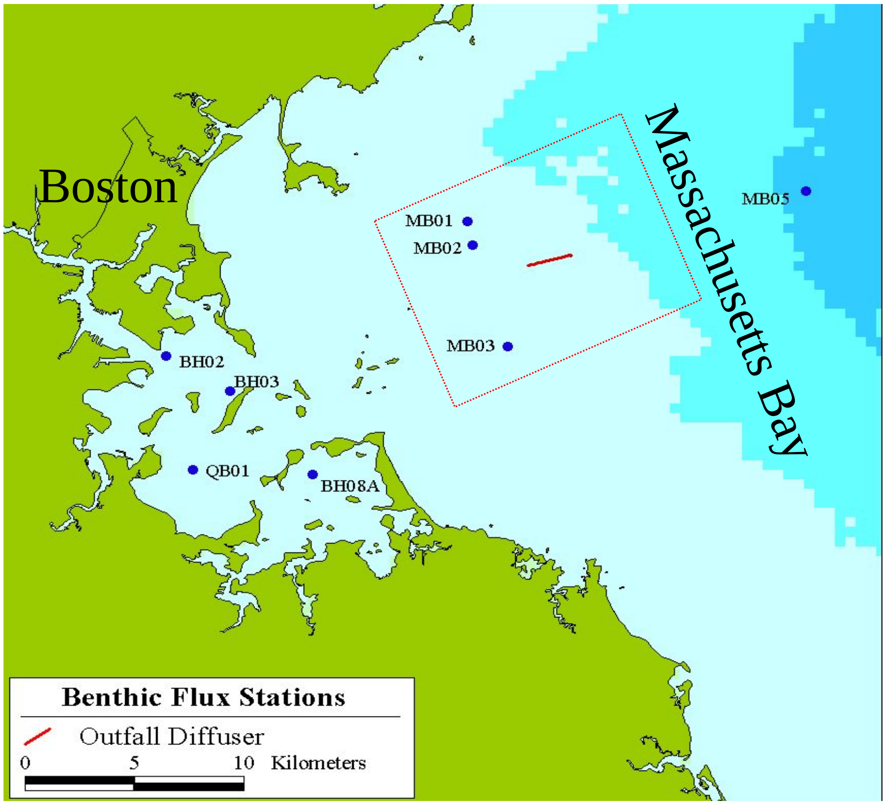

**Figure 4-9 Map of nutrient flux monitoring stations in Massachusetts Bay and Boston Harbor.**

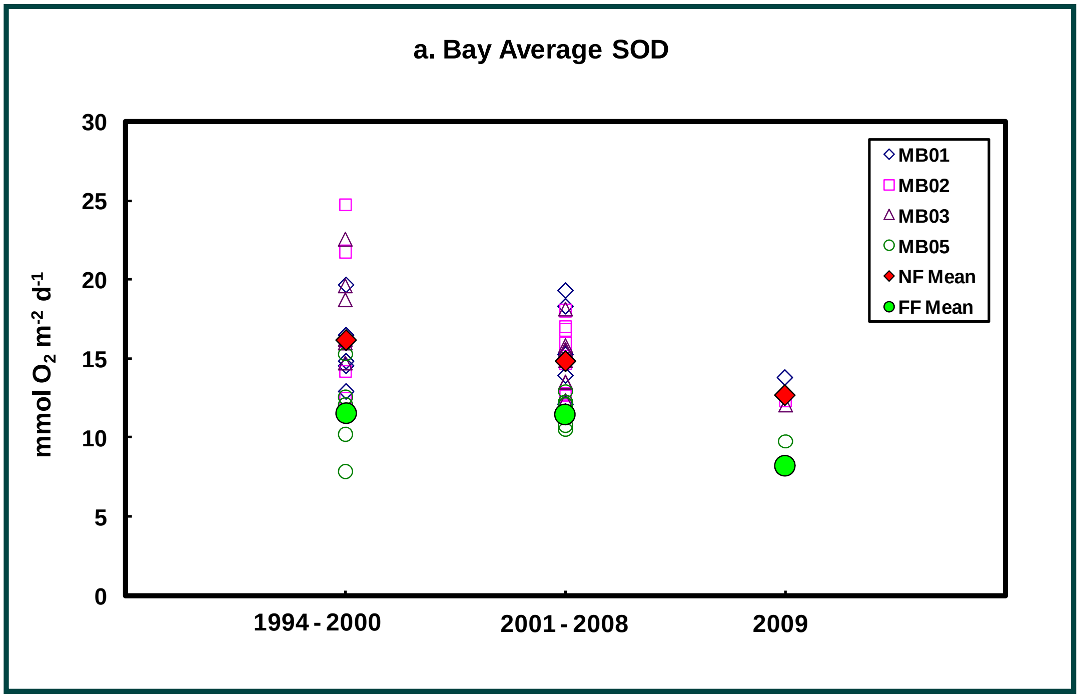

**Figure 4-10 Average sediment oxygen demand at the Massachusetts Bays stations has remained essentially unchanged since the outfall came on-line.**

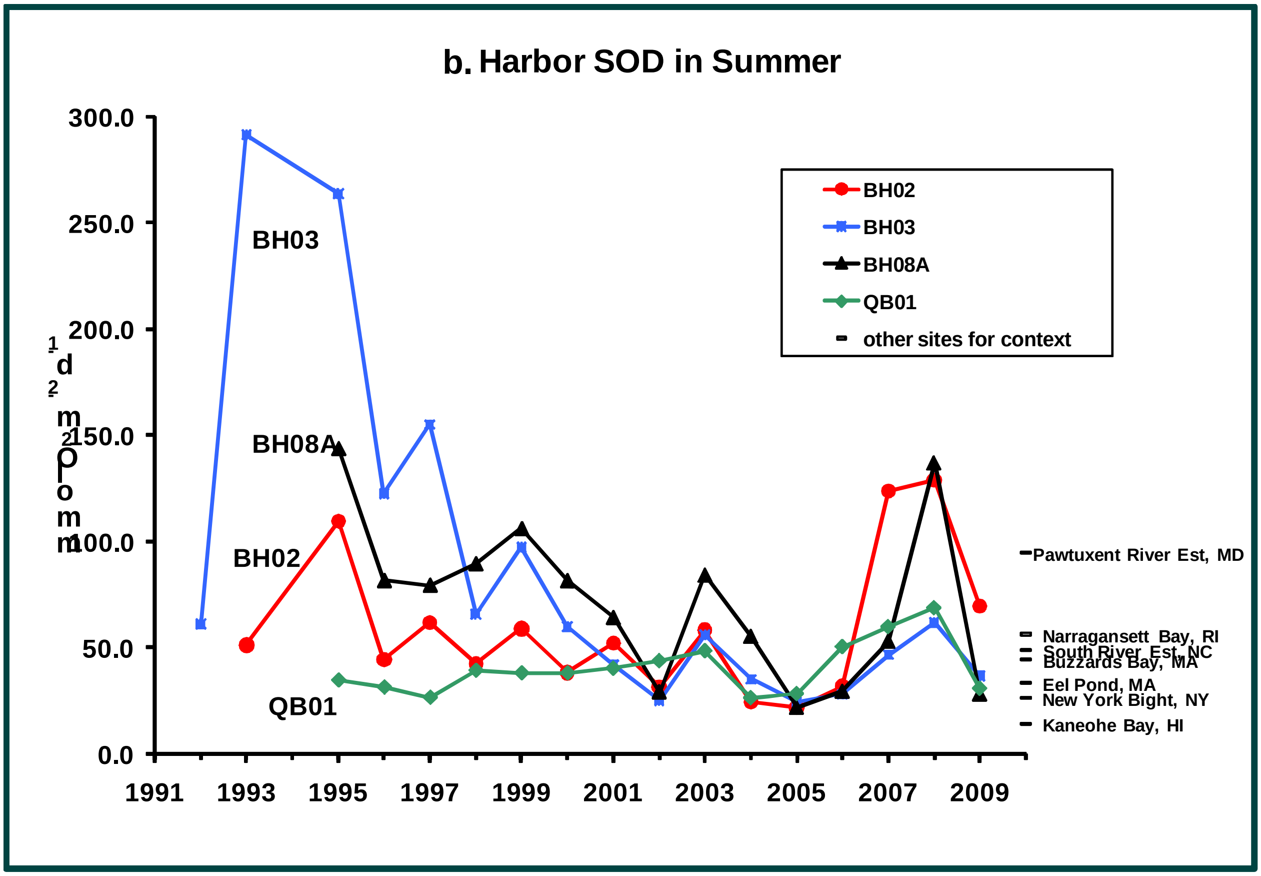

**Figure 4-11 Sediment oxygen demand in Boston Harbor has undergone dramatic changes over the monitoring program.**

**Early on some of the measurements were very high as accumulated organic matter was respired. Recently some previously azooic stations have been colonized, producing the increases in 2007 and 2008.**

Data from other areas (from Nixon 1981) is shown for comparison.

## 4.3 Benthic Monitoring Plan

### 4.3.1 Soft-bottom benthos in the nearfield and farfield

**Biology**

Measurement: Benthic species composition and abundance from 0.04 $m^2$ grab samples as retained on 0.3 mm sieves.

Location: Ten nearfield and three farfield stations (Figures 4-12 and 4-13). In a change from current monitoring, in which half of the stations are sampled in odd years and the other half sampled in even years, all stations will be sampled each survey. This is a reduction from the current 23 stations in western Massachusetts Bay and eight reference stations more distant from the outfall.

Frequency: One sampling per year in August

~~Measurements: Sediment profile images for measurement of RPD depth, and other physical and biological parameters.~~

~~Location: 23 stations in western Massachusetts Bay historically monitored for infauna and contaminants (Figure 4-14)~~

~~Frequency: One sampling per year in August.~~

~~**Chemistry**~~

~~Measurements: Chemical constituents including PAHs, PCBs, pesticides, metals.~~

~~Location: Ten stations in western Massachusetts Bay (nearfield) and three stations in the farfield (See and Figures 4-11 and 4-12).~~

~~Frequency: Sampling every three years at all stations sampled for infauna. (Annual chemistry sampling at stations NF12 and NF17 discontinued.)~~

**Sediment characteristics/tracers**

Measurements: TOC, sediment grain size, *Clostridium perfringens* spore counts in the 0-2 cm depth fraction.

Location: Ten stations in the nearfield and three farfield stations (see Figures 4-12 and 4-13).

Frequency: One sampling per year in August.

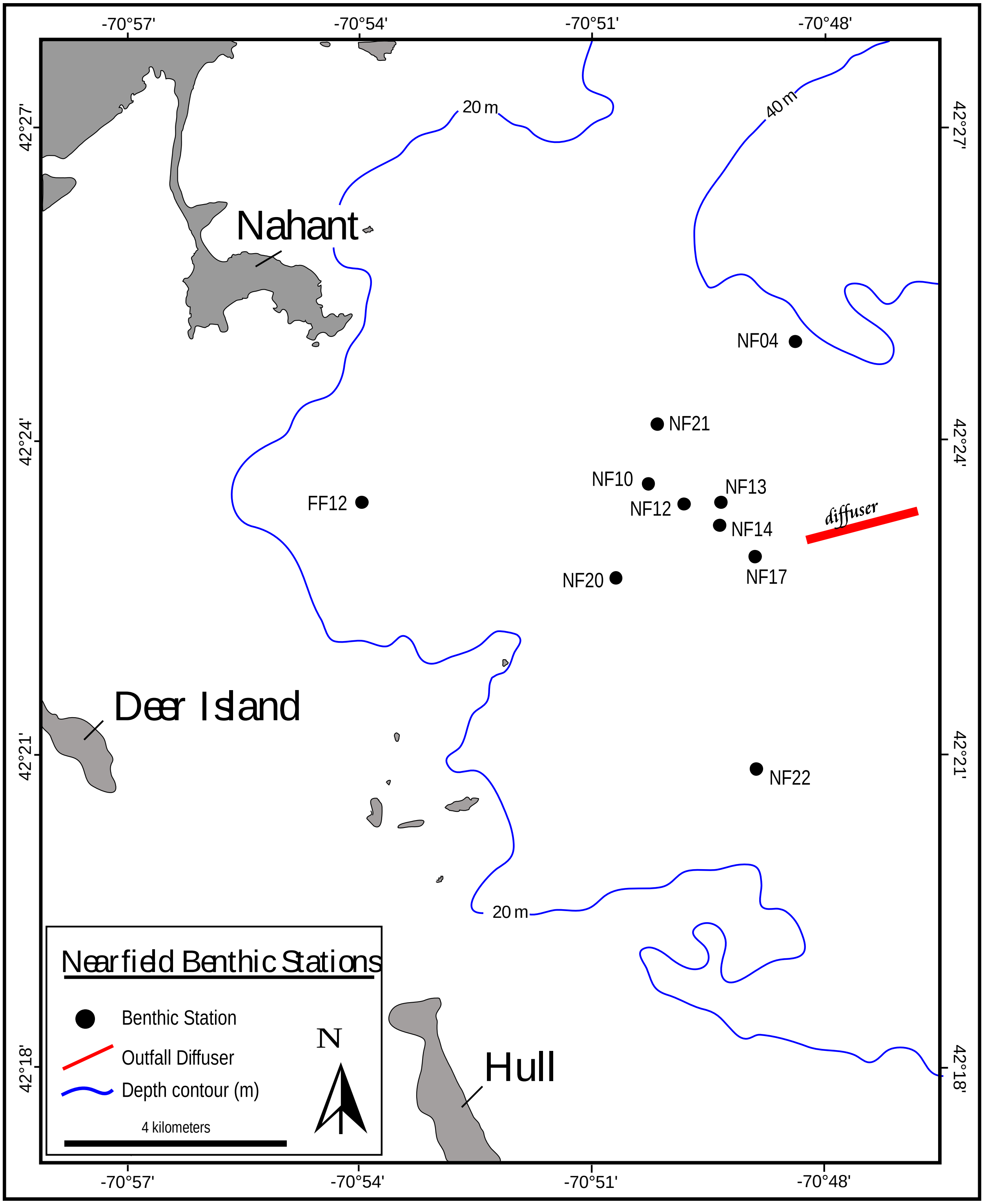

**Figure 4-12 Map of locations of nearfield soft-bottom community stations.**

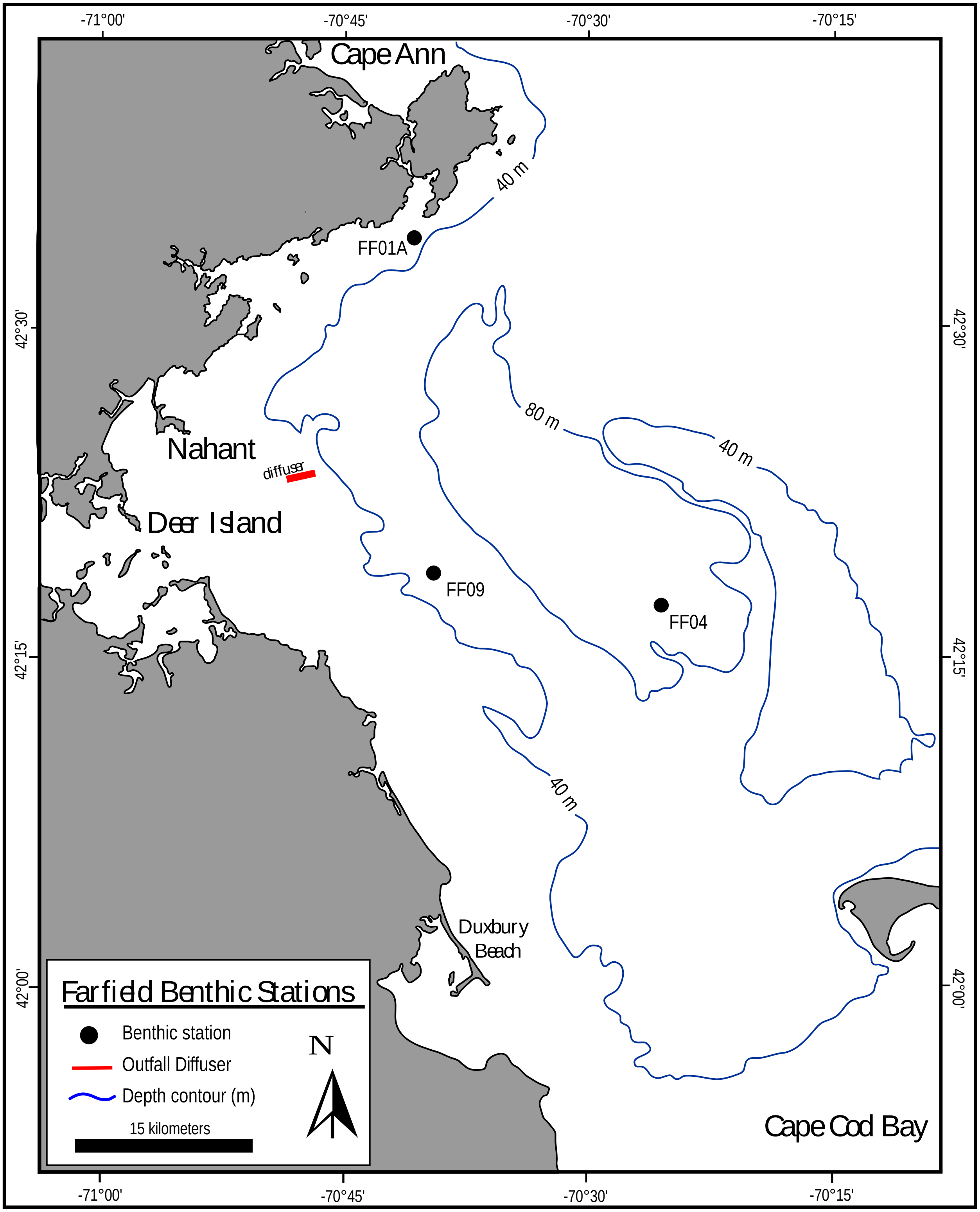

**Figure 4-13 Map of locations of farfield monitoring soft-bottom community stations.**

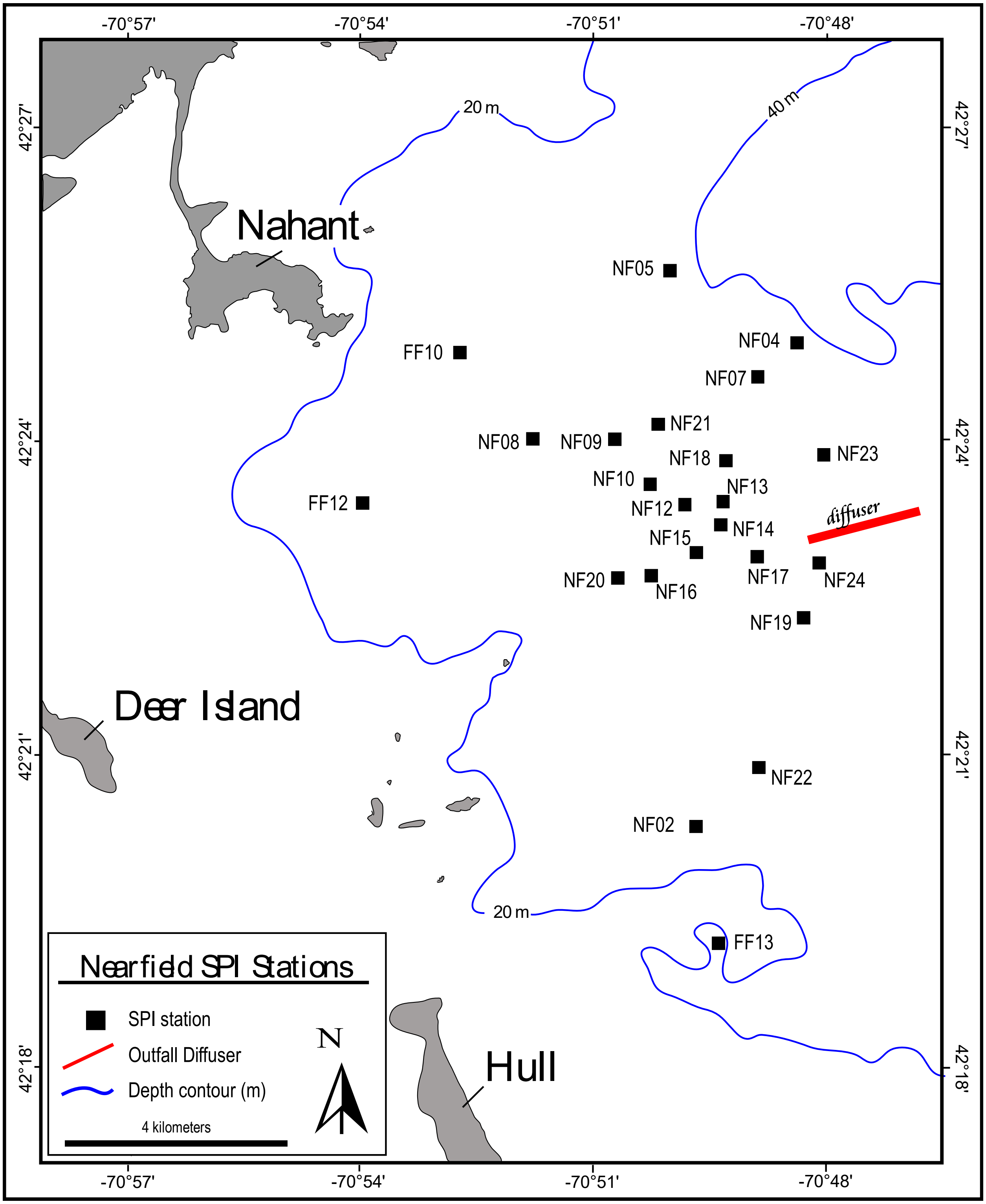

**Figure 4-14 Map of locations of nearfield sediment profile imaging stations.** **Revision 2.1 -** ***Sediment profile image monitoring ended after 2019.***

### 4.3.2 Special study of hard-bottom benthos in the nearfield

Monitoring has documented that changes to the rocky seafloor environments have been subtle. Because rocky habitats are sporadically swept clean of fine particulates, it is difficult to detect small changes and attribute such changes to a particular source such as an outfall. However, substantial, potentially outfall-related changes have not been detected. Hard-bottom habitats are not particularly suitable for assessing small, subtle impacts due to low levels of sediment accumulation. Although we now know that significant impacts are very unlikely, such effects would only be detected after a period of sediment accumulation. Therefore, it is appropriate to decrease the effort on this study by decreasing the frequency of the surveys to every third year.

Measurements: Benthic hard-bottom species composition as determined by digital video analysis, supplemented by stills as appropriate; topography and sediment cover.

Location: 23 stations along drumlins and other rocky features in the vicinity of the outfall to a distance of 3.2 km north and 5 km south, plus a station east of Scituate in the vicinity of $42^{o}$ 14.5'N, $70^{o}$ 33.0'W. (Figure 4-15).

Frequency: One sampling every third year, in the same year sediment contaminant sampling is conducted.

Responsive hard bottom survey:

If the treatment plant discharges a 7-day average total suspended solids load exceeding 180,000 lbs/day, during a year when a hard bottom survey is not planned, MWRA will carry out an appropriate hard bottom survey within 45 days. The exact design and timing of the survey will depend upon the timing and nature of the triggering event. Depending upon the event, the responsive survey could be a visual inspection of the outfall diffusers using a remotely operated vehicle with videographic recorder ranging up to a complete hard bottom survey. Factors to be considered include the nature and extent of the discharge, the seasonal timing of the discharge (historic hard bottom data have been collected in June therefore data collected at other times of the year would not be directly comparable), and logistical factors including weather, ship, scientists and other equipment availability. In addition, MWRA will use modeling hindcasts to help determine the most likely area of particle settling to help determine where the observations should be focused. MWRA will discuss the design of the survey and the use of the hindcast model with EPA, DEP, and OMSAP.

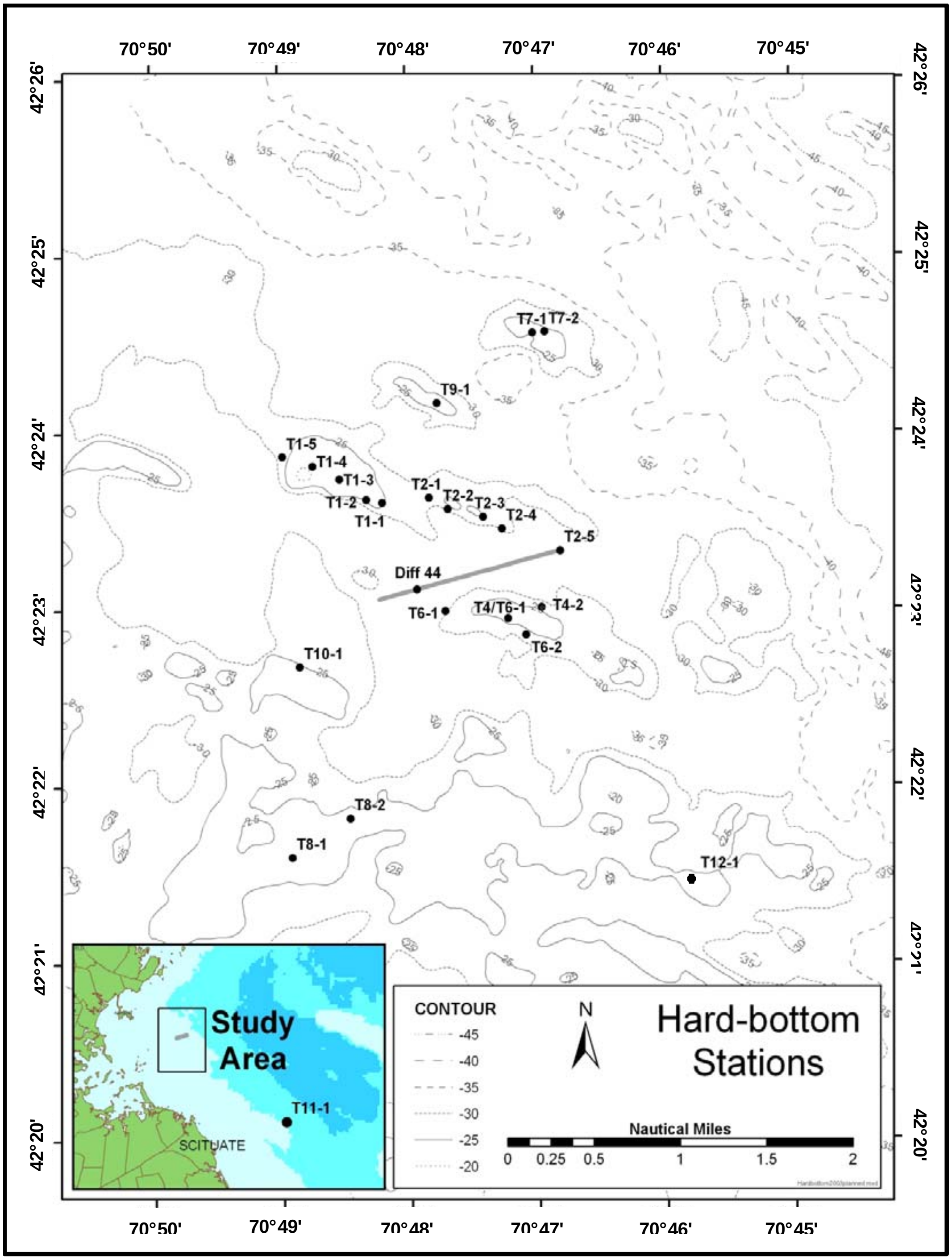

Figure 4-15 Map of locations of hard-bottom monitoring stations

## 4.4 Data evaluation

Contingency Plan threshold testing will continue. For example, the infaunal diversity and percent opportunist thresholds will be tested annually for the new proposed station array, and, as is done now, the contaminant thresholds will be tested every three years when contaminant analyses are conducted.

In addition to testing Contingency Plan thresholds, data from the benthic monitoring program will be evaluated to further address the monitoring questions listed in section 4.2. For example, the concentrations of sewage tracers in sediments have changed only modestly and only in the immediate vicinity of the outfall in the first seven years after diversion, and there have been no widespread changes in the concentrations of contaminants.

Calculation of standard diversity and evenness measures can indicate whether a change in infaunal communities has occurred. Univariate and multivariate analyses such as those presented in MWRA (2003c) and Maciolek *et al.* (2008) will provide sensitive tests of possible outfall effects.

The sewage tracer and organic carbon data will be evaluated to ensure that there are no sudden changes.

## 4.5 Rationale for benthic monitoring plan redesign

Nine years of discharge monitoring have well characterized the very minor effects of the discharge on nearfield sediments. There is no detectable impact on sediments or communities more distant from the outfall.

The previous design was adopted in 2004, and includes odd-year and even-year station sets with only minimal overlap. This design allowed significant cost reductions while continuing to obtain data from all stations occupied during baseline monitoring. Results from the previous design, however, have proven cumbersome to analyze and interpret in annual reporting. The revised design eliminates alternating year station sets, simplifying evaluations.

Figure 4-16 documents that the proposed station array very closely reproduces the patterns observed in total species at nearfield stations.

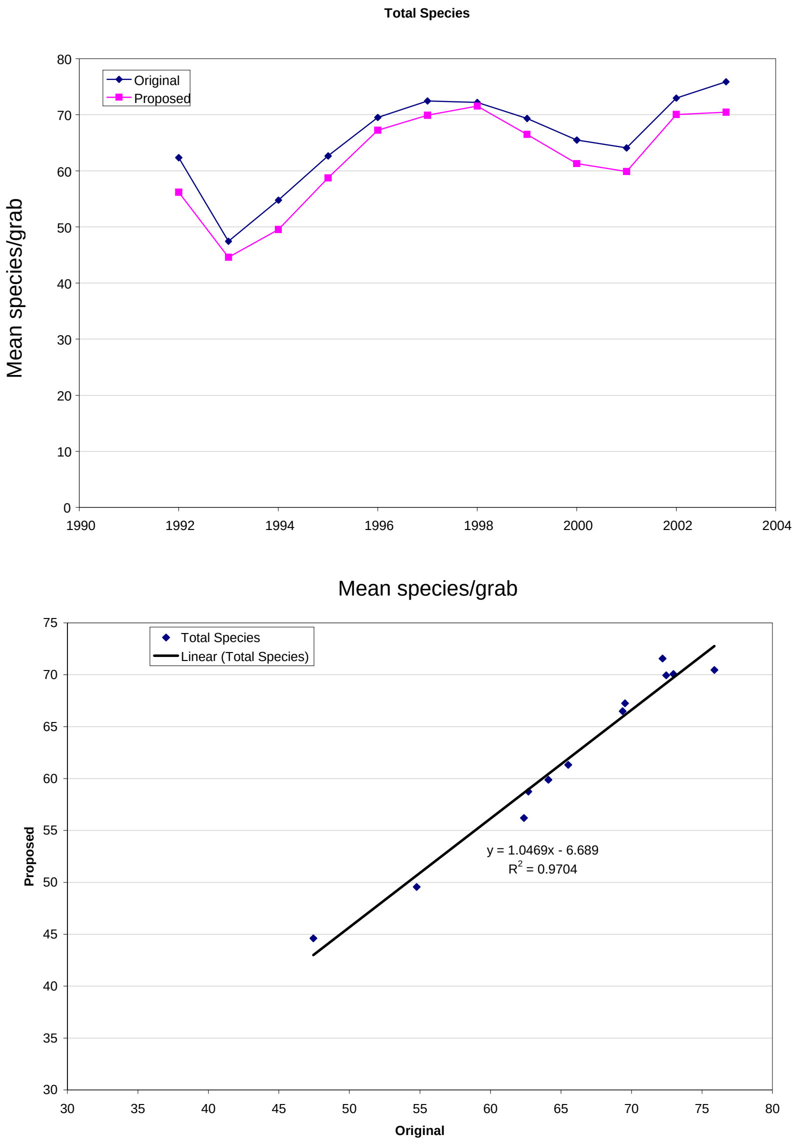

**Figure 4-16 Mean total infaunal species per grab (a Contingency Plan threshold parameter) for nearfield samples, 1992-2003.**

**Averages are shown both for the original 23-station nearfield array and for the revised 10-station subset. Because the revised station array includes sites currently sampled in either even years (e.g. 2008) or odd years (e.g. 2007), an exact comparison cannot be made for data from 2004-2008.**

# 5 FISH AND SHELLFISH MONITORING

## 5.1 Purpose of fish and shellfish monitoring

Commercial and recreational fishing are important parts of the regional identity and economy of Massachusetts. Concerns have been expressed that the relocation of treatment plant effluent into the relatively clean waters of Massachusetts Bay could adversely affect the health of the local marine ecosystem or result in the chemical contamination of commercial fisheries. Because many toxic contaminants adhere to particles, animals that live on the bottom, in contact with sediments, and animals that eat bottom-dwelling organisms were thought to be most vulnerable. Shellfish that feed by filtering suspended matter from large volumes of water are considered excellent indicators of the potential for the bioaccumulation of toxic contaminants. These shellfish are themselves resource species and are prey to other fisheries species. Consumption of these animals by predators could result in transferring contaminants up the food chain and ultimately to humans.

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. The blue mussel is also a fishery species and is a commonly employed biomonitoring organism.

### 5.1.1 Contingency Plan thresholds

The Contingency Plan (MWRA 2001) has thresholds for

- edible tissue levels of toxic contaminants
- flounder liver disease

Details are given in the Contingency Plan (MWRA 2001). The Outfall Monitoring Overview (e.g. Werme *et al.* 2008) summarizes the comparison of monitoring results with Contingency Plan thresholds.

## 5.2 Fish and shellfish monitoring questions and results

The fish and shellfish monitoring program is intended to answer the following questions (MWRA 1991):

→ *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 the outfall site, Boston Harbor, and a reference site?*

→ *Has the incidence of disease and/or abnormalities in fish or shellfish changed?*

Results of MWRA's fish and shellfish monitoring have been reported in a series of reports. http://www.mwra.state.ma.us/harbor/Boston: Massachusetts Water Resources Authority/trlist.html

***Flounder results***

**Flounder contaminants.** Analyses of the monitoring data for flounder found that the spatial distribution of the levels of contaminants in flounder fillet and liver is consistent with regional distributions of sediment contamination; levels are higher in Boston Harbor than offshore in Massachusetts Bay and Cape Cod Bay (Hunt *et al.* 2006; Nestler *et al.* 2007). Mercury levels in edible tissue were found to be higher than expected in 2003, although still lower than contingency plan thresholds (Nestler *et al*. 2007). Total PCBs were also found to be higher in the post-discharge period, possibly as a result of the wetter/snowier weather during 2000–2002, which may have resulted in increased flux of contamination in precipitation and runoff (Hunt *et al*. 2006). Reports also found that levels of metals in liver are often highest at the outfall site, but tend to be more variable than levels of organic contaminants, show no clear temporal trend, and are comparable during the pre- and post-discharge period (Nestler *et al.* 2007).

Before-After, Control-Impact statistical analyses were carried out on flounder tissue contaminant data (Kane-Driscoll *et al.* 2008) No increases in concentrations of contaminants in flounders at the Outfall Site as a result of the relocation of the outfall were found. Concentrations of all contaminants in flounder were below US Food and Drug Administration (FDA) action limits and MWRA thresholds. Concentrations of all contaminants, except PCBs, were below EPA screening-level Risk-based concentrations (RBCs). Concentrations of PCBs at all locations exceeded the EPA screening-level RBC, and 2006 concentrations of PCBs in flounder liver and fillet from the Outfall Site were significantly higher than concentrations at Cape Cod Bay.

**Flounder liver disease**. The most recent flounder report is Moore *et al*. 2009. Neoplasms were not observed in any of the winter flounder collected during 2009 (Figure 5-1) (report in prep). These lesions have always been rare or absent from all sites other than Deer Island, and none have ever been detected at the Outfall Site.

Along with neoplasms, hydropic vacuolation, because of its relationship to environmental contaminants, has been one of the principal lesions monitored in winter flounder throughout the program. Centrotubular hydropic vacuolation (CHV) is the least severe and most common form observed in the collections. In 2008, CHV prevalence at Deer Island dropped slightly from the 2007 level, continuing a general downward trend of contaminant-associated lesions at this site (Figure 5-1). In 2009, the prevalence rose slightly. The prevalence at Nantasket Beach returned to the normal level in 2008 and 2009 after a 2007 spike. CHV for 2009 at the Outfall Site was comparable to the low levels reported during the past three years, and is below the typical prevalence in the pre-discharge period. At the reference site in Eastern Cape Cod Bay, CHV prevalence remained consistent with the low levels seen throughout the study. Figure 5-1 shows the dramatic decrease in flounder liver disease in Boston Harbor. Liver disease may show a decreasing trend in the other monitored locations (except for a relatively stable low level in Cape Cod Bay). The top graph shows neoplasia (tumors) and the bottom graph shows the prevalence of early liver disease.

**Flounder skin lesions, special study**. In 2003, during the flounder surveys, scientists noticed that there was an unusually high incidence of skin ulcers on the blind side (the side in contact with sediment) of winter flounder caught in Boston Harbor and Massachusetts Bay. As a special study, MWRA had the fish tested in a veterinary pathology laboratory for a variety of possible causes of the lesions, and carried out special sampling to determine if the lesions had a seasonal pattern. No diagnosis of the cause was made. Seasonal sampling determined that the incidence decreased over the course of the year, and there was evidence of healing. The percent of affected fish caught has declined dramatically since 2004 to only a few affected fish in the last three years (Figure 5-2). In 2009 the prevalences were: Deer Island Flats 4%, Nantasket Beach 8%, Outfall Site 0%, and Cape Cod Bay 0% (report in prep).

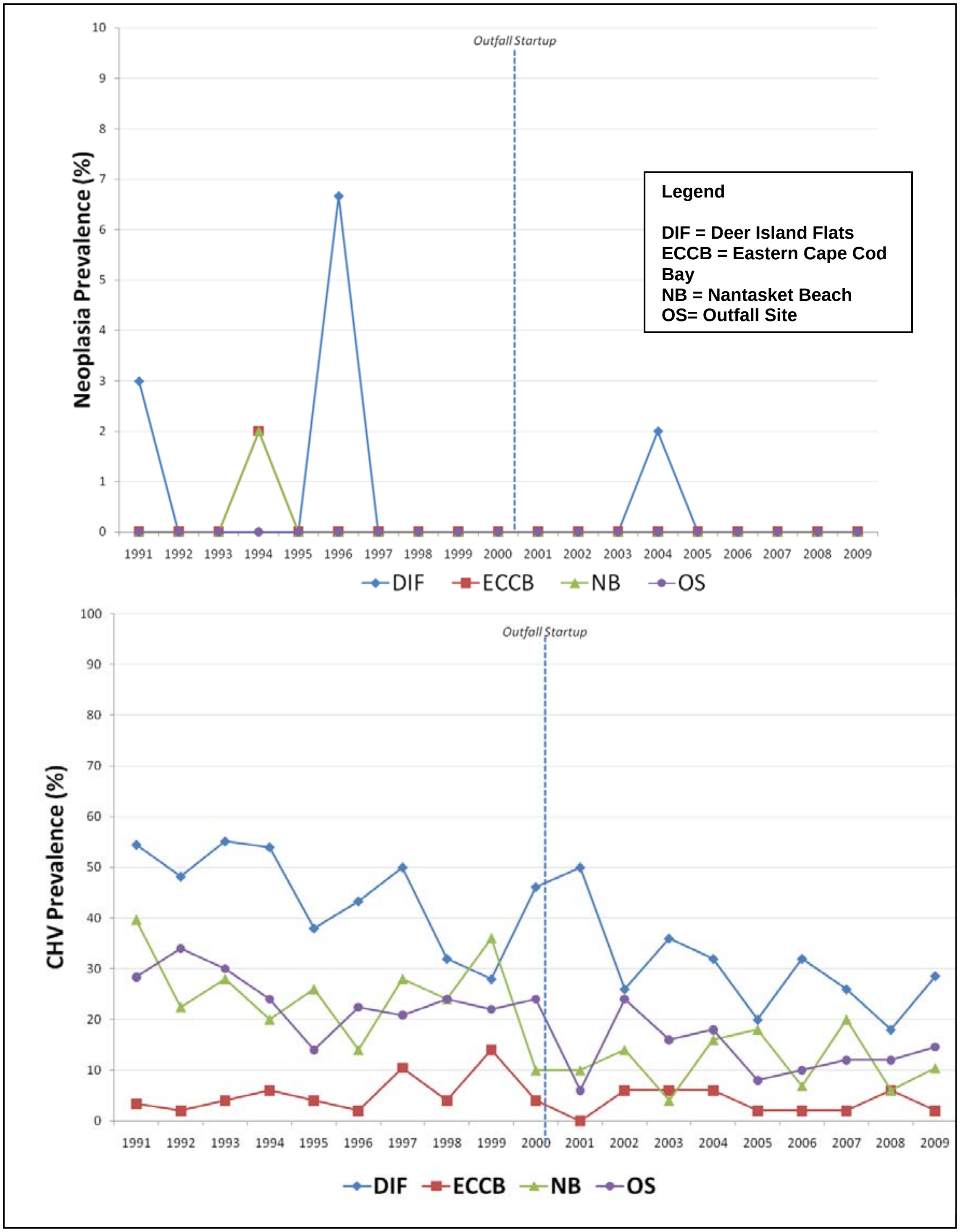

**Figure 5-1 Flounder liver disease 1991-2009.**

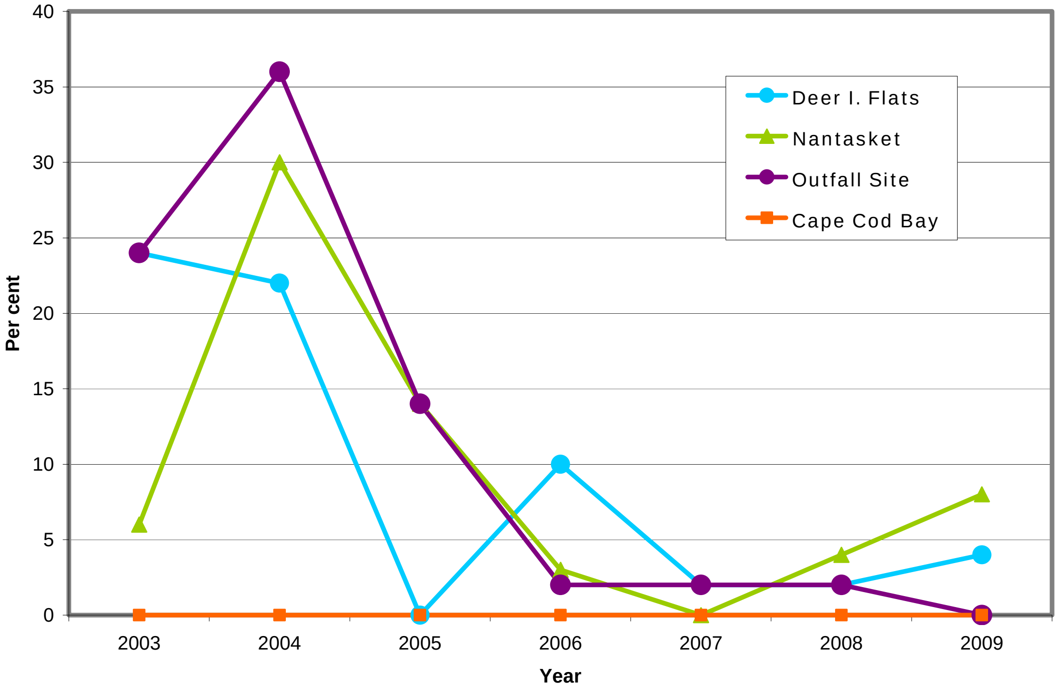

**Figure 5-2 Percent of winter flounder observed with blind-side ulcers 2003-2009.**

***Lobster results.*** The highest levels of organic contaminants tended to be found in lobsters collected from Deer Island Flats in Boston Harbor and the lowest levels were typically found at East Cape Cod Bay (Nestler *et al.* 2007). In general, contaminant concentrations in lobster meat in 2006 were comparable to, or at the lower end of, the historical range across all stations. Concentrations in hepatopancreas of several organic compounds increased in 2006 in comparison to 2003. For example, the concentrations of 4,4'-DDE at all locations were dramatically higher in 2006 than in previous years, matching historical highs at Deer Island Flats and East Cape Cod Bay. Increases were also observed in chlordane and selected PAHs at some locations. Levels of PCB congeners 138 and 153 were generally comparable to historical levels. Concentrations of metals in 2006 were also generally within historical ranges. A few metals, however, were at the upper end of the historical range, including nickel at Deer Island Flats and zinc at the outfall site (Nestler *et al.* 2007).

Before-After, Control-Impact statistical analyses were carried out on lobster tissue data (Kane-Driscoll *et al.* 2008). No increases in concentrations of contaminants in lobsters at the outfall site as a result of the relocation of the outfall were found. Concentrations of all contaminants were below MWRA thresholds and available FDA action limits, and concentrations of most contaminants were also below EPA screening-level RBCs. Although concentrations of PCBs exceeded the EPA screening-level RBC at all locations, 2006 concentrations of PCBs in lobsters from the Outfall Site are not significantly different from concentrations at Cape Cod Bay.

***Mussel results.*** In the early part of the period after the outfall was relocated (2001–2003) concentrations of certain contaminants (mercury, lead, total DDT, total PCBs, total PAHs, total chlordane, dieldrin, hexachlorobenzene, lindane, and high molecular weight (HMW) PAH) were significantly higher in mussels deployed at the outfall site than during the pre-discharge period (1998–2000) (Hunt, Abramson *et al* 2002, Wisneski *et al*. 2004). However, average discharge-period concentrations of mercury and lead at the outfall site were similar to concentrations in mussels before they were deployed. Most pesticides were within the historical range measured at the outfall site.

Total chlordane was an exception, being significantly higher in mussels deployed at the outfall site during the early post-discharge period compared to pre-discharge levels, and higher at the outfall site than at any other station in 2001 and 2002. In 2006, however, levels of chlordane trended substantially downward at the outfall site and were at or near historical lows at all stations (Nestler *et al*. 2007). Similar to chlordane, concentrations of HMW PAH and total PAHs (mostly because of the contribution of HMW PAH) increased at the outfall site coincident with outfall startup. Although HMW PAHs at the outfall site were elevated in the post-discharge period (2001–2006) in comparison to pre-discharge, concentrations were lower in 2006 than in the earlier period (2001–2003) (Nestler *et al.* 2007).

Concentrations of total PAHs and total chlordane in mussels deployed at the outfall site exceeded Contingency Plan caution levels in 2001 and 2002, and PAH thresholds were exceeded in 2003 (Hunt *et al.* 2006). An investigative study examined factors affecting contaminant levels and assessed the potential for environmental impact (Hunt *et al.* 2002). This study found that measured levels of PAHs and chlordane in mussels were below levels associated with impacts to growth and other chronic adverse impacts to aquatic organisms. In 2006, concentrations of total PAHs and chlordane were lower, and none of the contaminants exceeded the U.S. Food and Drug Administration (FDA) action limits or MWRA caution or warning thresholds.

Before-After, Control-Impact statistical analyses were carried out on mussel data (Kane-Driscoll *et al.* 2008). Post-relocation (After) concentrations of lead, PCBs, high molecular weight PAHs, total PAHs, chlordane and 4,4'-DDE were statistically significantly greater than Before at the outfall site taking into account changes at the control site (Cape Cod Bay). Although levels of these contaminants are higher at the outfall site, the concentrations are below MWRA threshold levels and FDA action limits. Also current concentrations of PAHs in mussels at all locations are below U.S. Environmental Protection Agency (EPA) benchmarks for the protection of aquatic organisms, and concentrations of lead, mercury, chlordane, and 4,4'-DDE were below EPA screening-level human health risk-based concentrations (RBCs)[11]. Average concentrations of PCBs exceeded the EPA screening-level RBC at all locations, although concentrations of PCBs at the outfall site were significantly lower than concentrations at Cape Cod Bay, indicating a broader regional distribution of PCBs. These results are consistent with expectations.

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[11] EPA RBCs are based on conservative estimates of the rates of consumption of fish or shellfish, and do not constitute regulation or guidance. RBCs are used primarily to screen out chemicals as contaminants of concern in an initial phase of a risk assessment.

## 5.3 Fish and shellfish monitoring plan

MWRA is not proposing changes to fish and shellfish monitoring. Figure 5-3 shows the sampling locations. Table 5-1 summarizes the chemical analyses performed for fish and shellfish. Gross deformities, parasites, or visually apparent diseases are noted for both collected flounder and lobster. In addition, histological measurements are made in flounders (in particular, liver lesions).

Table 5-2 summarizes the internal and external lesions measured in flounder and lobster. If lesions or gross deformities are observed, samples will be archived for additional tissue contamination if deemed necessary.

### 5.3.1 Flounder and lobster

| | |
|---|---|
| Measurements: | PCB, pesticides, mercury and lipids in flounder fillet and lobster meat. PCB, PAH, trace metals, pesticides, and lipids in flounder liver and lobster hepatopancreas. Histological analysis of flounder liver. Animal size, mass, and dry/lipid weight will also be recorded. |
| Location: | Flounder: Deer Island Flats, Outfall Site. ~~East Cape Cod Bay, and Nantasket Beach.~~<br>Lobster: Deer Island Flats, Outfall Site and East Cape Cod Bay. |
| Frequency: | Flounder: Sampled every year in April for histology and every third year for chemical constituents.<br>Lobster: Sampled in July-October, every third year.<br>Biological material from a minimum of fifteen flounder or lobster specimens from each station is pooled to form three composite samples of at least 5 individuals each for chemical analysis. Histological sections of flounder liver will be made for 50 fish per station. |

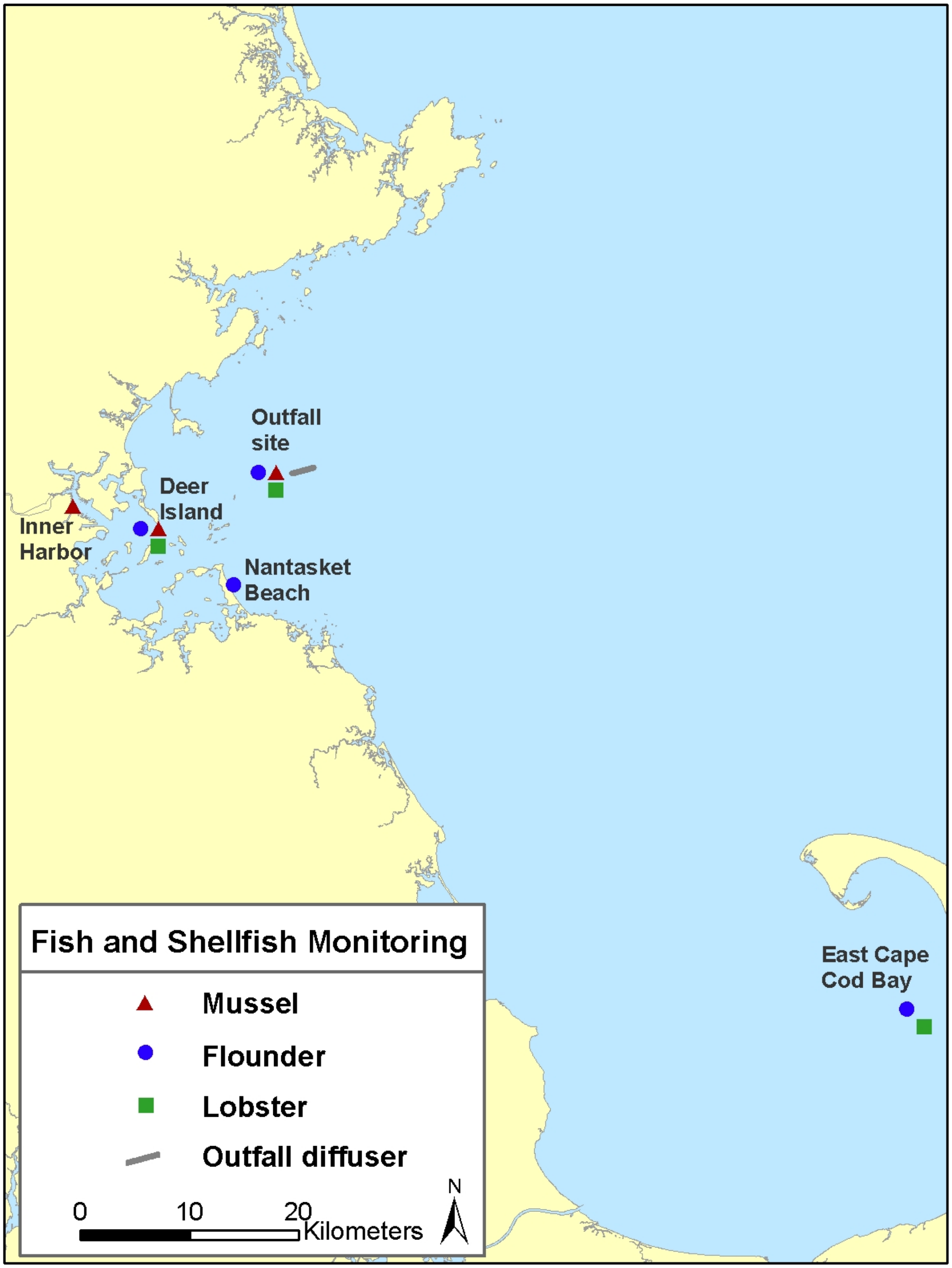

**Figure 5-3 Map of sampling stations for winter flounder, lobster and mussels.** ***Revision 2.1 – Nantasket Beach and East Cape Cod Bay site dropped from flounder study after 2020.***

**Table 5-1 Chemistry analyses for fish and shellfish monitoring**

| Organism | Number of stations | Number of samples of each type per station | Parameters |
|---|---|---|---|
| Flounder | 2 (after 2020) | 3 composites<br>(fillet from 5 flounder) | Mercury<br>PCB<br>Chlorinated pesticides<br>Lipids |
| Flounder | 2 (after 2020) | 3 composites<br>(liver from 5 flounder) | Trace metals<br>PAH<br>PCB<br>Chlorinated pesticides<br>Lipids |
| Lobster | 3 | 3 composites<br>(meat from approximately 5 lobster) | Mercury<br>PCB<br>Chlorinated pesticides<br>Lipids |
| Lobster | 3 | 3 composites<br>(hepatopancreas from approximately 5 lobster) | Trace metals<br>PAH<br>PCB<br>Chlorinated pesticides<br>Lipids |
| Mussel | 1 predeployment<br>and<br>3 postdeployment | 5 composites<br>(soft tissue from approximately 10 mussels) | Mercury<br>Lead<br>PAH<br>PCB<br>Chlorinated pesticides<br>Lipids |

### Table 5-2 Internal and external lesion scoring for fish and shellfish monitoring

| Species | Internal/external | Lesion[1] |
|---|---|---|
| *Pseudopleuronectes americanus* (Winter flounder) | Internal (liver) | Apoptotic lesions (Balloon hepatocytes) |
| | | Biliary proliferation |
| | | Centrotubular hydropic vacuolation |
| | | Focal hydropic vacuolation |
| | | Macrophage aggregation |
| | | Neoplasia |
| | | Tubular hydropic vacuolation |
| | | Gross lesions visible on whole flounder liver |
| | | Liver color |
| | External | Fin erosion (fin rot) |
| | | Net trauma |
| | | Viral lymphocystis |
| | | Skin ulceration, including blind side ulcers |
| | | Other external lesions |
| *Homarus americanus* (Lobster) | External | Black gill disease |
| | | External tumors |
| | | Parasites |
| | | Shell erosion |

[1] Lesions (except for liver color) are rated on a scale from 0 (absent) to 4 (severe)

### 5.3.2 Mussels

Measurements: PAH, PCB, pesticides, mercury and lead.

Location: Outside the mixing zone of the outfall (Outfall Site), Inner Harbor reference (Discovery site), Deer Island Light.[12]

Frequency: Every third year. Caged mussels in replicate arrays (with > 50 mussels each) deployed at mid-depth or below the pycnocline. Deployment will be for 60 days during June through August. A subset of mussels is collected at from each deployment at 40 days in case storms prevent the 60-day retrieval. For each station, biological material from at least 50 mussels is pooled to form five composite samples (at least 10 specimens per sample) for chemical analyses.

## 5.4 Data evaluation

The monitored parameters are examined for long-term temporal trends at the outfall site, and whether they might indicate potential human health risk (for example, approaching an FDA Action Level for seafood consumption) or changes in overall fish and shellfish community health. Data from the other stations help evaluate whether any changes are related to the outfall.

If unexpected changes are observed (for example, exceeding a Contingency Plan threshold for flounder tissue contamination), repeating the sampling the following year may be appropriate to monitor for an adverse trend.

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[12] MWRA will continue to deploy mussels at the Large Navigation Buoy (LNB) as long as practical *(i.e*. not overly burdensome in cost or time.)

# 6 REFERENCES

Note: All reports designated “Boston: Massachusetts Water Resources Authority” may be retrieved from http://www.mwra.state.ma.us/harbor/enquad/trlist.html

Anderson DM, Keafer BA, McGillicuddy DJ, Mickelson MJ, Keay KE, Libby PS, Manning JP, Mayo CA, Whittaker DK, Hickey JM, He R, Lynch DR, Smith KW. 2005. Initial observations of the 2005 *Alexandrium fundyense* bloom in southern New England: General patterns and mechanisms. Deep-Sea Research II 52 (19-21), 2856-2876.

Anderson DM, Libby PS, Mickelson MJ, Borkman DG, McGillicuddy DJ. 2007. The 2005 New England red tide of *Alexandrium fundyense*: observations, causes, and potential outfall linkages. Boston: Massachusetts Water Resources Authority. Report 2007-10. 85 p.

Bisson JW and Cabelli VJ. 1979. Membrane filter enumeration method for *Clostridium perfringens*. Applied and Environmental Microbiology. 37:1. p 55-66.

Bothner MH, Buchholtz ten Brink M, Parmenter CM, D'Angelo WM, Doughten MW. 1993. The distribution of silver and other metals in sediments from Massachusetts and Cape Cod Bays - an interim compilation. USGS. Open File Report 93-725.

Bothner MH, Buchholtz ten Brink M, Manheim FT. 1998. Metal concentrations in surface sediments of Boston Harbor—changes with time: Marine Environmental Research, v. 45, No. 2, p. 127-155.

Bothner MH, Casso MA, Rendigs RR, Lamothe PJ. 2002. The effect of the new Massachusetts Bay sewer outfall on the concentrations of metals and bacterial spores in nearby bottom and suspended sediments. Marine Pollution Bulletin v. 44, No. 2, p 1063-1070.

Bothner MH and Butman B (eds.). 2007. Processes influencing the transport and fate of contaminated sediments in the coastal ocean—Boston Harbor and Massachusetts Bay: U.S. Geological Survey Circular 1302. 89 p.

Butman B, Bothner MH, Lightsom FL, Gutierrez BT, Alexander PS, Martini MA, Strahle WS. 2002. Long-term oceanographic observations in western Massachusetts Bay offshore of Boston, Massachusetts: Data report for 1989-2000. U.S. Geological Survey digital data series 74.

Coats, DA, E Imamura, and JF Campbell. 1995. Hard-Substrate Reconnaissance Survey S9404 Final Analysis Report. Boston: Massachusetts Water Resource Authority. Boston: Massachusetts Water Resources Authority. Report 1995-01. 48 pp.

Cibik SJ, Howes BL, Taylor CD, Anderson DM, Davis CS, Loder TC, Boudrow RD, Bowen JD. 1996. 1995 Annual water column monitoring report. Boston: Massachusetts Water Resources Authority. Report 1996-07. 254 p.

Cibik SJ, Lemieux KB, Howes BL, Taylor CD, Davis CS, Loder III TC, Boudrow RD. 1998a. 1996 Annual water column monitoring report. Boston: Massachusetts Water Resources Authority. Report 1998-11. 416 p.

Cibik SJ, Lemieux KB, Tracey JK, Kelly SJ, Howes BL, Taylor CD, Loder III TC. 1998b. 1997 Annual water column monitoring report. Boston: Massachusetts Water Resources Authority. Report 1998-19. 258 p.

Cole BE and JE Cloern.  1987.  An empirical model for estimating phytoplankton productivity in estuaries. Mar Ecol Prog Ser 36:299–305.

Delaney MF. 2010. Addendum to Contaminant Monitoring of Deer Island Treatment Plant Effluent 2000 – 2005: Effluent Data for 2005-2009.  Boston: Massachusetts Water Resources Authority. Report Enquad 2010-14. 4 p.

Delaney M and Rex A. 2007. Contaminant monitoring of Deer Island Treatment Plant Effluent 2000-2005. Boston: Massachusetts Water Resources Authority. Report 2007-02. 40 p.

Durell G, Pala S, Field J. 2008. Sediment Contaminants near Combined Sewer Overflows in Dorchester Bay and at other areas in Boston Harbor: 1990-2006. Boston: Massachusetts Water Resources Authority. Report 2008-10. 156 pp.

EPA. 2006. National Recommended Water Quality Criteria: 2006. Environmental Protection Agency. Retrieved from: http://www.epa.gov

Geyer W, Gardner GB, Brown W, Irish J, Butman B, Loder T, and Signell RP. 1992. Physical oceanographic investigation of Massachusetts and Cape Cod Bays, Technical Report MBP-92-03, Massachusetts Bays Program, U.S. EPA Region I/Massachusetts Coastal Zone Management Office, Boston, Massachusetts. 497 pp.

Geyer WR, Libby PS,  Giblin A. 2002. Influence of physical controls on dissolved oxygen variation at the outfall site. Boston: Massachusetts Water Resources Authority. Letter report Boston: Massachusetts Water Resources Authority. 20 p.

GoMOOS.  2008. Gulf of Maine Ocean Observing System. Retrieved from http://www.neracoos.org/gomoos

Hilbig B and JA Blake. 2000. Long-term analysis of polychaete-dominated benthic infaunal communities in Massachusetts Bay. *Bulletin of Marine Science*. 67(1):147–164.

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

Hunt CD, Hall M, Pala SL, Dahlen DT. 2006. A review and summary of toxic contaminants in Boston Harbor and Massachusetts Bay: 1990 to 2005. Boston: Massachusetts Water Resources Authority. Report 2006-23. 136 p.

Hunt CD, Steinhauer WS, Mansfield AD, Albro CA, Roberts PJW, Geyer WR, Mickelson MJ. 2002. Massachusetts Water Resources Authority outfall effluent dilution: April 2001. Boston: Massachusetts Water Resources Authority. Report 2002-06. 69 p.

Hunt CD, Mansfield AD, Roberts PJW, Albro CA, Geyer WR, Steinhauer WS, Mickelson MJ. 2002. Massachusetts Water Resources Authority outfall effluent dilution: July 2001. Boston: Massachusetts Water Resources Authority. Report 2002-07. 77 p.

Hunt CD, Hall M, Pala SL, Dahlen DT. 2006. A review and summary of toxic contaminants in Boston Harbor and Massachusetts Bay: 1990 to 2005. Boston: Massachusetts Water Resources Authority. Report 2006-23. 136 p.

HydroQual. 2001. Boundary sensitivity for the Bays Eutrophication Model (BEM). Boston: Massachusetts Water Resources Authority. Report 2001-14. 90 p.

Jiang M, Zhou M. 2006. Massachusetts Bay Eutrophication Model: 2002-2004 Simulation. Boston: Massachusetts Water Resources Authority. Report 2006-13. 126 p.

Jiang M, Zhou M. 2008. Massachusetts Bay Eutrophication Model: 2005 simulation. Boston: Massachusetts Water Resources Authority. Report 2008-13. 82 p.

Jiang M, Zhou M, Libby PS, Hunt CD. 2007. Influences of the Gulf of Maine intrusion on the Massachusetts Bay spring bloom: A comparison between 1998 and 2000. Continental Shelf Research. 27:2465–2485.

Kane-Driscoll S, Edwards M, Pembroke A, Nestler EC, Gurshin C. 2008. Changes in contaminants in winter flounder, lobster, and caged mussels in Massachusetts and Cape Cod Bays and Boston Harbor: 1995-2006. Boston: Massachusetts Water Resources Authority. Report 2008-09. 73 p.

Kelly JR, Doering PH. 1995. Nutrient issues update 1995: metabolism in Boston Harbor, Massachusetts and Cape Cod Bays, MA (USA) during 1992-1994. Boston: Massachusetts Water Resources Authority. Report 1995-19. 38 p.

Kelly JR and Doering PH. 1997. Monitoring and modeling primary production in coastal waters: studies in Massachusetts Bay 1992–1994. Mar Ecol Prog Ser 148:155–168.

Kropp RK, Diaz RJ, Hecker B, Dahlen DT, Boyle JD, Abramson SL, Emsbo-Mattingly S. 2002. 2001 outfall benthic monitoring report. Boston: Massachusetts Water Resources Authority. Report 2002-15. 137 p.

Lavalli KL, Kropp RK. 1998. Abundance of juvenile lobsters at the new outfall site: comparisons with inshore abundances and discussion of potential impacts on lobster populations. Boston: Massachusetts Water Resources Authority. Report 1998-14. 26 p.

Lefkovitz LF, Dahlen DT, Hunt CD, Ellis BD. 1999. 1998 CSO sediment study synthesis report. Boston: Massachusetts Water Resources Authority. Report 1999-12. 68 p.

Libby PS, Albro CS, Hunt CD, Geyer WR, Keller AA, Oviatt CA, Turner JT. 1999. 1998 Annual water column monitoring report. Boston: Massachusetts Water Resources Authority. Report 1999-16. 180 p.

Libby PS, Hunt CD, Geyer WR, Keller AA, Oviatt CA, Turner JT. 2000. 1999 Annual water column monitoring report. Boston: Massachusetts Water Resources Authority. Report 2000-09. 180 p.

Libby PS, Hunt CD, McLeod LA, Geyer WR, Keller AA, Oviatt CA, Borkman DG, Turner JT. 2001. 2000 Annual water column monitoring report. Boston: Massachusetts Water Resources Authority. Report 2001-17. 196 p.

Libby PS. 2006. Standing survey plan: rapid response Alexandrium survey. Boston: Massachusetts Water Resources Authority. Report 2006-05. 19 p.

Libby PS, Geyer WR, Keller AA, Turner JT, Borkman D, Oviatt CA, Hunt CD. 2003. 2002 annual water column monitoring report. Boston: Massachusetts Water Resources Authority. Report Boston: Massachusetts Water Resources Authority 2003-09. 111 p.

Libby PS, Geyer WR, Keller AA, Turner JT, Borkman DG, Oviatt CA. 2004. 2003 Annual Water Column Monitoring Report. Boston: Massachusetts Water Resources Authority. Report 2004-07. 154 p.

Libby PS, Geyer WR, Keller AA, Turner JT, Mansfield AD, Borkman DG, Oviatt CA. 2006a. 2004 Annual water column monitoring report. Boston: Massachusetts Water Resources Authority. Report 2006-15. 177 p.

Libby PS, Geyer WR, Keller AA, Mansfield AD, Turner JT, Donald M Anderson, Borkman DG, Rust S, Hyde K, Oviatt CA. 2006b. 2005 Annual water column monitoring report. Boston: Massachusetts Water Resources Authority. Report 2006-20. 182 p.

Libby PS, Geyer WR, Keller AA, Mansfield AD, Turner JT, Anderson DM, Borkman DG, Rust S, Hyde K, Oviatt CA. 2007. Water Column Monitoring in Massachusetts Bay: 1992-2006. Boston: Massachusetts Water Resources Authority. Report 2007-11. 228 p.

Libby PS, Borkman DG, Geyer WR, Keller AA, Turner JT, Mickelson MJ, Oviatt CA. 2008. Water Column Monitoring in Massachusetts Bay: 1992-2007. Boston: Massachusetts Water Resources Authority. Report 2008-16. 170 p.

Libby PSA, Donald M, Borkman DG, Geyer WRK, Aimee A Oviatt, Candace A, Turner JT. 2009. 2008 Water Column Monitoring Results. Boston: Massachusetts Water Resources Authority. Report 2009-12. 31 p. plus appendices.

Maciolek NJ, Dahlen D, Diaz RJ, Gallagher ED, Hecker B, Blake JA, Hunt CD, Keay KE, Emsbo-Mattingly S, Williams IP. 2003. 2002 outfall benthic monitoring report. Boston: Massachusetts Water Resources Authority. Report 2003-13. 166 p.

Maciolek NJ, Dahlen DT, Diaz RJ, Hecker B. 2009. Outfall Benthic Monitoring Report: 2008 Results. Boston: Massachusetts Water Resources Authority. Report 2009-13. 36 pages plus appendices.

Maciolek NJ, Diaz RJ, Dahlen DT, Hecker B, Williams IP, Hunt CD. 2004. 2003 Outfall Benthic Monitoring Report. Boston: Massachusetts Water Resources Authority. Report 2004-14. 125 p.

Maciolek NJ, Diaz RJ, Dahlen DT, Hecker B, Williams IP, Hunt CD, Smith W. 2007. 2006 Outfall benthic monitoring report. Boston: Massachusetts Water Resources Authority. Report 2007-08. 162 p.

Maciolek NJ, Doner S, Simmons D, Blake JA. 2008. Combined Work/Quality Assurance Project Plan (QAPP) for Benthic Monitoring 2008-2009. Boston: Massachusetts Water Resources Authority. Report 2008-11. 95 p.

Maciolek NJ, Doner SA, Diaz RJ, Dahlen DT, Hecker B, Williams IP, Hunt CD, Smith W. 2008. Outfall benthic monitoring interpretive report 1992-2007. Boston: Massachusetts Water Resources Authority. Report 2008-20. 149 p.

Maciolek NJ, Diaz RJ, Dahlen DT, Doner SA. 2008. 2007 Boston Harbor benthic monitoring report. Boston: Massachusetts Water Resources Authority. Report 2008-22. 54 p. + appendices

Maciolek NJ, Winchell P, Moore MJ. 2008. Combined Work/Quality Assurance Project Plan (QAPP) for Flounder Monitoring: 2008-2009. Boston: Massachusetts Water Resources Authority. Report 2008-15. 56 p.

Montoya JP, Rathbun KM, Mayo CS. 2003. Information Briefing to Outfall Monitoring Science Advisory Panel. Recent nitrogen isotope data from Massachusetts and Cape Cod Bays. January 6 2003. 8 p. Retrieved from https://www3.epa.gov/region1/npdes/mwra/omsap/pdfs/OMSAP0103.pdf

Moore MJ. 2006. 2005 Flounder report for fish and shellfish monitoring. Boston: Massachusetts Water Resources Authority. Report 2006-14. 18 p.

Moore MJ, Maciolek NJ, Winchell P. 2009. 2008 report for flounder monitoring. Boston: Massachusetts Water Resources Authority. Report 2009-01. 17 p.

Moore G, Mayo C, Collier J, Bessinger M, Montoya J. 2005. Effects of Boston Outfall on the Marine Community of Cape Cod Bay. Provincetown Center for Coastal Studies. March 7, 2005. Retrieved from https://coastalstudies.org/wp-content/uploads/2013/12/CCBFinalCCC.pdf.

MWRA. 1991. Effluent outfall monitoring plan: phase I baseline studies. Massachusetts Water Resources Authority, Boston, MA.

MWRA. 1997. Massachusetts Water Resources Authority effluent outfall monitoring plan: Phase II post discharge monitoring. Boston: Massachusetts Water Resources Authority. Report ms-044. 61 p.

MWRA. 2001. Massachusetts Water Resources Authority Contingency Plan Revision 1. Boston: Massachusetts Water Resources Authority. Report ms-071. 47 p.

MWRA. 2008. Massachusetts Water Resources Authority Industrial Waste Report, No. 24. Boston: Massachusetts Water Resources Authority. October 2008.

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

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

MWRA. 2003c. Briefing for OMSAP workshop on ambient monitoring revisions, July 24, 2003. Boston: Massachusetts Water Resources Authority. Report ms-86. 64 p.

MWRA. 2004. Massachusetts Water Resources Authority effluent outfall ambient monitoring plan Revision 1 March 2004. Boston: Massachusetts Water Resources Authority. Report ms-092. 65 p.

MWRA.2008.Massachusetts Bay bacteria monitoring. Retrieved from http://www.mwra.state.ma.us/harbor/html/mb_bacteria.htm

NASA. 2008. Ocean Biology Processing Group. Retrieved from http://oceancolor.gsfc.nasa.gov/

Nestler EC, Pembroke A, Moore MJ, Chapnick S. 2007. 2006 Annual fish and shellfish report. Boston: Massachusetts Water Resources Authority. Report 2007-06. 200 p.

Nixon, S.W. 1981. Remineralization and nutrient cycling in coastal marine ecosystems. In: BJ Nielson and LE Cronin, eds. Estuaries and Nutrients. Pp 111-138.

NMFS. 1993 . NOM Fisheries Endangered Species Act Section 7 consultation- biological opinion for Boston Harbor Project. Issuance of a National Pollutant Discharge Elimination

System permit for the Massachusetts Water Resources Authority outfall. National Oceanic and Atmospheric Administration. Rockville MD.

NRC. 1990. Managing troubled waters: The role of marine monitoring. National Research Council. National Academy Press, Washington, DC. 125pp.

OMSAP. 2002. US Environmental Protection Agency Region 1. Minutes of Outfall Monitoring Science Advisory Panel meeting, September 24 2002, Boston, MA. Retrieved from https://www.epa.gov/npdes-permits/outfall-monitoring-science-advisory-panel#meeting-minutes

OMSAP. 2003a. US Environmental Protection Agency Region 1. Minutes of Outfall Monitoring Science Advisory Panel 2003 monitoring review workshop #1, March 31-April 1, 2003, Woods Hole, MA. Retrieved from https://www.epa.gov/npdes-permits/outfall-monitoring-science-advisory-panel#meeting-minutes.

OMSAP. 2003b. US Environmental Protection Agency Region 1. Minutes of Outfall Monitoring Science Advisory Panel 2003 monitoring review workshop #2, June 18-19, 2003, Woods Hole, MA. Retrieved from https://www.epa.gov/npdes-permits/outfall-monitoring-science-advisory-panel#meeting-minutes.

OMSAP. 2003c. US Environmental Protection Agency Region 1. Minutes of Outfall Monitoring Science Advisory Panel 2003 Monitoring review workshop #3, July 24, 2003, Boston, MA Retrieved from https://www.epa.gov/npdes-permits/outfall-monitoring-science-advisory-panel#meeting-minutes.

OMSAP. 2003d. US Environmental Protection Agency Region 1. Draft summary, OMSAP mussel tissue contaminant focus group meeting, Wednesday, March 5, 2003, MADEP Boston. Retrieved from https://www.epa.gov/npdes-permits/outfall-monitoring-science-advisory-panel#meeting-minutes.

OMSAP. 2003e. US Environmental Protection Agency Region 1. [draft] Minutes of Outfall Monitoring Science Advisory Panel 2003 meeting, October 21, 2003, Woods Hole, MA. Retrieved from https://www.epa.gov/npdes-permits/outfall-monitoring-science-advisory-panel#meeting-minutes.

Pala S, Lefkovitz LF, Moore MJ, Schaub E. 2003. 2002 annual fish and shellfish report. Boston: Massachusetts Water Resources Authority. Report 2003-05. 176 p.

Parmenter CM and MH Bothner. 1993. The distribution of *Clostridium perfringens*, a sewage indicator, in sediments of coastal Massachusetts. US Geological Survey Open File Report 93-8.

Rex AC, Tyler C, Wu D, Liang SY. 2008. Summary of floatables observations in Deer Island Treatment Plant effluent and at the Massachusetts Bay discharge site 2000-2007. Boston: Massachusetts Water Resources Authority. Report 2008-08. 20 p.

Schubel JR. 2003. Monitoring of San Francisco Bay: Is the whole less than the sum of the parts? Presentation at the 2003 annual meeting of the regional monitoring program of the San Francisco Estuary Institute. Retrieved from https://www.sfei.org/documents/monitoring-san-francisco-bay-whole-less-sum-parts.

Signell RP, Jenter HL, Blumberg AF. 1996. Circulation and effluent dilution modeling in Massachusetts Bay: Model implementation, verification and results. US Geological Survey Open File Report 96-015, Woods Hole MA.

Taylor DI. 2006. 5 years after transfer of Deer Island flows offshore: an update of water-quality improvements in Boston Harbor. Boston: Massachusetts Water Resources Authority. Report 2006-16. 77 p.

Tucker J, Giblin AE. 2008. Combined work/quality assurance plan for benthic nutrient flux studies: 2008-2009. Boston: Massachusetts Water Resources Authority. Report 2008-06. 61 p.

Tucker J, Kelsey S, Giblin AE. 2009. 2008 Annual benthic nutrient flux monitoring: summary report. Boston: Massachusetts Water Resources Authority. Report 2009-08. 31 p.

Tucker J, Kelsey S, Giblin AE, Hopkinson Jr CS. 2008. 2007 Annual benthic nutrient flux monitoring report. Boston: Massachusetts Water Resources Authority. Report 2008-14. 59 p.

Tucker J, Kelsey S, Giblin AE, Hopkinson CS Jr . 2003. 2002 Annual Benthic Nutrient Flux monitoring report. Boston: Massachusetts Water Resources Authority. Report 2003-08. 52 p.

USEPA. 1988. Boston Harbor wastewater conveyance system. Supplemental Environmental Impact Statement (SEIS). United States Environmental Protection Agency Region I, Boston, MA.

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

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

USGS. 2003. Boston sewage outfall: the fate of sediments and contaminants in Massachusetts Bay. Retrieved from https://www.usgs.gov.

Werme C, Hunt CD. 2008. Outfall monitoring overview BACKGROUND. Boston: Massachusetts Water Resources Authority. Report 2008-18. 54p.

Werme C, Rex AC, Hall M, Keay KE, Leo WS, Mickelson MJ, Hunt CD. 2009. 2008 Outfall monitoring overview. Boston: Massachusetts Water Resources Authority. Report 2009-16. 69 p.

Wu D. 2009. NPDES compliance summary report, fiscal year 2008. Boston: Massachusetts Water Resources Authority. Report 2009-03. 133 p.

# 2004 AMBIENT MONITORING STUDY DESIGN

This appendix includes descriptions of the sampling designs for water column and benthos monitoring 2004 through 2009 to facilitate comparison of the proposed and existing plans.

The complete Ambient Monitoring Plan, Revision 1 can be retrieved from:

http://www.mwra.state.ma.us/harbor/enquad/trlist.html

Citation:

MWRA. 2004. Massachusetts Water Resources Authority effluent outfall ambient monitoring plan Revision 1, March 2004. Boston: Massachusetts Water Resources Authority. Report 2004-ms-92. 65 p.

# 2004 Water Column Monitoring Plan

MWRA monitors the water column in stations near the outfall, and reference stations distant from the outfall.

## Nearfield sampling design

Seven nearfield stations (Figure A-1). *In-situ* parameters, inorganic nutrients and other nutrients are collected at all stations, plankton and rates of productivity are measured at two stations.

**Sampling schedule.** As of 2004, water column monitoring includes 12 nearfield surveys and six farfield surveys (Table A-1).

**Table A-1 Water column survey schedule**

| Month | Target week of year | Survey type |
|---|---|---|
| February | 6 | Nearfield and farfield |
| February | 9 | Nearfield and farfield |
| March | 12 | Nearfield |
| April | 15 | Nearfield and farfield |
| May | 20 | Nearfield |
| June | 25 | Nearfield and farfield |
| July | 30 | Nearfield |
| August | 34 | Nearfield and farfield |
| September | 36 | Nearfield |
| September | 40 | Nearfield |
| October | 43 | Nearfield and farfield |
| November | 46 | Nearfield |

**In-situ parameters.** At each station there will be measurements (Table A-2) using *in-situ* sensors. The *in-situ* sensors attached to the water sampler electronically measure the parameters. As the water sampler descends the sensors provide data at half-meter resolution from surface to within five meters of the bottom at each station. On the ascent the sensors provide data during collection of discrete water samples. An appropriate number of water samples will be also be collected for laboratory analysis of dissolved oxygen and fluorescence sufficient to calibrate the field instruments.

### Table A-2 Nearfield *in-situ sensor* measurements

| Stations | Depths | Parameters |
|---|---|---|
| N01 N04<br>N07 N10<br>N16 N18<br>N20 | Every half-meter | Temperature<br>Salinity<br>Dissolved oxygen<br>Chlorophyll fluorescence<br>Transmissometry<br>Irradiance<br>Depth of sensors |

**Inorganic nutrients.** Water samples are collected at all seven stations for analysis of inorganic nutrients (Table A-3). The samples will be collected at five depths: one surface sample and one bottom sample, with three intermediate depths which may be adjusted to span the chlorophyll maximum or the pycnocline.

### Table A-3 Nearfield inorganic nutrients sampling

| Stations | Depths | Parameters |
|---|---|---|
| N01 N04<br>N07 N10<br>N16 N18<br>N20 | Five | Ammonium<br>Nitrate<br>Nitrite<br>Phosphate<br>Silicate |

**Other nutrients.** At each station, water samples are collected for analysis of additional nutrients (Table A-4). The samples will be collected at three depths: one surface sample and one bottom sample, with one intermediate depth which may be adjusted to capture the chlorophyll maximum or the pycnocline.

### Table A-4 Nearfield sampling for additional nutrients

| Stations | Depths | Parameters |
|---|---|---|
| N01 N04<br>N07 N10<br>N16 N18<br>N20 | Three | Dissolved organic carbon<br>Dissolved nitrogen<br>Dissolved phosphorus<br>Particulate carbon<br>Particulate nitrogen<br>Particulate phosphorus<br>Particulate biogenic silica<br>Total suspended solids |

**Rates and plankton.** At two of the seven stations water samples are collected for analysis of rates and plankton (Table A-5). Primary productivity is measured by 14-carbon uptake rate and respiration is measured as dissolved oxygen uptake rate. At each depth for productivity, water samples are collected for analysis of chlorophyll-*a* by filtration and extraction. Phytoplankton and zooplankton are identification and counted, with particular attention paid to three target nuisance phytoplankton species, *Alexandrium spp, Pseudonitzschia pungens* and *Phaeocystis pouchetii*.

Water samples will be collected at five depths for productivity, three depths for respiration, and two depths for phytoplankton. Zooplankton are caught on a fine net lowered to sample the upper 30m of the water column.

**Table A-5 Nearfield sampling for rates and plankton**

| Stations | Depths | Parameters |
|---|---|---|
| N04<br>N18 | Varies | Primary productivity Respiration<br>Phytoplankton<br>Zooplankton |

## Farfield sampling design

The particular methods used on the farfield survey are identical to those used on the nearfield survey, and are summarized below for convenience in Tables A-6 through A-8. There are 25 farfield stations (Figure A-1), but not all stations are sampled for all parameters.

**Table A-6 Farfield in-situ sensor measurements**

| Stations | Depths | Parameters |
|---|---|---|
| F01 F02 F03<br>F05 F06 F07<br>F10 F12 F13 F14<br>F15 F16 F17 F18<br>F19 F22 F23 F24<br>F25 F26 F27<br>F28 F29 F30 F31 | Every half-meter | Temperature<br>Salinity<br>Dissolved oxygen<br>Chlorophyll fluorescence<br>Transmissometry<br>Irradiance<br>Depth of sensors |

An appropriate number of water samples will be also be collected for laboratory analysis of dissolved oxygen and fluorescence sufficient to calibrate the field instruments.

**Table A-7 Farfield inorganic nutrients**

| Stations | Depths | Parameters |
|---|---|---|
| F01 F02 F03<br>F05 F06 F07<br>F10 F12 F13<br>F14 F15 F16<br>F17 F18 F19<br>F22 F23 F24<br>F25 F26 F27<br>F28 F29 | Five | Ammonium<br>Nitrate<br>Nitrite<br>Phosphate<br>Silicate |
| F30 F31 | Three | |

The samples will be collected at five depths except that three depths suffice at the shallow stations F30 and F31 in Boston Harbor.

**Table A-8 Farfield nutrients, plankton and rates**

| Stations | Depths | Parameters |
|---|---|---|
| F01 F02 F06<br>F13 F23 F24<br>F25 F27 F30<br>F31 | Variable | Dissolved organic carbon<br>Dissolved nitrogen<br>Dissolved phosphorus<br>Particulate carbon<br>Particulate nitrogen<br>Particulate phosphorus<br>Particulate biogenic silica<br>Total suspended solids<br>Phytoplankton<br>Zooplankton |
| F23 | Five<br>Three | Primary productivity<br>Respiration |
| F19 | Three | Respiration |

Nutrients and plankton are collected at 10 stations. Water samples are collected at three depths for nutrients and two depths for phytoplankton. Zooplankton are caught on a fine net lowered to sample the upper 30m of the water column. Water samples will be collected at five depths for productivity and three depths for respiration.

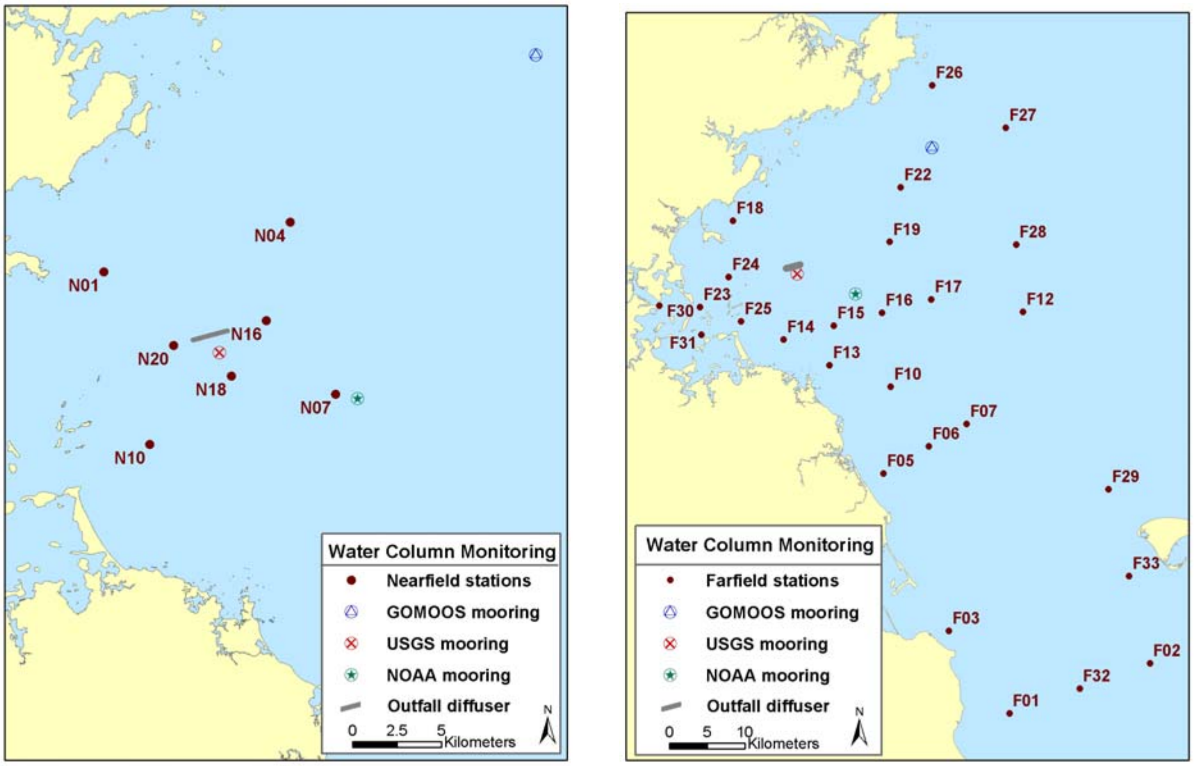

**Figure A-1 Nearfield monitoring stations and farfield monitoring stations 2004 plan**

## Special studies

### Other nutrients to aid modeling.

During farfield surveys, additional water samples are collected at F19, F22 and F26, northeast of the outfall, for analysis of

- dissolved organic carbon, nitrogen, and phosphorus.
- particulate carbon, nitrogen, phosphorus, and biogenic silica.
- total suspended solids.

These data help model the water quality as it enters Massachusetts Bay from the Gulf of Maine. Addition of these stations in 2000 was recommended by the Bays Eutrophication Model Evaluation Group to improve model boundary conditions and to examine the Gulf of Maine's influence on the nearfield.

### Plankton measurements to put local blooms in regional context.

During farfield surveys since spring 2000, additional water samples are collected at stations F22 and F26, northeast of the outfall, for analysis of phytoplankton and zooplankton identification and enumeration.

### Special zooplankton study in Cape Cod Bay.

During the first three farfield surveys of each year, since 1998, an extra zooplankton tow and in-situ measurements are made halfway between stations F01 and F02, and F02 and F29 for analysis of

- temperature, salinity, dissolved oxygen, chlorophyll fluorescence, transmissometry, irradiance and the depth of the sensors.
- zooplankton identification and enumeration.

### Additional nearfield nutrients and plankton.

During weeks where nearfield and farfield sampling both occur, sometimes the farfield and nearfield stations are sampled several days apart. In these cases, data are also collected at nearfield station N16 during the farfield survey to study short term chemistry variability and to provide supplementary synoptic plankton data. The following measurements are made:

- temperature, salinity, dissolved oxygen, chlorophyll fluorescence, transmissometry, irradiance, and the depth of the sensors.
- ammonium, nitrate, nitrite, phosphate, and silicate.
- dissolved organic carbon, nitrogen, and phosphorus.
- particulate carbon, nitrogen, phosphorus, and biogenic silica. (since 1995)
- total suspended solids.
- phytoplankton and zooplankton identification and enumeration.

### Water circulation and particle fate.

The USGS mooring near the outfall diffuser (Figure 3-4) provides continuous monitoring of currents, salinity, temperature, chlorophyll, and turbidity, and periodic measurement of sedimentation rate. USGS uses the data to improve their capability to predict the fate of contaminants associated with fine-grained sediments on a regional basis (USGS 2003). MWRA uses the data to track effluent particles, interpret monitoring observations and for model calibration. This study will continue through 2005.

### Continuous measurement of biological parameters.

As recommended by OMSAP (October 21, 2003), MWRA plans to hold a workshop on May 19, 2004 to discuss the goals, issues, technologies, and costs of augmenting its ambient monitoring with continuous water quality monitoring and additional use of satellite data. Some suggested goals include detecting events that should be sampled, and providing coverage between scheduled surveys to compensate for fewer scheduled surveys. Following the workshop, OMSAP may recommend further evaluation, or may recommend implementation of specific technology (for example adding chlorophyll sensors to the existing GoMOOS mooring off Cape Ann, or providing USGS mooring data in real-time). Some recommendations could be implemented later in 2004.

### Remote Sensing.

Remote sensing via satellite imagery offers the opportunity to evaluate spatial variations in the system, and to provide information on changes within the system that occur between monitoring surveys. Parameters available from satellite imagery include sea surface temperature and chlorophyll. The monitoring program accesses this imagery and uses it in the synthesis of water column monitoring results and interpreting unusual events, for example the major chlorophyll bloom of Fall 2000 shows in the imagery as a broad regional event (the cause is unknown but the extent was too broad to be caused by the outfall). MWRA intends to use remote sensing data provided they continue to be readily available.

### Modeling.

The BEM is being used to see whether dissolved oxygen conditions in 1992 to 1995 and 1998-present can be reproduced. The model aims to help establish cause and effect relations between nutrients, plankton growth and the subsequent impact on dissolved oxygen.

### Floatables.

To address concerns raised about anthropogenic debris possibly associated with the discharge, two floating debris tows are carried out on all nearfield surveys. The first tow is conducted in the northwestern corner of the nearfield in the vicinity of station N01 (Figure A-1), while the second is conducted across the outfall alignment near its midpoint, or through a surfacing plume if one is observed.

#### Marine Mammal Observations.

All MWRA monitoring activities are conducted in compliance with state and federal guidelines for vessel operations in areas where endangered right whales might be present. In addition, at the request of NMFS, trained marine mammal observers participate in all nearfield water column surveys and in all farfield surveys carried out in February-June each year (when right whales commonly visit Cape Cod Bay). All marine mammal observations are logged and summarized in an annual report.

# 2004 Benthic Monitoring Plan

## Soft-bottom benthos in the nearfield and farfield

### Biology

Measurement: Benthic species composition and abundance from 0.04 $m^2$ grab samples as retained on 0.3 mm sieves.

Location: 23 nearfield and eight farfield stations (Figures B-1 and B-2). Nearfield[13] stations NF12 and NF17 will be sampled annually. Remaining stations nearfield and farfield station groups (see Table B-1). Stations were randomly split into 2 subsets to be sampled in alternate years[14], so that all stations are sampled every two years.

Frequency: One sampling per year in August, alternating station groups, replication and timing as shown in Table B-1.

**Table B-1 Benthic station sampling and replication**

| Station group name | Stations | Year sampled | Replication: biology | Replication: chemistry | Replication: TOC/grain size |
|---|---|---|---|---|---|
| Core (2 stations) | NF12, NF17 | 2004, 2005 | 3 | 2 | 2 |
| 2004 replicated nearfield (2 stations) | FF10, FF13 | 2004 | 3 | 0 | 2 |
| 2004 unreplicated nearfield (9 stations) | NF05, NF07, NF08, NF09, NF16, NF18, NF19, NF22, NF23 | 2004 | 1 | 0 | 1 |
| 2004 farfield (4 stations) | FF04, FF05, FF07, FF09 | 2004 | 3 | 0 | 2 |
| 2005 replicated nearfield (2 stations) | FF12, NF24 | 2005 | 3 | 2 | 2 |
| 2005 unreplicated nearfield (8 stations) | NF02, NF04, NF10, NF13, NF14, NF15, NF20, NF21 | 2005 | 1 | 1 | 1 |
| 2005 farfield (4 stations) | FF01A, FF06, FF11, FF14 | 2005 | 3 | 2 | 2 |

---

[13] The nearfield for benthic monitoring is defined as the area within 8 km around the outfall in which changes are most likely to occur. Stations FF10, FF12, and FF13 were originally considered farfield stations but were later reclassified as nearfield stations based on analysis of baseline data.

[14] Stations were binned by region and level of replication before the random selection.

## Biology continued

Measurements: Sediment profile images for measurement of RPD depth, and other physical and biological parameters.

Location: Twenty-three stations in the nearfield (NF02, NF04, NF05, NF07, NF08, NF09, NF10, NF12, NF13, NF14, NF15, NF16, NF17, NF18, NF19, NF20, NF21, NF22, NF23, NF24, FF10, FF12, FF13).

Frequency: One sampling per year in August.

## Chemistry

Measurements: Chemical constituents including PAHs, PCBs, pesticides, metals.

Location: Twelve or thirteen stations in the nearfield, four stations in the farfield (depending on year, see Table B-1).

Frequency: One sampling per year in August for all parameters at stations NF12 and NF17. Sampling every 3 years at all stations sampled for infauna; next sampling scheduled for 2005. (See Table B-1 and Figures B-1 and B-2).

## Sediment characteristics/tracers

Measurements: TOC, sediment grain size, *Clostridium perfringens* spore counts in the 0-2 cm depth fraction.

Location: Twelve or thirteen stations in the nearfield, four stations in the farfield (depending on year, see Table B-1).

Frequency: One sampling per year in August at twelve or thirteen stations in the nearfield, four stations in the farfield (depending on year, see Table B-1).

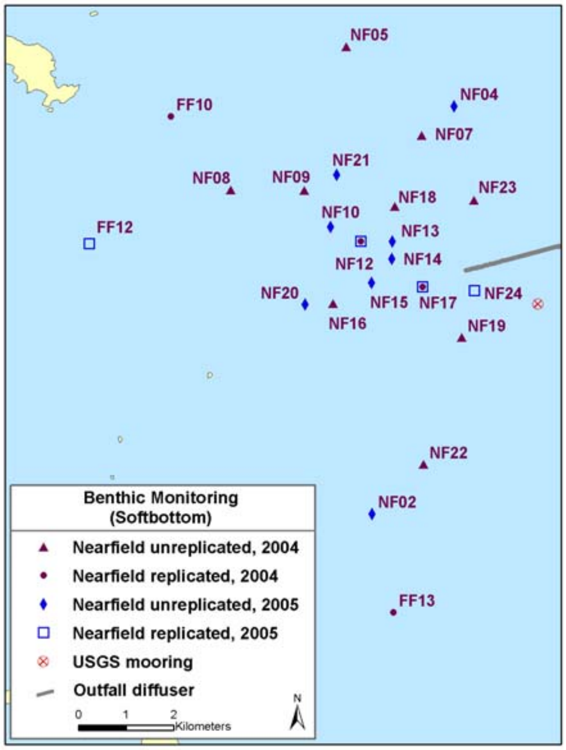

Figure B-1 Locations of nearfield  soft-bottom stations.

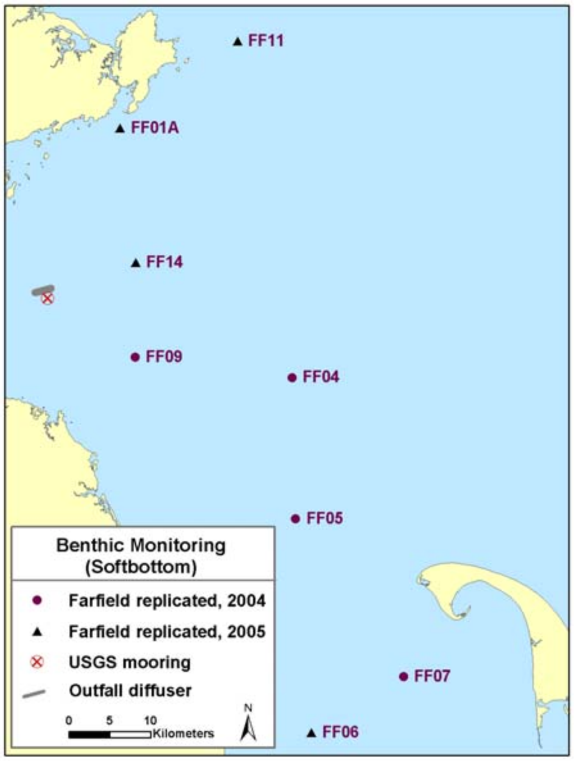

Figure B-2 Locations of farfield soft-bottom stations

## Special study of hard-bottom benthos in the nearfield

| | |
|---|---|
| Measurements: | Benthic hard-bottom species composition as determined by 35-mm photography and video analysis; topography and sediment cover. |
| Location: | 23 stations along drumlins and other rocky features in the vicinity of the outfall to a distance of 3.2 km north and 5 km south, plus a station east of Scituate in the vicinity of 42$^{o}$ 14.5'N, 70$^{o}$ 33.0'W. |
| Frequency: | One sampling per year (June to August timeframe). |

Through 2002 the hard-bottom study included two other stations (T4-1 and T4-3); analysis of the data indicated that these two sites were of only marginal benefit to the study. They were therefore dropped in favor of two new stations, first occupied in June 2003 to expand the spatial coverage to a greater distance from the outfall. The Scituate site was occupied in 1999 for a different (non-MWRA) project that will provide baseline information; it is more than twice as distant from the discharge as any used in 1995-2002. The second new site is 4-5 kilometers south of the outfall, further than other hard-bottom stations in the vicinity of the outfall. They are at depths and in substrates similar to other stations in the study.

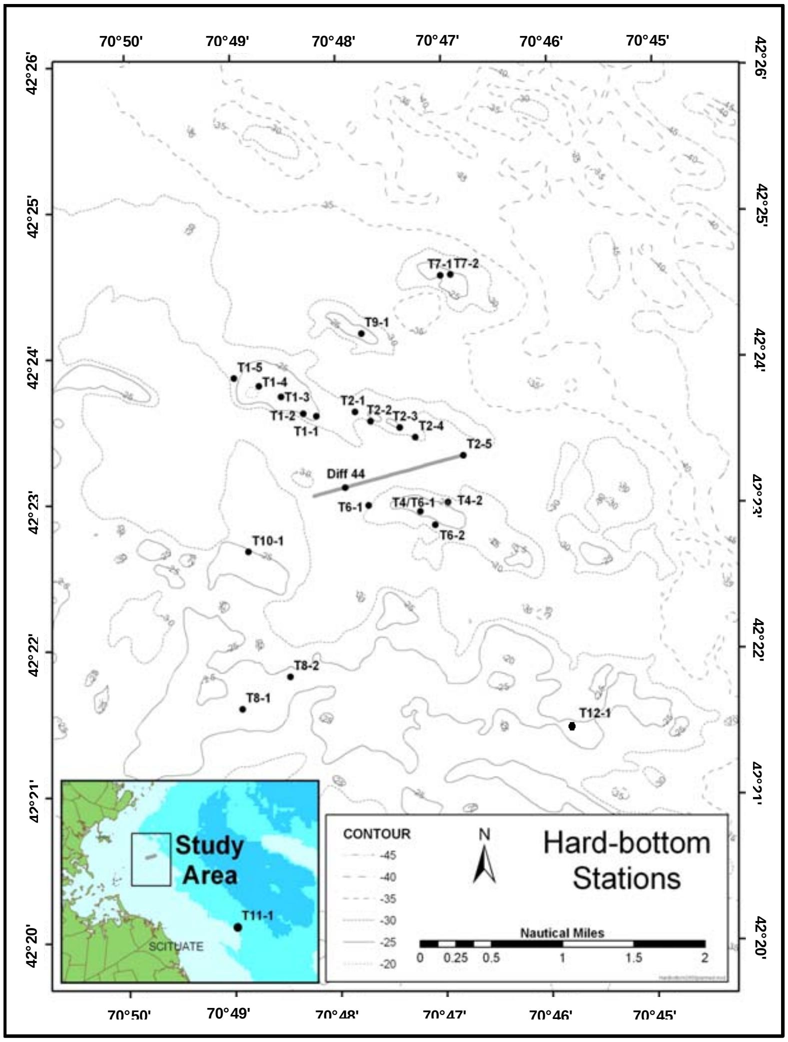

Figure B-3 Hard-bottom stations.

## Special studies of benthic nutrient flux

Benthic flux measurements have provided important information on bounds of the sediment denitrification rate, as well as the contribution of sediment oxygen demand to overall bottom water dissolved oxygen depletion rates.

| | |
|---|---|
| Measurements: | Temperature, salinity and dissolved oxygen of the bottom water at each station when surveyed. Two cores per station will be incubated and measured for ammonia, nitrate + nitrite, phosphate, silica, and dissolved oxygen in the overlying water of those two cores per station every 2-8 hours. Total carbon dioxide will be measured at the beginning and end of the incubation. In addition, undisturbed sediment cores will be obtained from each station and measured for profiles of porewater pH, alkalinity and redox potential in at least 10 depths per station. Surficial sediments from each station will also be analyzed for total organic carbon, total nitrogen and grain size. |
| Location: | See Figure B-4 for location of benthic flux sampling locations. |
| Frequency: | Four surveys each year during May, July, August, and October. |

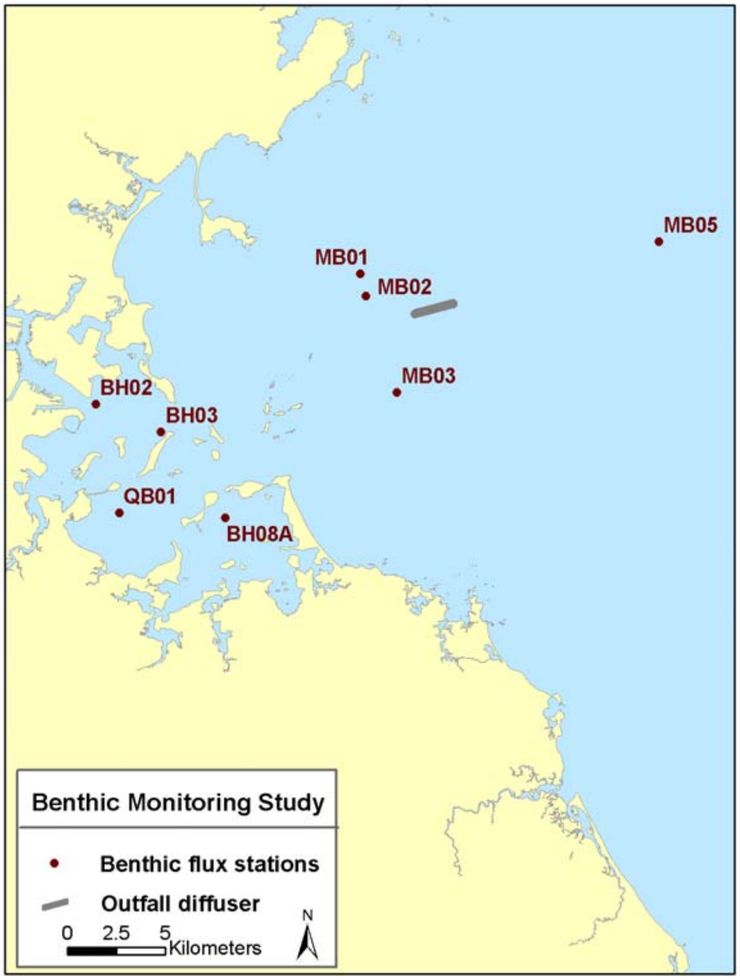

Figure B-4 Benthic nutrient flux stations.

### Special studies of sediment transport

The USGS has been researching the transport of sediments and associated contaminants in Massachusetts Bay, in cooperation with the MWRA, since 1989. Since 1989 USGS has taken sediment cores three times a year from two stations, one sandy (NF17) and one muddy (NF12), near the Massachusetts Bay outfall (USGS 1997b; Figure 4-4). The study also uses a mooring in the nearfield (Figure 4-4) to collect hydrographic data and samples of suspended matter that deposits in sediment traps. Suspended matter samples are analyzed for metals, grain size, TOC, and effluent tracers. These sediment trap samples have proven to be one of the most sensitive measures of possible outfall influence on sediments, detecting a signal not seen in bulk seafloor sediments.

Both silver and *C. perfringens* in sediment trap samples from the first several months of outfall discharge showed significant increases over concentrations observed in the first 8 months of 2000, prior to outfall relocation. Both tracers were significantly elevated compared to levels observed at the site when DITP was discharging secondary-treated effluent to Boston Harbor. However, concentrations of both silver and *C. perfringens* in the sediment traps were within the range observed there prior to 1998, when DITP was discharging primary-treated effluent into Boston Harbor; those tracers were transported to the outfall site (MWRA 2003a, Bothner *et al.* 2002). Thus, for these particle-borne effluent tracers, the local effect of transferring the discharge from Boston Harbor to Massachusetts Bay is mitigated by the additional removal of solids and contaminants accomplished by secondary treatment.

As recommended by OMSAP (OMSAP 2003a) MWRA and USGS will continue the measurements made under this special study through 2005, and review the results after the 2005 field season to determine whether additional work is needed.

## 2004 Fish and Shellfish

The fish and shellfish monitoring plan in the proposed revision is unchanged from the existing plan. See pages 59-68.

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