Ambient Monitoring Plan for the Massachusetts Water Resources Authority Effluent Outfall
Revision 1
November 2003

Massachusetts Water Resources Authority

Environmental Quality Department
ENQUAD Report ms-087

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November 14, 2003

Mr. Glenn Haas, Director
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Department of Environmental Protection
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Boston, MA 02108

Ms. Linda Murphy, Director
Office of Ecosystem Protection
U.S. Environmental Protection Agency
Water Technical Unit "SEW"
P.O. Box 8127
Boston, MA 02114

Re: Massachusetts Water Resources Authority, Permit Number MA0103284
Submission Pursuant to Part I.7.c. Ambient Monitoring Plan modifications

Dear Mr. Haas and Ms. Murphy:

Pursuant to Section 1.7.c. of its National Pollutant Discharge Elimination System permit, the Massachusetts Water Resources Authority ("MWRA") hereby submits a list of proposed modifications to its Effluent Outfall Ambient Monitoring Plan.[1] The proposed changes are incorporated into the *Massachusetts Water Resources Authority Effluent Outfall Ambient Monitoring Plan Revision 1, November 2003*, which is attached for your review and approval. MWRA has submitted notice of these requested changes in the Environmental Monitor.

Modifications to the 1997 Effluent Outfall Ambient Monitoring Plan[2] were developed during public workshops held by the Outfall Monitoring Science Advisory Panel ("OMSAP") during the spring and summer of 2003.[3,4,5] This process entailed an extensive scientific review of MWRA's monitoring results to date, and the scientific rationales for the proposed changes. The changes are based on analyses of more than a decade of monitoring data. All the proposed changes have been reviewed and unanimously recommended by OMSAP. The monitoring plan revisions reflect the fact that some questions have been answered, or have been answered in terms of immediate effects of the outfall. The focus of the monitoring program should now appropriately shift to monitoring for longer-term changes.

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[1] Section I.7.c. of MWRA's NPDES permit states: "The monitoring plan described in Attachment N may be modified as follows: i. By November 15 of each year the permittee shall submit a list of any proposed modifications to the monitoring plan, including any interim modifications which have become effective pursuant to paragraph I.7.c.iii below, to EPA, MADEP, and the public (See: Part I.20.e. of this permit), and shall publish the list in the Environmental Monitor for the purpose of soliciting public comment. These modifications shall become effective upon approval by EPA and the MADEP."

[2] 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 (Attachment N to permit).

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

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

[5] MWRA. 2003. *Briefing for OMSAP workshop on ambient monitoring revisions, July 24, 2003*. Boston: Massachusetts Water Resources Authority. Report ms-086. 64 p.

The clarifications, updates, and changes from the 1997 plan that are included in the attached *Effluent Outfall Ambient Monitoring Plan Revision 1* are summarized below.

I. Clarifications

The *Effluent Outfall Ambient Monitoring Plan Revision 1* lists the monitoring questions that guided the study design of the 1991 monitoring plan. Details of specific Contingency Plan[6] thresholds are removed, so that if the Contingency Plan is revised, as it was in 2001, the Ambient Monitoring Plan will not become out-of-date. As in the 1997 monitoring plan, some parts of the monitoring are "special studies" which focus on emerging issues, use developing or non-standard methods, and are designed to be completed in a definite time-frame.

II. Updates

The results sections summarizing monitoring findings have been updated. Completed studies (e.g. plume tracking) have been removed from the plan. The list of special studies has been updated, (e.g. additional sites for water column monitoring, effluent floatables measurements, effluent pathogens, etc.). The "Data Evaluation" sections have been updated; descriptions of methods and timetables for comparison to thresholds are no longer included because they are in the Contingency Plan and NPDES permit.

III. Changes to monitoring activities

Page numbers refer to the relevant pages in the *Effluent Outfall Ambient Monitoring Plan Revision 1*("AMP"), or in one of the three 2003 OMSAP workshop briefings referenced previously: March-April ("ms-083")[3], June ("ms-085")[4], or July ("ms-086").[5]

A. Changes already formally requested in 2002, and approved in 2003:

1. Delete total coliform measurements from effluent monitoring.

2. Delete urea measurements from water column monitoring.

B. Changes recommended by OMSAP and approved by USEPA and MADEP on an interim basis in 2003:[7]

1. Shift the location of two stations for hard-bottom monitoring (AMP p. 39-40). *Rationale*: The new stations expand the spatial coverage to a greater distance from the outfall (ms-083 p. V-8—V-10).

2. Change the sampling schedule for comprehensive sediment contaminant monitoring from every year to every third year, with two stations being sampled every year (p. 35-38) *Rationale*: MWRA found no increases in contaminants or reducing conditions in sediments in 2001 or 2002. Change in sediment quality is occurring slowly if at all, making a reduced sampling frequency appropriate (ms-083 p. IV-15—IV-18.) Monitoring of MWRA effluent for contaminants will continue.

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[6] MWRA. 2001. *Massachusetts Water Resources Authority Contingency Plan Revision 1*. Boston: Massachusetts Water Resources Authority. Report ms-071. 47 p.
[7] July 31, 2003 correspondence from Linda Murphy, USEPA and Glenn Haas, MADEP approving interim revisions to hard bottom community and sediment contaminant monitoring.

C. Additional changes recommended by OMSAP in 2003:

1. Reduce the number of water column nearfield stations sampled from 21 to 7 and the number of nearfield surveys carried out annually from 17 to 12 (AMP p. 20-22). *Rationale*: Statistical analysis showed high levels of spatial redundancy and moderate temporal redundancy in nearfield data. Therefore, the proposed reductions have relatively little effect on the ability of the proposed reductions to measure change (ms-085 p.7-1—7-53). The 12 surveys are scheduled to characterize key events in Massachusetts Bay.

2. Add a special study to evaluate the feasibility of using instrumented moorings near the outfall to provide continuous real-time monitoring for phytoplankton blooms (AMP p. 27). *Rationale*: If feasible, instrumentation may in the future provide better temporal coverage at a reasonable cost than shipboard sampling.

3. Reduce the number of soft-bottom community monitoring stations sampled annually, so that half the stations are sampled in alternate years (AMP p. 35-38). *Rationale*: Statistical analyses showed the previous sampling design could detect a potential outfall impact of as little as a 5% change in average abundance or diversity, but no significant change due to the outfall was detected. Also, the rates of change in benthic species and their patterns of relative abundance were slow. Thus, the level of sampling in both the nearfield and the farfield could be reduced without affecting the monitoring's integrity (ms-086 p. 3-1—3-30).

4. Drop measurements of urea fluxes and porewater profiles from the benthic nutrient flux special study (AMP p. 41). *Rationale*: Urea fluxes have proven to be not useful as a measure of nitrogen flux from the sediments in Boston Harbor, Massachusetts Bay, or Stellwagen Basin. Other monitoring measurements (e.g. redox profiles and nutrient fluxes) provide much of the same information as porewater profiles (ms-086 p. 2-1—2-13).

5. Reduce frequency of sampling for fish and shellfish contaminants from every year to every three years, and delete one flounder sampling station (AMP p. 46-48). *Rationale:* There have been no short-term changes in contaminant body burdens in lobster or flounder. Except for chlordane and PAHs, mussel contaminant levels have not changed. Thus a shift to less frequent monitoring for tissue contaminants is appropriate. Dropping the Broad Sound reference station will not compromise the ability to interpret flounder data. (ms-083 p. III-1—III-15.) Annual monitoring for flounder histopathology will continue.

6. Add a special flounder study (AMP p. 49). *Rationale*: At its October, 2003 meeting, OMSAP recommended that MWRA continue its special study of flounder investigating recent observations of an apparent increased prevalence of blind side flounder lesions in Boston Harbor and Massachusetts Bay (including Broad Sound), coordinating with other agencies.

MWRA believes that these changes to the monitoring represent a major improvement; the monitoring will make more efficient use of public resources while maintaining the ability to track impacts of the outfall should they occur. Additional special studies reflect emerging issues and new technologies.

The review and revision of this large, technically complex, and important monitoring program required substantial effort from many people. MWRA would like to thank staff from the many state and federal regulatory agencies, members of OMSAP, and the public who actively participated in this review process. All participants focused on ensuring that the monitoring and the changes are based on the best science possible. Their comments and feedback substantively improved this monitoring plan.

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

Sincerely,

Michael J. Hornbrook
Chief Operating Officer

Attachment:
Massachusetts Water Resources Authority effluent outfall ambient monitoring plan Revision 1, November 2003. Boston: Massachusetts Water Resources Authority. Report ms-087. 52 p.

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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 its subcommittees (as of June 2003):

Andrew Solow (chair)	Woods Hole Oceanographic Institution
Robert Beardsley	Woods Hole Oceanographic Institution
Norbert Jaworski	Retired
Robert Kenney	University of Rhode Island
Scott Nixon	University of Rhode Island
Judy Pederson	Massachusetts Institute of Technology
Michael Shiaris	University of Massachusetts, Boston
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Public Interest Advisory Committee is advisory to OMSAP

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Center for Coastal Studies	Peter Borrelli
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FOREWORD

Genesis of the plan

When the 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 (EOEA). 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). 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 (USGS) -MWRA study of sediment transport, and the benthic nutrient flux study.

The monitoring program was quite comprehensive because of concern about the effects of a primary treated discharge on dissolved oxygen, organic loading to the sea floor, 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 before offshore discharge started. Also, measured toxic contaminant concentrations in actual secondary effluent are lower than the imprecise estimates assumed in outfall siting studies (USEPA 1988).

Evolution of the monitoring plan

The transfer of outfall discharge into Massachusetts Bay was planned for 1995 but was delayed until September 2000. This allowed collection of over nine years of baseline data, from February 1992 to August 2000, rather than the minimum three years required by regulators. The post-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 (MWRA 1997) by reference as Attachment N.

Starting in mid-2002, MWRA and the Outfall Monitoring Science Advisory Panel (OMSAP) embarked on a process to revise the Ambient Monitoring Plan as recommended by the National Research Council (NRC 1990). There are now more than two years of post-discharge monitoring to compare with baseline conditions; monitoring results to date document minimal environmental effect. Thus, MWRA has refocused the monitoring program on the potential for long-term chronic effects. Ongoing effluent monitoring remains the core of the monitoring program.

Earlier versions of the plan are available at MWRA in Charlestown, Massachusetts or by request from MWRA. The 1997 plan is also available on the MWRA web site (www.mwra.com) and at a repository library on Cape Cod as required by the NPDES permit.

Changes from 1997 Ambient Monitoring Plan

Changes to the plan were developed during workshops held by OMSAP during the spring and summer of 2003 (OMSAP 2003a, b, c). The monitoring plan revisions reflect the fact that some questions have been answered, or have been answered in terms of immediate effects of the outfall. The focus of the monitoring program now appropriately shifts to monitoring for longer-term changes. The updates and changes from the 1997 plan in this revision are summarized below.

Clarification of the monitoring plan

- The introduction has been updated and somewhat shortened, and this foreword added to describe the evolution of the monitoring plan.
- The plan lists the monitoring questions that guided the study design of the 1991 monitoring plan. OMSAP (2002) reviewed the monitoring questions as the first stage of the review of the monitoring plan.
- Details of specific Contingency Plan (MWRA 2001) thresholds have been removed, so that if the Contingency Plan is revised, as it was in 2001, the Ambient Monitoring Plan will not become out-of-date.
- The effluent section has been clarified to distinguish between requirements from the NPDES permit, the Contingency Plan, and special studies.
- As in the 1997 monitoring plan, some parts of the monitoring are labeled “special studies.” These studies are intended to be the most flexible part of the monitoring program. MWRA evaluates designs and proposals for special studies as scientific and environmental issues arise, and often will co-fund special studies with other funding agencies. These studies differ from ongoing, “routine” monitoring in that they focus on emerging issues, use developing or non-standard methods, and are designed to be completed in a definite time-frame.

Updates to the monitoring plan

- The results sections have been updated. Only a brief summary of observed pre- versus post-diversion differences is given. A more complete description of results to date is given in briefing documents prepared for the OMSAP workshops (MWRA 2003a, b, c) and in synthesis reports in the various study areas (e.g. Darling and Wu 2001; Tucker et al. 2002, 2003; Hunt et al. 2002b, c; Kropp et al. 2002; Lefkowitz et al. 2002b; Libby et al. 2002b, 2003; Maciolek et al. 2003; Pala et al. 2003; Wu and Paleti 2003).
- The "Data Evaluation" sections have been updated. Descriptions of methods and timetables for comparison to thresholds are no longer included because they are covered in the Contingency Plan (MWRA 2001) and NPDES permit, respectively. Instead, these sections give examples of analyses that will be used to answer monitoring questions, or information that would be useful in future refinement of the monitoring program.
- Completed studies have been removed from the plan, e.g. plume tracking. 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 to 2003.

Changes to monitoring activities

This revised Ambient Monitoring Plan incorporates changes recommended by OMSAP (OMSAP 2003 a,b,c) after discussion at the 2002-2003 workshops.

- Effluent – In 2002, MWRA requested a change in effluent monitoring to delete total coliform measurements; this was approved by USEPA and DEP.
- Water column – reduce number of nearfield stations sampled from 21 to 7 and the number of nearfield surveys carried out annually from 17 to 12. Delete measurement of urea.
- Moorings – MWRA will evaluate the feasibility of augmenting the existing instrumented moorings near the outfall, among other mooring locations and technologies, to provide continuous real-time monitoring for phytoplankton blooms. The feasibility of posting the data on the internet in real time to show the condition of the bay between surveys will also be evaluated.
- Benthic – reduce the number of soft-bottom community monitoring stations sampled annually; better integrate ongoing sediment chemistry studies; sample most stations for the full suite of contaminants every third year; drop highly variable hard-bottom monitoring stations and add a reference station; drop some measurements from benthic nutrient flux special study.
- Fish and shellfish – reduce frequency of sampling and delete one flounder sampling station.

Contents

Tables and Figures

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 on September 6, 2000. The outfall is located in Massachusetts Bay approximately 15 km from the 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 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		Baseline (Phase I) monitoring initiated.
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.	NPDES permit issued in August incorporates Ambient Monitoring Plan and Contingency Plan by reference. 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.
2003		Review of Ambient Monitoring Plan, MWRA proposes revisions.

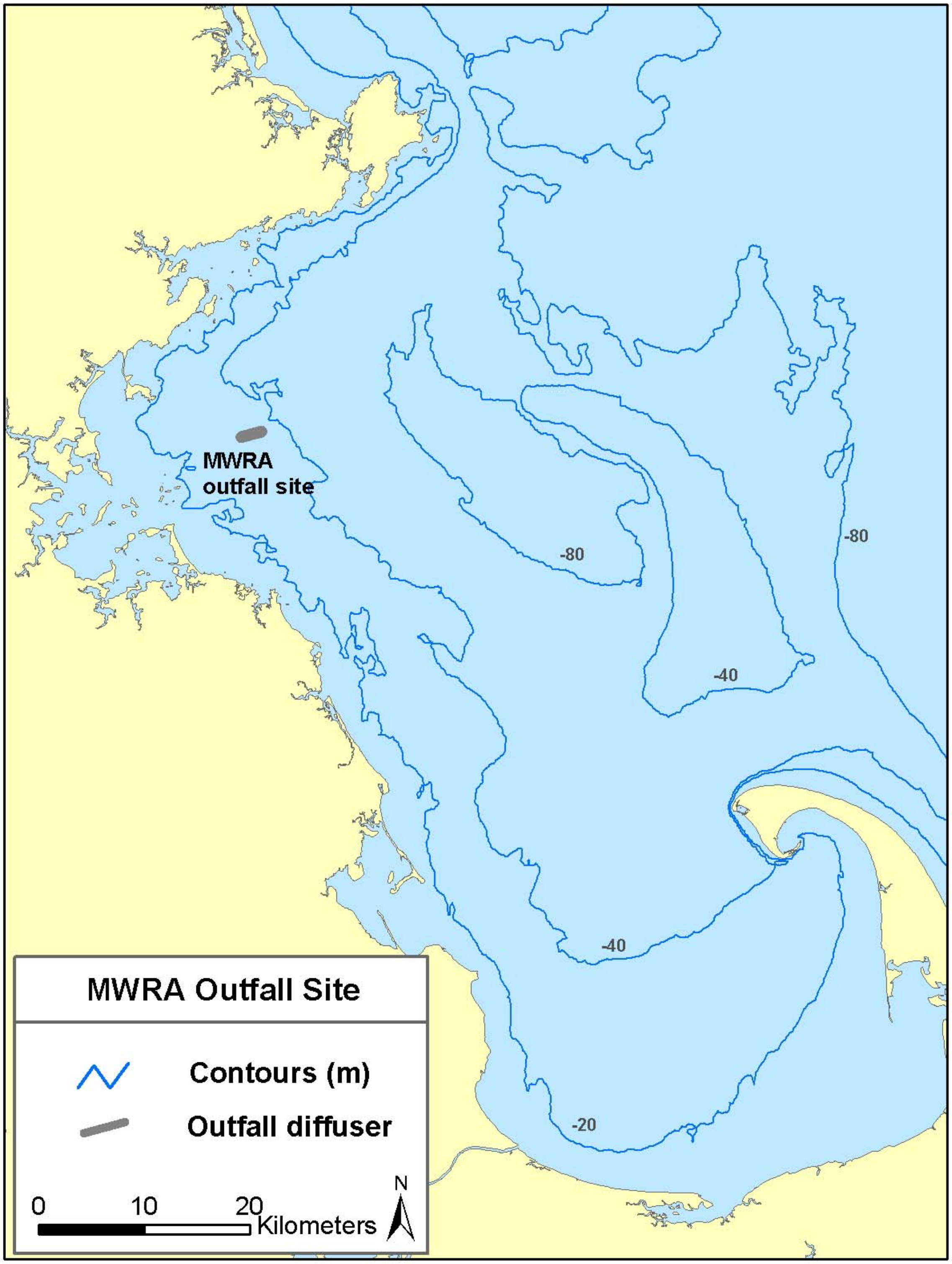

Figure 1-1 Map of Massachusetts and Cape Cod bays showing MWRA outfall location 9.5 miles from Deer Island in 30 meters of water.

MWRA is required to monitor for environmental impacts of the new outfall. 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.

The major emphasis in the ambient monitoring is on the vicinity of the new outfall, with additional effort in Cape Cod and Massachusetts Bay. Improvements in Boston Harbor are also monitored by MWRA but that monitoring is not covered by this plan. A companion document to this monitoring plan, the Contingency Plan (MWRA 2001) describes the response to exceedances of threshold values. 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.

Over time, 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 is examining transport of sediments and contaminants from the outfall in Massachusetts Bay. MWRA also participates in opportunities for regional monitoring such as the Gulf of Maine Ocean Observing System (GoMOOS 2003), and uses satellite imagery from the Sea-viewing Wide-Field-of-View Sensor Project (NASA 2003) to understand large-scale patterns in the ocean.

Results of monitoring are described in several technical reports and in an annual Outfall Monitoring Overview (e.g. Werme and Hunt 2002). Details of the field and analytical program are provided in a series of Combined Work/Quality Assurance Project Plans (e.g. Lefkovitz et al. 2002a, Libby et al. 2002a, Williams et al. 2002).

1.2 Monitoring objectives

The primary objectives of the Monitoring Plan are as follows:

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

MWRA has 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 for 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 within the 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:

- Purpose of the monitoring (environmental concerns)
- Monitoring questions and brief summary of results
- Monitoring plan
- Data evaluation

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. The studies described in the monitoring plan are more extensive than those necessary to just calculate the Contingency Plan threshold values. This is because there is extensive interaction among water quality and ecological parameters and natural variability in a complex environmental system such as Massachusetts Bay. The additional information collected is necessary to gain a more complete understanding of the system, and provide data to explain changes in the system, and whether MWRA’s discharge contributed to the change.

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 2002).

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. Solids discharges from MWRA sources, including Deer Island and Nut Island treatment plants and sludge, have decreased by 80% since the beginning of the Boston Harbor project. The effluent consistently meets permit limits for solids and organic material in both wet and dry conditions.

Results of the extensive monitoring required in MWRA's stringent discharge permit, and the additional 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 (MWRA 2003a).

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, floatables, and oil and grease.

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 28 months of discharge through the Massachusetts Bay outfall is given in MWRA (2003b).

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?

Permit discharge monitoring results

The treatment plant reliably meets its permit requirements. From the time that the permit became effective in August 2000 through mid-2003, there have been only a few violations of permit limits: one violation of the residual chlorine limit and one of the fecal coliform limit, two toxicity violations, and a high total suspended solids event that resulted in two weekly and one monthly violation.

Contingency Plan results

None of the Contingency Plan (MWRA 2001) thresholds for overall plant performance, total nitrogen load, or oil and grease has been exceeded. A threshold for floatables is under development and will be incorporated in the Contingency Plan following approval.

Special studies

Detailed effluent characterization of toxic contaminants. Because priority pollutant concentrations in Deer Island effluent are very low, MWRA must use methods that are more sensitive than those used for permit discharge monitoring to quantify them. Even with these methods, the majority of priority pollutant parameters were below detection levels; those that were detected had low concentrations. The maximum and average values measured for all metals except copper, meet marine receiving water quality criteria in effluent *before dilution*. The water quality criteria apply *after* initial dilution (MWRA 2003b, Wu and Paleti 2003). Detected organic contaminants from August 2000 through the most recent data (June 2003) were at low concentrations, and none of these contaminants would exceed any applicable marine water quality criteria after dilution (MWRA 2003b, Wu and Paleti 2003).

Nutrients. Annual average loadings of total nitrogen (TN) in effluent have shown no trend for the period 1996 through 2002. During the same period, average loadings of the dissolved inorganic nitrogen (DIN) fraction, largely as ammonium, have shown a small increase, as a result of the upgrade to secondary treatment.

Pathogens and indicators. Massachusetts water quality standards use fecal coliform bacteria counts as the indicator of the risk from human pathogens. To evaluate other indicators of human pathogens, MWRA and virologists at the University of New Hampshire have conducted studies of viral pathogens and pathogen indicators in DITP influent and effluent. The data suggest that viral pathogens are reduced by treatment, although not in the same way as the indicator bacteria. Furthermore, phages are not a better indicator of the presence of pathogenic viruses than are indicator bacteria (MWRA 2003b).

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.

NPDES Permit discharge monitoring requirements

Table 2-1 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 2-1 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		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	Report	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

Monitoring in support of the Contingency Plan

All of the permit limits are echoed in the Contingency Plan (MWRA 2001) as Warning Level thresholds. Additional monitoring is done for two Contingency Plan parameters (Table 2-2).

Table 2-2 Effluent sampling for special Contingency Plan parameters

Parameter	Sample Type	Frequency
Oil and grease	Grab	Weekly
Floatables	Continous	Under development

Special studies

Tables 2-3 through 2-5 summarize effluent special studies of toxic contaminants, nutrients, and pathogens and their indicators.

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.[1] 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[2] 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 2-3. After 2005 data will be reviewed to determine the appropriate sampling frequency.

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1 As of 2003, metals are analyzed using USEPA approved low-detection-limit methods, based on inductively coupled plasma atomic emission spectrometry (ICP) or graphite furnace atomic absorption spectrometry (GFAA). The analytical methods for organic contaminants are derived from the USEPA methods approved for the NPDES program, but modified to achieve increased sensitivity. For example, currently selected ion monitoring (SIM) gas chromatography / mass spectrometry (GC/MS) is used to increase the sensitivity of the PAH method. MWRA developed a method for determining 67 individual PCB congeners based on dual-column gas chromatography with electron capture detection (GC/ECD). This method is capable of detecting sub-parts-per-trillion (ng/L) levels of these congeners. The methods used in the detailed effluent characterization may be revised as improved methods become available.

2 Through 1997 linear alkyl benzenes (LAB) were measured with PAH as a sewage tracer. Effluent monitoring of LAB was discontinued after the major industrial source of LAB to MWRA influent ended, rendering it useless as an MWRA sewage tracer.

Table 2-3 Special Study: Detailed Effluent Characterization of Toxic Contaminants

Parameter	Sample type	Frequency
Acid base neutrals	24-hr composite	bimonthly
Volatile Organic Compounds	grab	bimonthly
Low detection limit analyses		
Cadmium	24-hr composite	weekly
Copper	24-hr composite	weekly
Chromium	24-hr composite	weekly
Mercury	24-hr composite	weekly
Lead	24-hr composite	weekly
Molybdenum	24-hr composite	weekly
Nickel	24-hr composite	weekly
Silver	24-hr composite	weekly
Zinc	24-hr composite	weekly
17 chlorinated pesticides	24-hr composite	weekly
Extended list of PAHs	24-hr composite	weekly
20 PCB congeners	24-hr composite	weekly

Nutrients. To interpret the Massachusetts Bay water column monitoring data, more frequent and additional nutrient measurements are required 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 2-4. After 2005 data will be reviewed to determine the appropriate sampling frequency.

Table 2-4 Special Study: Effluent Nutrient Monitoring

Parameter	Sample type	Frequency
Total Kjeldahl nitrogen	24-hr composite	weekly
Ammonia	24-hr composite	weekly
Nitrate	24-hr composite	weekly
Nitrite	24-hr composite	weekly
Total phosphorus	24-hr composite	weekly
Total phosphate	24-hr composite	weekly

Pathogens. In addition to monitoring for fecal coliform, MWRA evaluates how pathogens and their indicators are affected by the wastewater treatment process by sampling influent and effluent for the presence of pathogenic viruses and other microbial indicators. *Enterococcus* is important to measure because it is the indicator recommended by USEPA for marine waters.

Table 2-5 Special Study: Effluent monitoring for pathogens and indicators

Parameter	Sample type	Frequency
Enteroviruses	Grab	6 /year
Bacteriophages	Grab	6/year
Enterococcus	Grab	Daily

Special Study: Sewage tracers. MWRA evaluates proposals to study emerging potential effluent tracers on an ongoing basis as new scientific developments occur. MWRA is co-sponsoring, with SeaGrant, a University of Massachusetts and Tufts University study of endocrine disruptors and possible tracers (e.g. caffeine) in Deer Island influent and effluent, in Boston Harbor, and around the new outfall site. Sampling for that study has been completed. Another special study with the Woods Hole Oceanographic Institution is examining the utility of a gel membrane sensor to detect what proportion of copper in the effluent is bioavailable.

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.

3 WATER COLUMN MONITORING

3.1 Purpose of Water Column Monitoring

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. The Deer Island Treatment Plant effectively removes suspended solids, oxygen-consuming organic material, pathogens, and floatables from wastewater, but removes only about 20% of the nitrogen. Furthermore, the 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.

Contingency Plan thresholds

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

- dissolved oxygen 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 (e.g. Werme and Hunt 2002) summarizes the comparison of monitoring results with Contingency Plan thresholds.

3.2 Water Column Monitoring Questions and Monitoring Results

MWRA has produced detailed technical reports and broader overviews of the results of water column monitoring (Libby et al. 2002a, 2002b, 2003, Werme and Hunt 2002, Kropp et al. 2003.) MWRA (2003b) summarized the findings of eleven years of water column monitoring in Massachusetts Bay. Routine water column monitoring focuses on the nearfield, supplemented by less frequent measurements at farfield stations covering Massachusetts and Cape Cod bays and Boston Harbor.

MWRA and OMSAP reviewed the monitoring questions relative to water column impacts (OMSAP 2002). It was agreed that most of the questions have been answered with respect to acute impacts on the environment (none or minimal), but that the potential for more long-term effects still exists, and therefore continued monitoring was necessary to evaluate whether the outfall may yet have unanticipated impacts. The monitoring questions and threshold related to outfall dilution were answered by MWRA's dye dilution study (Hunt et al. 2002b, 2002c). The remaining questions and thresholds continue to guide the design of the monitoring plan.

Monitoring questions: Dilution

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

Answer: Yes. The outfall performs as designed. During summer 2001, a dye study of effluent dilution was conducted (Hunt et al. 2002c). 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 no longer part of the monitoring plan.

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

Answer: 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 et al. 2002c). 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.

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?

Answer: No. Sampling results and the measured dilution show that shellfish beds and beaches are not impacted by the outfall discharge.

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 Massachusetts 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. MWRA has completed sampling for a four-year special study of pathogenic viruses, including viral and bacterial indicators, at the outfall site. The presence of viruses before the outfall came on line will be compared to those after the outfall began operating.

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 are 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. Rarely, 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. 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 appears as a subtle 30-m diameter circle of calmer water over each diffuser riser.

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: 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 input 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 provide water with characteristic dissolved oxygen and plankton, 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 et al. 2002c, Libby 2003).

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: As anticipated from model predictions, nutrient concentrations have changed in the nearfield. Since the diversion of effluent from the mouth of Boston Harbor, ammonium concentrations fell dramatically in Boston Harbor, and increased although to a lesser amount within the nearfield area in Massachusetts Bay (Figure 3-1).

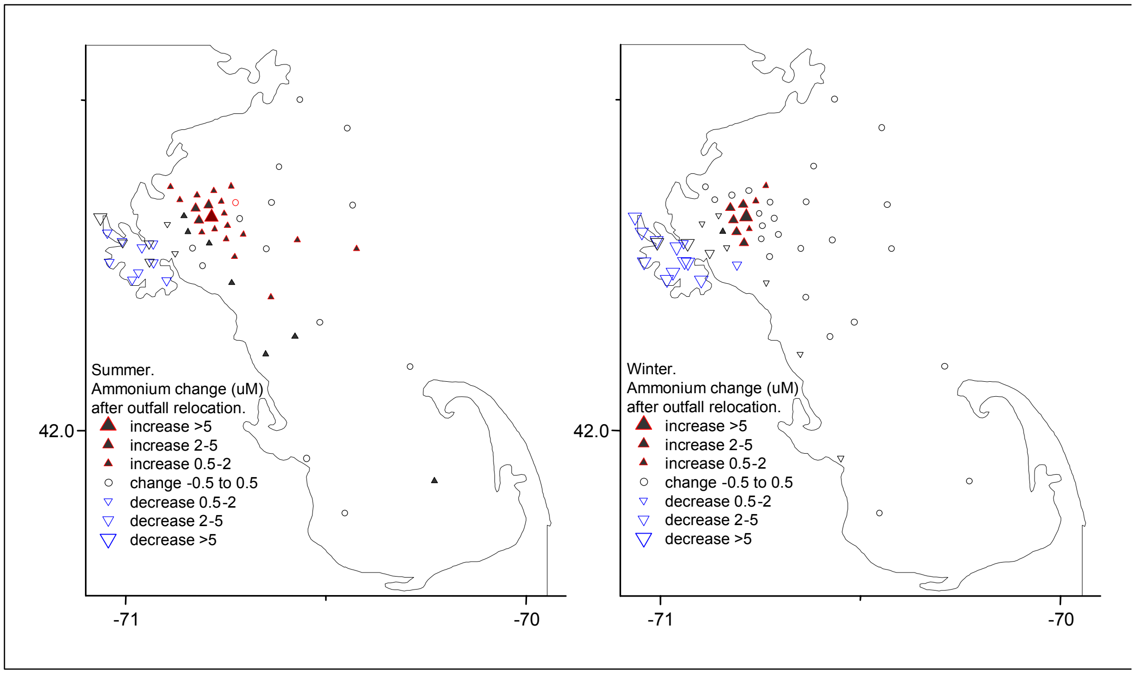

Figure 3-1 Change in NH4 concentration: 2001 versus baseline in summer (April – October) and winter (November – March).

There has been little if any change in ammonium concentrations beyond the harbor and the nearfield.

→ 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 sentinel areas, the nearfield and Stellwagen Basin, have not yet fallen below natural background values.

→ 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 has been no apparent change relative to baseline in dissolved oxygen concentrations or percent saturation in the nearfield or Stellwagen Basin. Modeling and statistical analyses indicate that interannual patterns in dissolved oxygen concentration and percent saturation at nearfield, Stellwagen Basin, and northern boundary stations are all correlated. Regional processes and advection are the primary factors governing bottom water dissolved oxygen concentrations in Massachusetts Bay (Geyer et al. 2002).

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 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?

→ Have production rates changed in the vicinity of the outfall or Boston Harbor and, if so, can these changes be correlated with changes in ambient water nutrient concentrations?

Results: Elevated chlorophyll concentrations measured in fall 2000, just after outfall start-up (Figure 3-2) were associated with a widespread regional bloom. Slightly elevated nearfield chlorophyll concentrations in early February of 2001 and 2002 were coincident with elevated primary production rates and the occurrence of earlier than usual winter/spring blooms. If this were to continue, that might suggest somewhat higher chlorophyll biomass in the unstratified season than seen during baseline monitoring. However, factors other than the outfall may explain the increase, such as phytoplankton species blooming in these periods and interactions between temperature and zooplankton abundance. The higher chlorophyll levels in the spring and fall also resulted in higher particulate organic carbon levels in the water column than typically observed during the baseline, indicating the transfer of carbon into non-chlorophyll biomass.

Initial results suggest that rates of primary productivity in the nearfield may have increased slightly since outfall start-up, and that rates have decreased in Boston Harbor at the only farfield station where productivity is measured (MWRA 2003b, Libby et al. 2003).

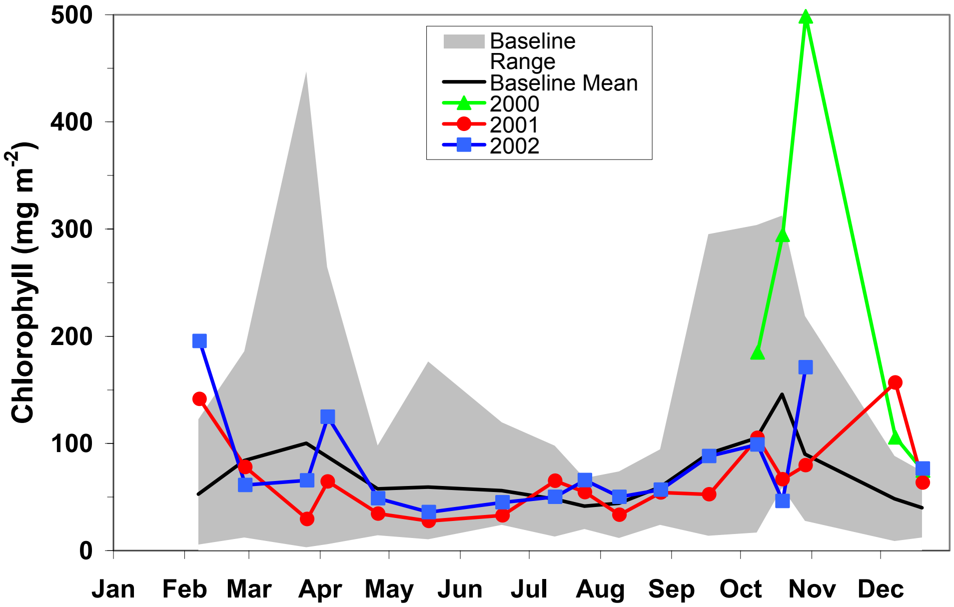

Figure 3-2 Time-series of survey mean areal chlorophyll concentrations in the nearfield in Autumn 2000, and in 2001 and 2002, compared against the baseline ranges and means.

Phytoplankton in the bays and harbor respond to a variety of factors including light and nutrients, although the timing and magnitude of blooms varies year to year. Nuisance species in the system tend to occur intermittently and at low levels. Post diversion changes in phytoplankton species and abundance are not evident within the bays. Zooplankton communities in Massachusetts and Cape Cod bays are dominated by copepods. Approximately a dozen species have widespread distributions in the Gulf of Maine, and some are found throughout the east coast waters of the United States. The monitoring data suggest zooplankton species reach peak abundances at the same time throughout the system. Statistical analyses of zooplankton data show that communities after the outfall began discharging are similar to those found during baseline.

Although the nutrient loading to the bays from MWRA treatment plants has been relatively constant through time, changing the entry point to the bays has caused substantial improvement in the water quality of Boston Harbor without causing adverse alteration of the basic ecology and species comprising the base of the food web and associated primary consumers in Massachusetts Bay. The observed changes in Massachusetts and Cape Cod bays have been restricted to the area around the outfall, possibly extending southward from the diffuser approximately 20 km (12 miles) but not eastwards towards the Stellwagen Bank area. Small increases in nutrients have occurred around the outfall, but the phytoplankton and zooplankton data are within baseline results. Through 2002, there has been no short-term, acute adverse response in the ecology of Massachusetts Bay.

Key design considerations

Review of the monitoring in light of the first 2+ years of post-discharge monitoring results (MWRA 2003b) indicates the key features that MWRA should continue to characterize with the monitoring and special studies described in this plan:

- the winter/spring bloom, including estimate of peaks in chlorophyll, production, and phytoplankton biomass in the nearfield
- early spring *Phaeocystis* blooms and resulting effect on zooplankton
- spatial extent of chlorophyll blooms (SeaWiFS satellite images)
- late spring occurrence of paralytic shellfish poisoning (Division of Marine Fisheries monitoring and targeted studies of *Alexandrium*, Anderson et al. 2002).
- stratification, dissolved oxygen, and nutrient levels at the beginning of summer
- summertime levels of chlorophyll and nutrients in the nearfield
- rate of decline of dissolved oxygen over the summer, and fall dissolved oxygen minimum
- summer upwelling or mixing events (USGS moorings and SeaWiFS)
- fall bloom peaks in chlorophyll, carbon, phytoplankton, and production in the nearfield
- phytoplankton and zooplankton community structure through the growing season
- exchange between the Gulf of Maine and Massachusetts Bay (GoMOOS and USGS moorings and boundary stations)

MWRA's water column monitoring (Section 3.3) is designed to capture these key features.

3.3 Water Column Monitoring Plan

Sampling schedule. As of 2004, water column monitoring includes 12 nearfield surveys and six farfield surveys (Table 3-1).

Table 3-1 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

Nearfield sampling design

There are seven nearfield stations (Figure 3-3). *In-situ* parameters, inorganic nutrients and other nutrients are collected at all stations, plankton and rates of productivity are measured at two stations.

In-situ parameters. At each station there will be measurements (Table 3-2) 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 3-2 Nearfield in-situ sensor measurements

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

Inorganic nutrients. Water samples are collected at all seven stations for analysis of inorganic nutrients (Table 3-3). 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 3-3 Nearfield inorganic nutrients sampling

Stations	Depths	Parameters
N01 N04 N07 N10 N16 N18 N20	Five	Ammonium Nitrate Nitrite Phosphate Silicate

Other nutrients. At each station, water samples are collected for analysis of additional nutrients (Table 3-4). 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 3-4 Nearfield sampling for additional nutrients

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

Rates and plankton. At two of the seven stations water samples are collected for analysis of rates and plankton (Table 3-5). 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 3-5 Nearfield sampling for rates and plankton

Stations	Depths	Parameters
N04 N18	Varies	Primary productivity Respiration Phytoplankton 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 3-6 through 3-8. There are 25 farfield stations (Figure 3-4), but not all stations are sampled for all parameters.

Table 3-6 Farfield *in-situ* sensor measurements

Stations	Depths	Parameters
F01 F02 F03 F05 F06 F07 F10 F12 F13 F14 F15 F16 F17 F18 F19 F22 F23 F24 F25 F26 F27 F28 F29 F30 F31	Every half-meter	Temperature Salinity Dissolved oxygen Chlorophyll fluorescence Transmissometry Irradiance 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 3-7 Farfield inorganic nutrients

Stations	Depths	Parameters
F01 F02 F03 F05 F06 F07 F10 F12 F13 F14 F15 F16 F17 F18 F19 F22 F23 F24 F25 F26 F27 F28 F29	Five	Ammonium Nitrate Nitrite Phosphate 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 3-8 Farfield nutrients, plankton and rates

Stations	Depths	Parameters
F01 F02 F06 F13 F23 F24 F25 F27 F30 F31	Variable	Dissolved organic carbon Dissolved nitrogen Dissolved phosphorus Particulate carbon Particulate nitrogen Particulate phosphorus Particulate biogenic silica Total suspended solids Phytoplankton Zooplankton
F23	Five Three	Primary productivity 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.

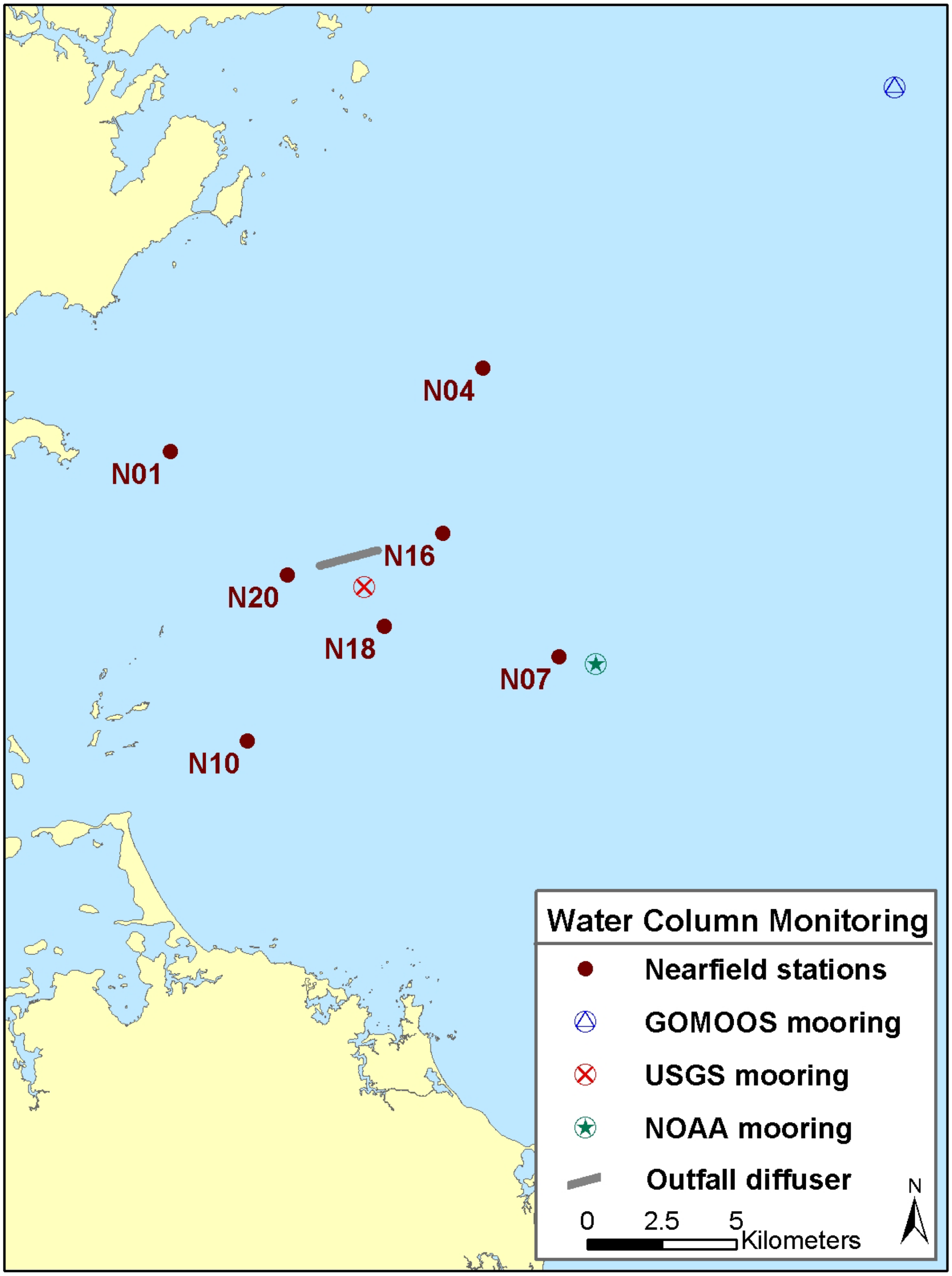

Figure 3-3 Nearfield monitoring stations

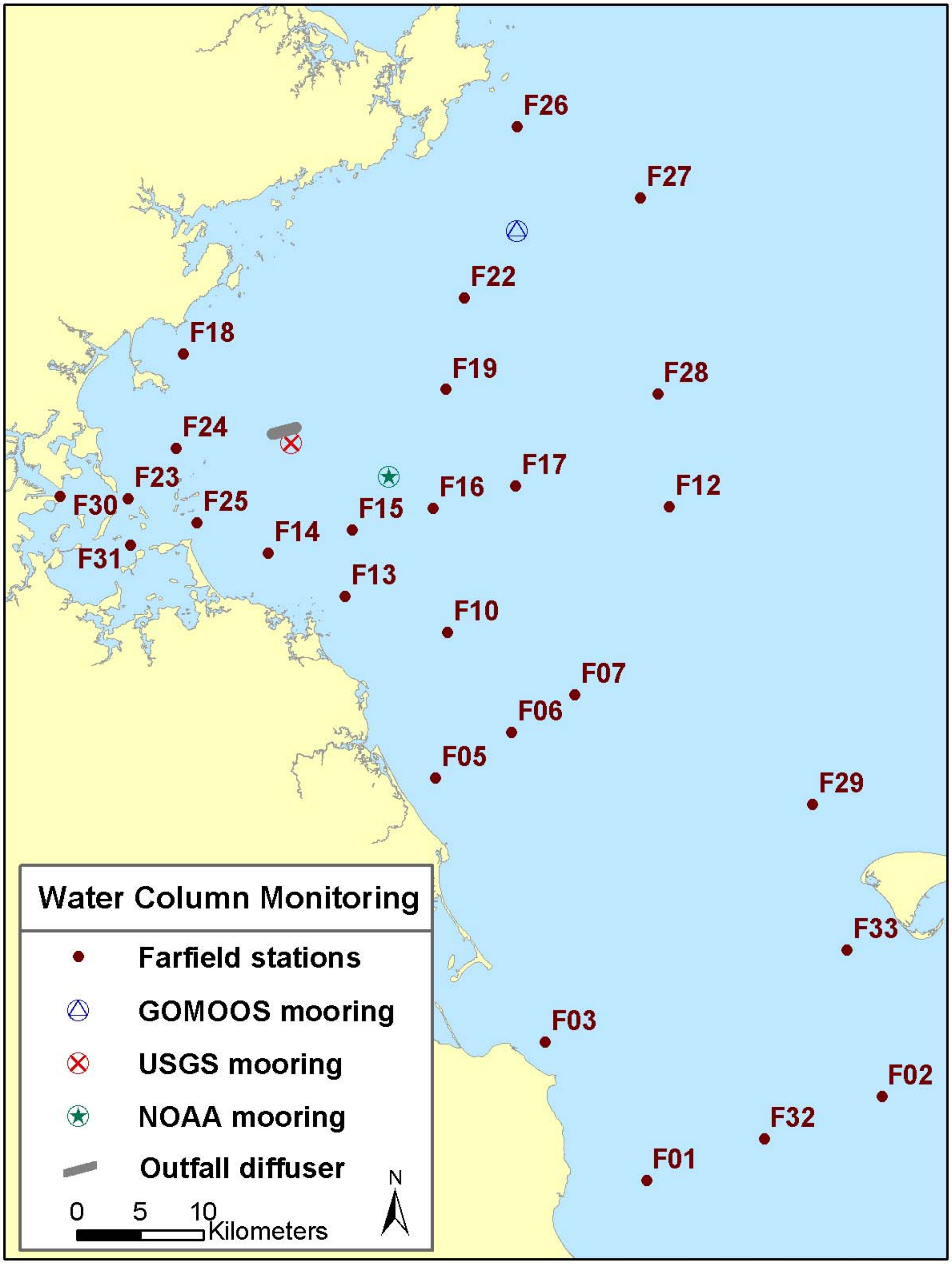

Figure 3-4 Farfield monitoring stations.

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. MWRA will evaluate the feasibility of augmenting the existing instrumented moorings near the outfall, among other mooring locations and technologies, to provide continuous real-time monitoring for phytoplankton blooms. The feasibility of posting the data on the internet in real time to show the condition of the bay between surveys will also be evaluated.

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 NPDES permit requires that the Bays Eutrophication Model (BEM) be updated, maintained, and run annually. 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 3-3), 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.

3.4 Data evaluation

The suite of measurements provides the necessary information for Contingency Plan threshold comparisons (chlorophyll, dissolved oxygen, and plankton). The data are also used to address the monitoring questions. For example, any change in zooplankton species composition could be compared with effluent or ambient water nutrient concentrations and with phytoplankton biomass and community composition data to determine whether it might be related to the outfall discharge.

The data are also used for input to the Bays Eutrophication Model (as boundary conditions) and to validate the model results.

4 BENTHIC MONITORING

4.1 Purpose of benthic monitoring

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, Lefkovitz et al. 1999, Kropp et al. 2002). However, relocating the outfall raised concerns about potential effects of the relocated discharge on the offshore sea floor. 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.

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 2002) summarizes the comparison of monitoring results with Contingency Plan thresholds.

4.2 Benthic monitoring questions and results

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?

→ Has 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. Two years of post-discharge sampling have found no evidence of acute outfall-related impacts on sediment contamination, which was a major concern in the early 1990's. The monitoring program has therefore been re-focused on measuring long-term effects.

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). 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).

Contaminant concentrations in surficial sediments (MWRA 2003a, Maciolek et al. 2003, Bothner et al. 2002) and in sediment traps nearfield (Bothner et al. 2002) have not shown rapid increases since outfall startup. An effluent signal was detected in the most sensitive sewage tracers measured, i.e. silver and *Clostridium perfringens* spores in sediment trap samples (Bothner et al. 2002) and *C. perfringens* spores in nearfield sediments (Maciolek et al. 2003, Kropp et al. 2002). The signal is subtle and there has been no generalized increase in contaminants in nearby sediments.

Monitoring questions: Benthic communities

Has the soft-bottom community changed?

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

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

→ Has the hard-bottom community changed?

Results for soft-bottom benthos. A detailed overview of the infaunal monitoring results is provided in chapter 3 of MWRA (2003c), with more detail on the analyses appearing in the 2002 outfall benthic monitoring report Maciolek et al. (2003) and in previous benthic monitoring reports (e.g. Kropp et al. 2002).

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 shows the importance of grain size and regional (or depth) differences between samples as important structuring factors for community composition (Figure 4-1).

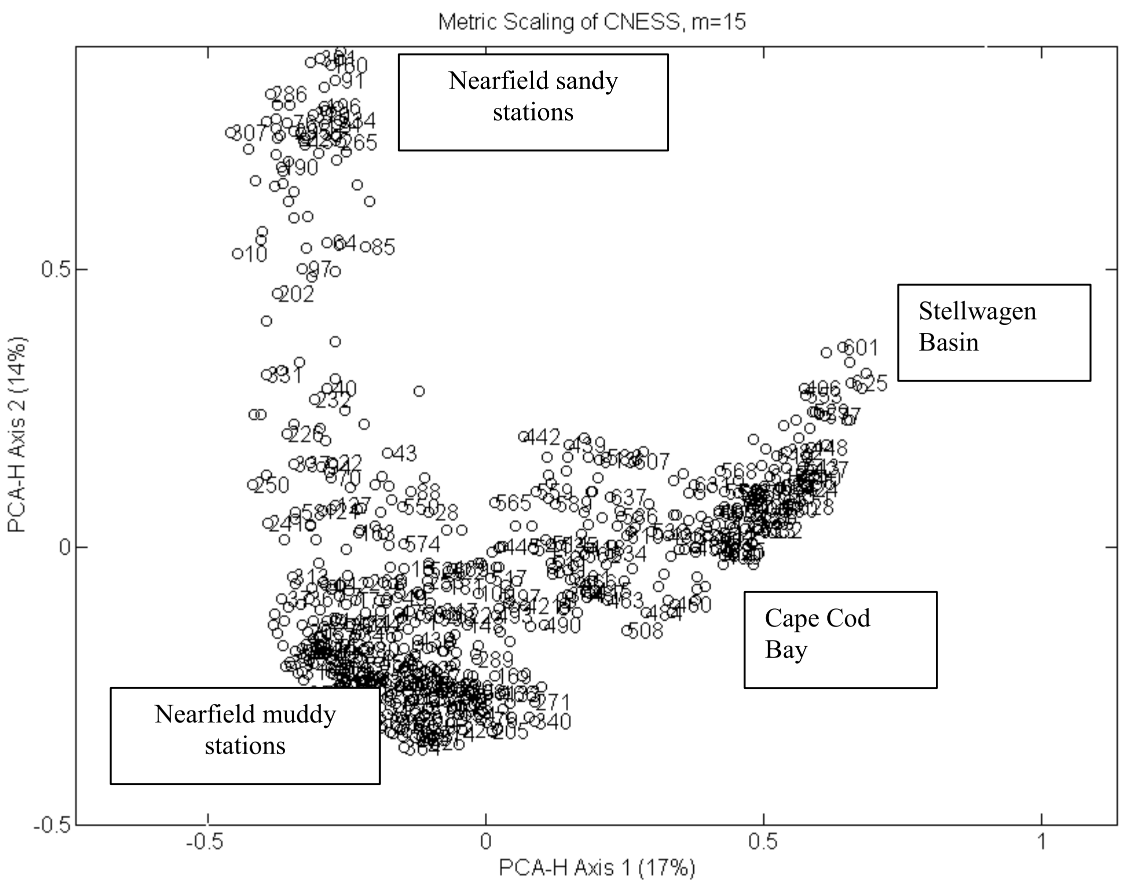

Figure 4-1 Metric scaling plot of CNESS distance, PCA-H Axis 1 versus Axis 2, among the 640 nearfield and farfield samples collected 1992-2002. Text boxes show regions whose samples consistently plot in that area of the graph.

Benthic infaunal monitoring data since outfall startup in 2000 does not indicate major departures from the baseline monitoring period in any parameters measured. Nearfield infaunal abundances in 2002 were higher than previously observed (Figure 4-2). This appears to be a result of increases in the abundance of several polychaete species normally present in nearfield muddy sediments. It is not clear whether the increased infaunal abundances observed in 2002 are a response to outfall discharge or not; this will continue be further investigated as data from 2003 become available.

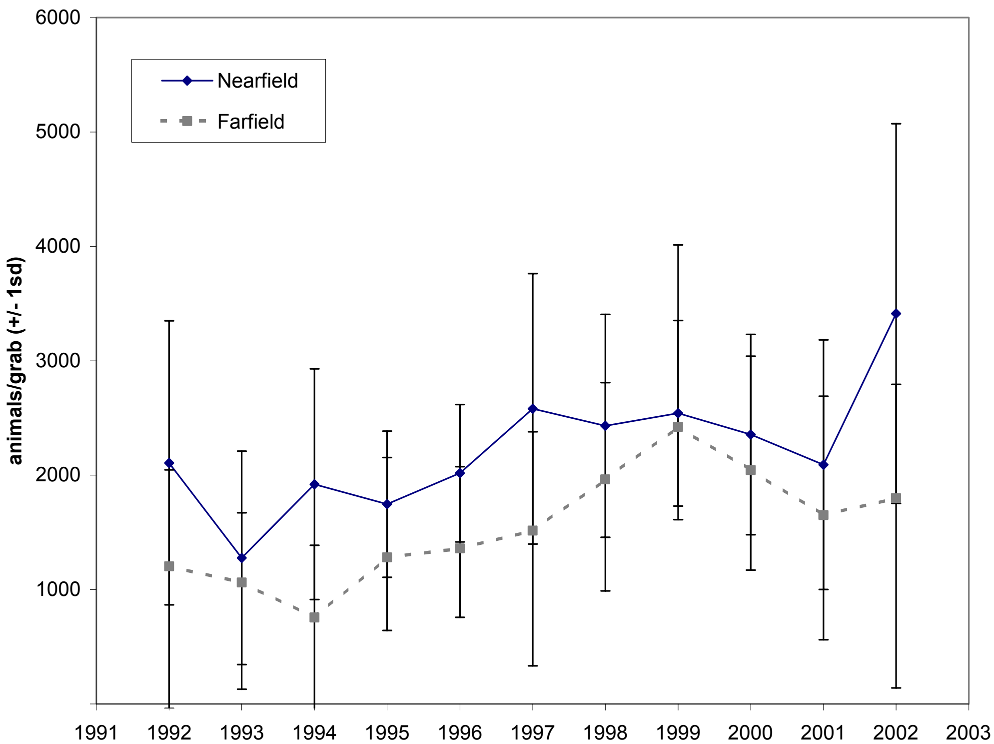

Figure 4-2 Average infaunal abundance in nearfield and farfield samples, 1992-2002.

During the nine years of baseline monitoring, annual measurements of community parameters showed somewhat similar temporal patterns in the nearfield and farfield. In the nearfield, there was a large reduction in infaunal abundance and in species richness of between 1992 and 1993 (Figure 4-3). This decline has been attributed to the severe winter storm in December 1992. The effects of the storm were not apparent in the farfield. Infaunal abundance (Figure 4-2) increased in both the nearfield and farfield in the mid 1990s, with a baseline peak in 1999. As mentioned previously, nearfield abundance increased in August 2002 to levels not previously observed. Species richness in both nearfield and farfield sediments increased in 1994 through 1997, decreased between 1998 and 2000, then increased in both regions in 2001 and 2002 (Figure 4-3). Overall, data for both nearfield and farfield stations are suggestive of a long-term cycle in species richness.

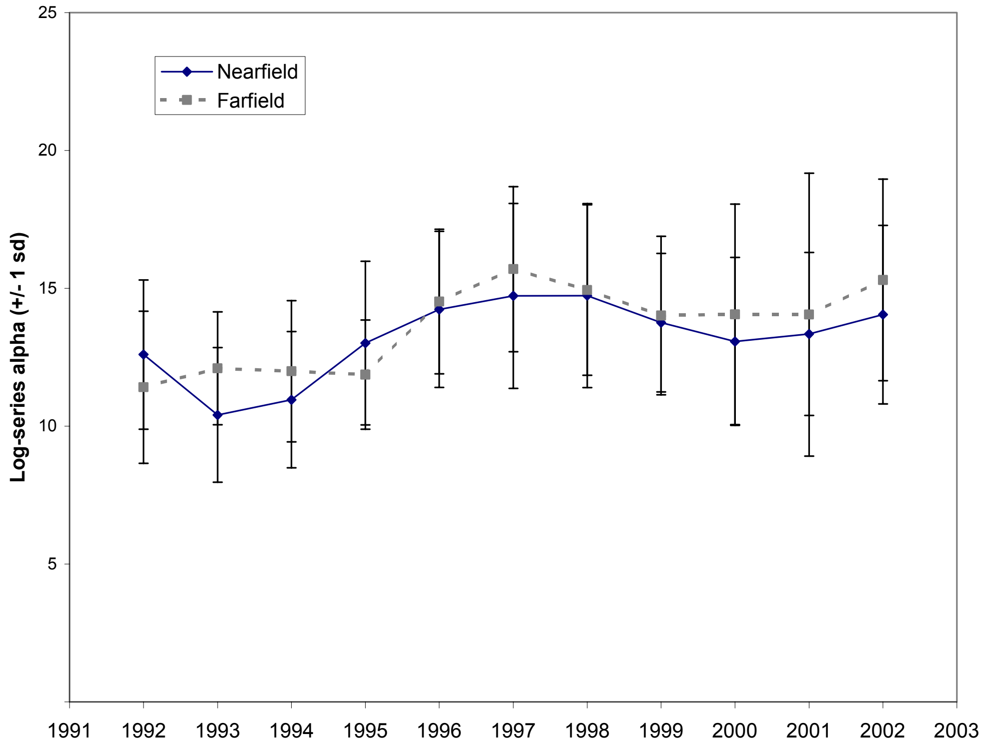

Figure 4-3 Average infaunal log-series alpha (a measure of species richness, relatively insensitive to changes in sample abundance) at nearfield and farfield stations, 1992-2002.

MWRA carried out statistical analyses of the species diversity data using a nested ANOVA design. The analysis would have detected an outfall effect of as little as a 5% change in the patterns of species richness or evenness (how evenly individuals are distributed among species) between the nearfield and farfield following outfall startup. No significant outfall effect was detected in the species richness data, although the results of those analyses do support the potential existence of a long-term cycle in both nearfield and farfield` sediments (MWRA 2003c, Maciolek et al. 2003). A statistically significant outfall effect on species evenness data was suggested in the analysis of species evenness, though the magnitude of the change detected is tiny and does not appear to be ecologically meaningful (MWRA 2003c, Maciolek et al. 2003).

In addition to the analyses of species diversity, MWRA has evaluated the community composition data through time to see if those data show any indications of outfall impact. They do not (MWRA 2003c, Maciolek et al. 2003, Kropp et al. 2002).

Sediment RPD, the depth of oxygen penetration into the sediments, has shown no change since outfall startup (MWRA 2003c, Maciolek et al. 2003).

Results for hard-bottom study. The stable hard-bottom benthic communities near the outfall did not substantially change with the activation of the outfall. The only observable change during the two years of discharge monitoring was an increase in sediment drape, and a concurrent decrease in percent cover of coralline algae, at a subset of stations north of the outfall and at the two northernmost reference sites. Whether these modest changes are related to the outfall discharge is not known at present (MWRA 2003a, Maciolek et al. 2003, Kropp et al. 2002).

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: No large changes in the rates of benthic nutrient cycling have been observed in Massachusetts Bay after two years of diversion of effluent. While local sea-floor metabolism (oxygen uptake) rates are appreciable, bottom-water oxygen levels appear to be controlled by the effects of advection. Sediment processes are integrative, and typically have a slow response time, suggesting that about 5 years of discharge monitoring will be necessary to determine whether outfall impacts are occurring or not (MWRA 2003c, Tucker et al. 2003, Tucker et al. 2002).

4.3 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 4-4 and 4-5). Nearfield[3] stations NF12 and NF17 will be sampled annually. Remaining stations nearfield and farfield station groups (see Table 4-1). Stations were randomly split into 2 subsets to be sampled in alternate years[4], 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 4-1.

Table 4-1 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

[3] 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.

[4] 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 4-1).

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 4-1 and Figures 4-4 and 4-5).

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 4-1).

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 4-1).

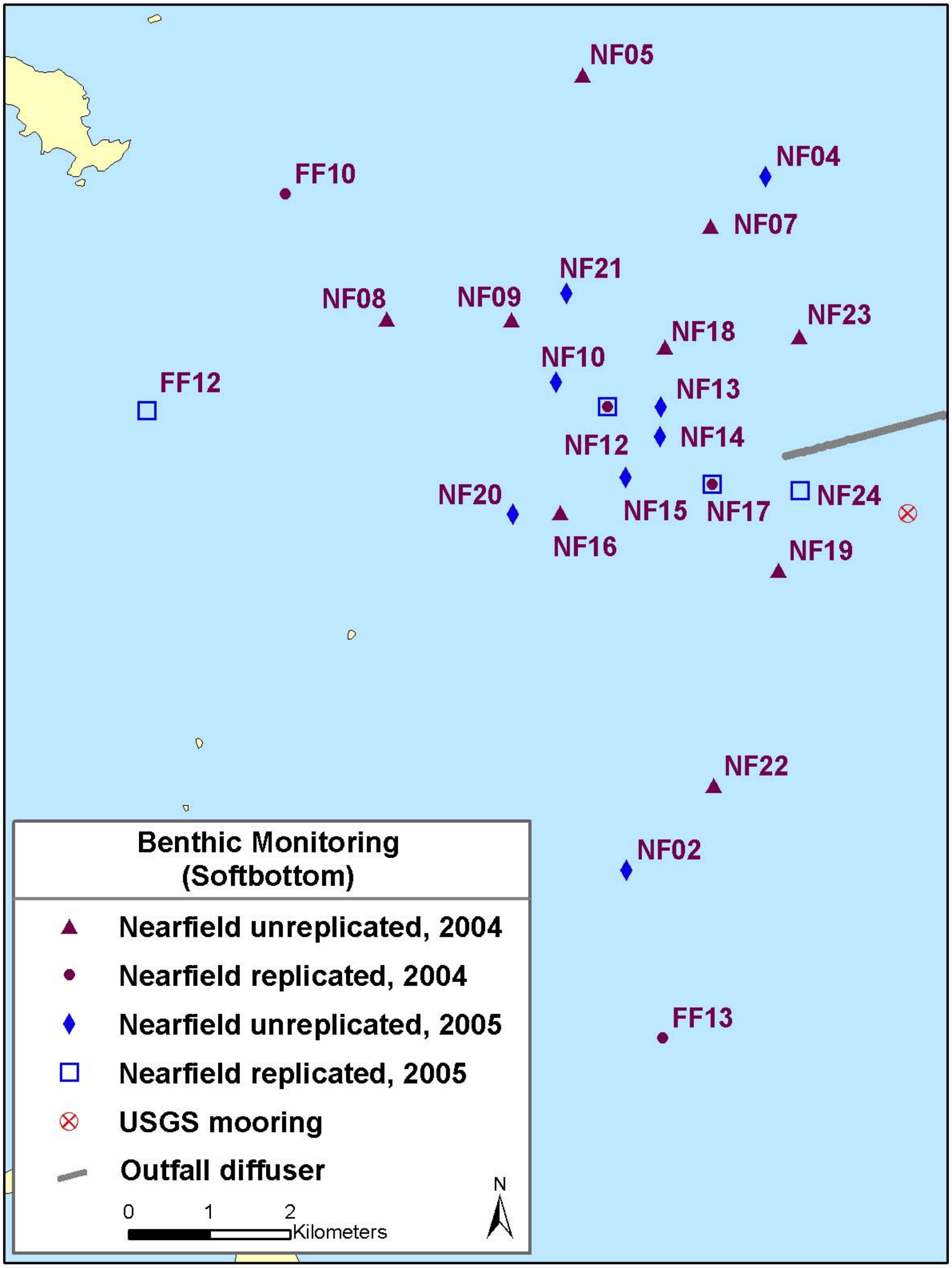

Figure 4-3 **Locations of nearfield soft-bottom stations to be sampled in 2004 and 2005.**

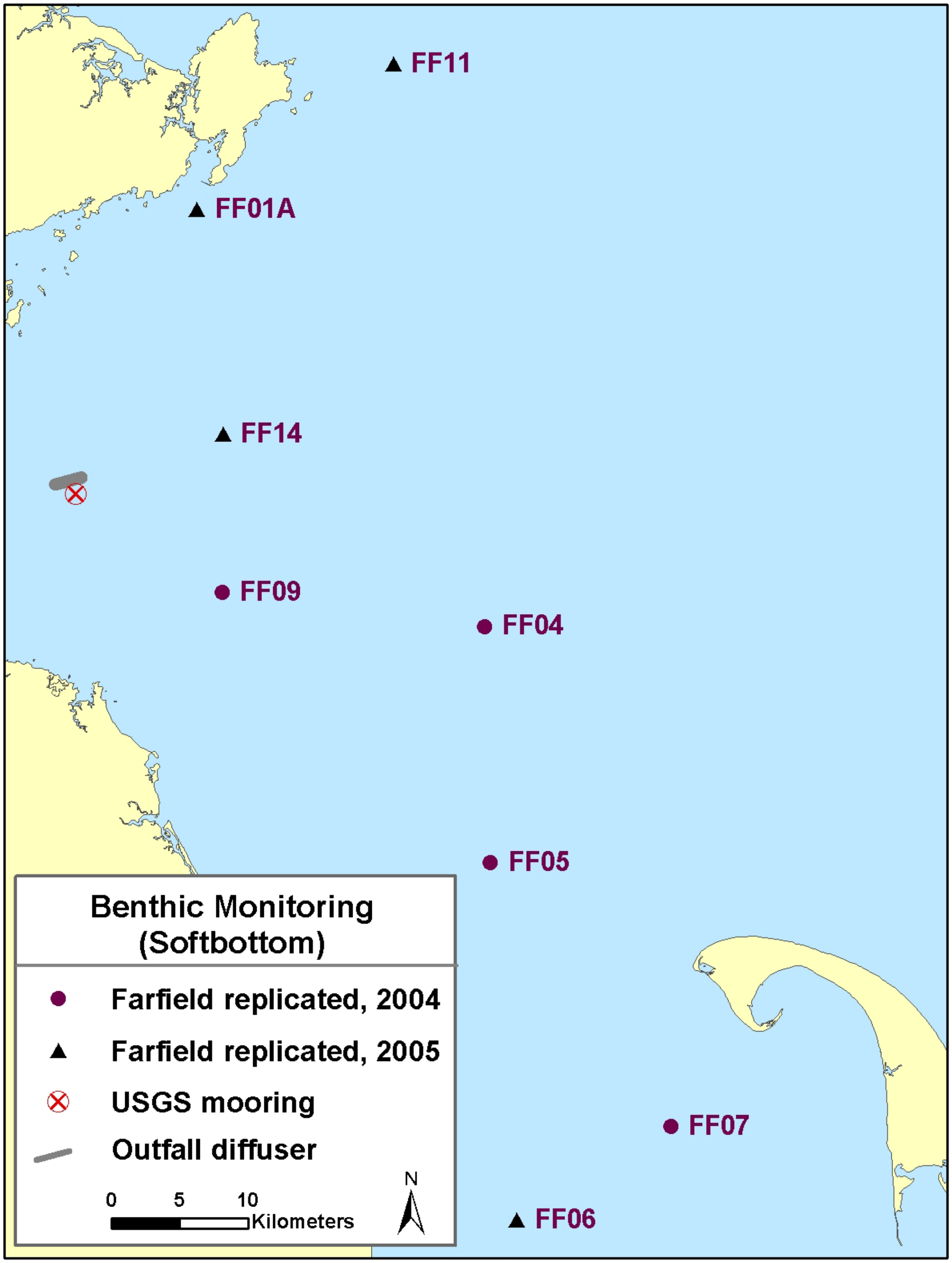

Figure 4-4 Locations of farfield soft-bottom stations to be sampled in 2004 and 2005.

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° 14.5'N, 70° 33.0'W. See Figure 4-6 for new station locations.
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.

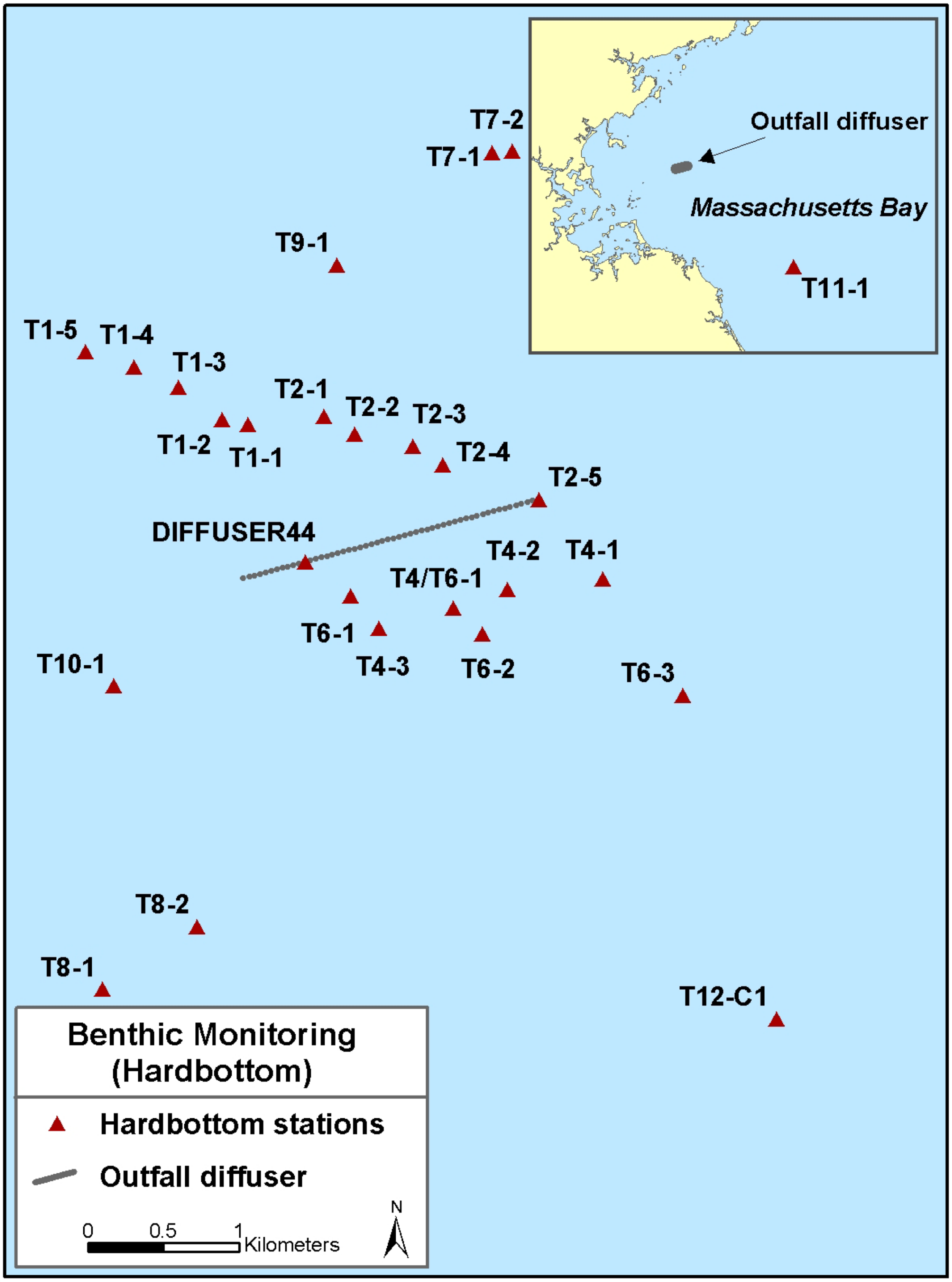

Figure 4-5 **Existing and candidate new hard-bottom stations.**

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 4-7 for location of benthic flux sampling locations.
Frequency:	Four surveys each year during May, July, August, and October.

OMSAP (OMSAP 2003c) agreed with MWRA's recommendation to continue the benthic nutrient flux study through 2005, and review the results at that time to determine if the study should continue.

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.

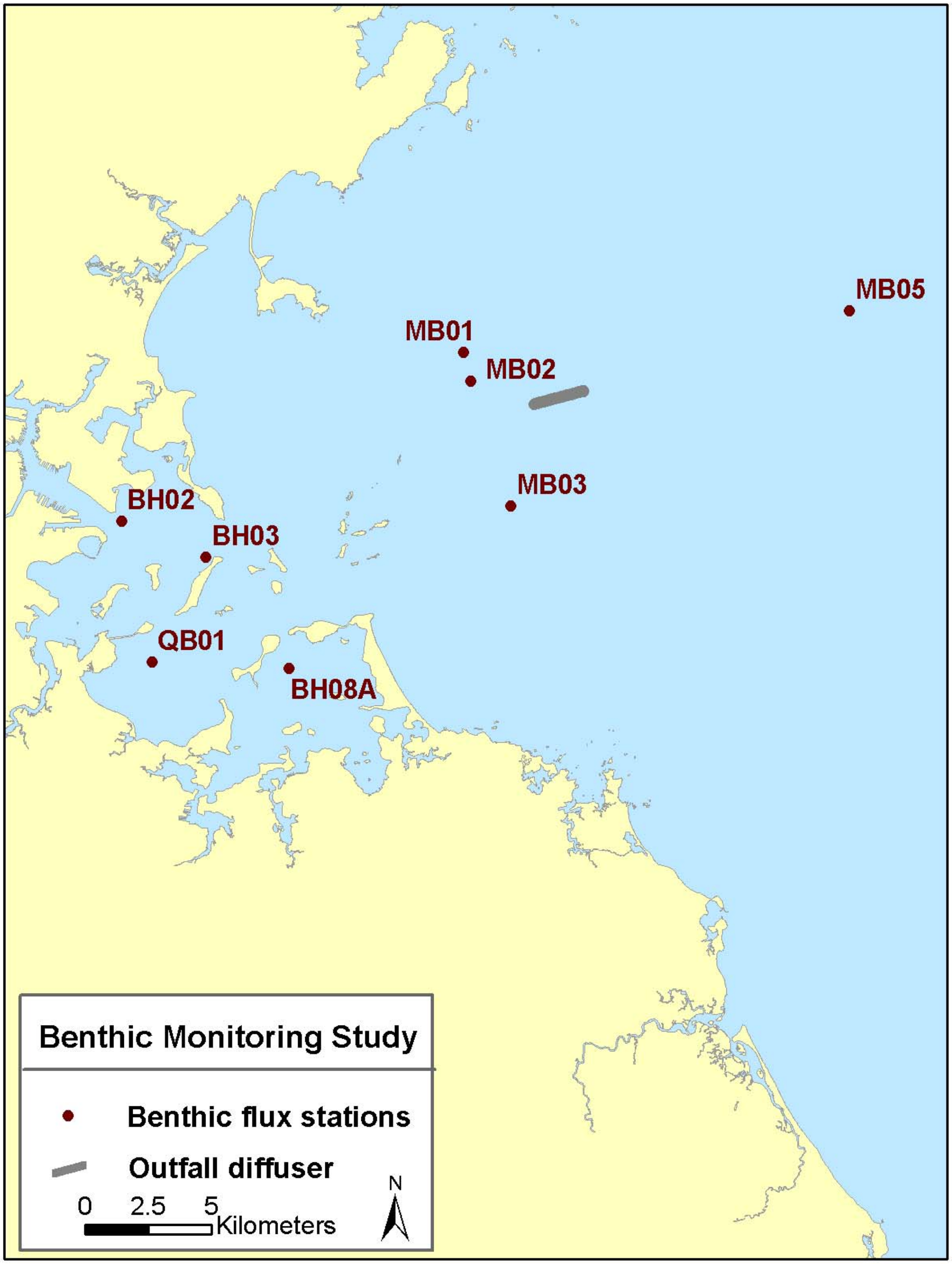

Figure 4-6 **Benthic nutrient flux stations.**

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.

4.4 Data evaluation

In addition to testing Contingency Plan thresholds, data from the benthic monitoring program will be evaluated to answer the monitoring questions listed in section 4.2. For example, the concentrations of contaminants and of sewage tracers in sediments has changed only modestly and only in the immediate vicinity of the outfall in the first two years after diversion. The sewage tracer and organic carbon data, and sediment trap data, will be evaluated to ensure that there continue to be no sudden changes in the next few years. If the sediments are still not accumulating contaminants, it may be appropriate to make chemistry sampling still less frequent, as long as effluent toxic contaminant concentrations remain low. 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. (2003) will provide sensitive tests of possible outfall effects, even with the collection of smaller numbers of samples.

Results of annual sediment contaminant sampling at stations NF12 and NF17 in 2003 will be used to complement the other results. They would help evaluate whether, for example, unexpected results from the *C. perfringens* sampling (if observed) might be reflected in contaminant concentrations at those sites. Such information could be used in consultation with OMSAP and regulators to determine whether more widespread sediment contaminant sampling should occur before 2005.

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, rendering them unfit for human consumption. 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 (*Pleuronectes 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.

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 and Hunt 2002) 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 outfall, Boston Harbor, and a reference site?

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

Flounder results. In the first two years since effluent was diverted to the new outfall, no flounder contamination or health Contingency Plan thresholds have been exceeded. Contaminant levels from each of the two years have generally been well below the baseline average. Flounder livers of fish collected at the outfall site also generally show no apparent contaminant increases as a result of the wastewater diversion. Blind side ulcers were observed on flounder from Deer Island and western Massachusetts Bay in 2001 and 2003. This observation is being further studied.

Lobster results. As for flounder, neither 2001 nor 2002 results approached any Contingency Plan thresholds. In most cases lobster meat contaminant levels were below the baseline. Similarly, lobster hepatopancreas contaminant data show most 2001 and 2002 results are well within the baseline range.

Mussel results. With the exception of chlordanes and PAHs, 2001 and 2002 results were well below threshold levels and at or below baseline values. Hunt et al. 2002a and Lefkovitz et al. 2002b discuss the 2001 mussel contingency plan exceedances in detail. They concluded that using more recent data on the bioavailability of PAHs and chlordanes in MWRA effluent to mussels placed within the outfall mixing zone allows reasonably good predictions of the observed mussel concentrations. Hunt et al. 2002a also provides an analysis of whether the observed mussel concentrations pose or suggest an environmental risk and conclude that they do not. A recent OMSAP focus group on the 2002 exceedances reached the same conclusion (OMSAP 2003d).

5.3 Fish and shellfish monitoring plan

Table 5-1 summarizes the chemical analyses performed for fish and shellfish. Figure 5-1 shows the sampling locations.

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).

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 and East Cape Cod Bay, and Nantasket Beach. 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 example skipping 2004 and 2005) for chemical constituents. Lobster: Sampled in July-October, every third year (for example skipping 2004 and 2005). Biological material from fifteen specimens from each station is pooled to form three composite samples of 5 individuals each for chemical analysis. Histological sections of flounder liver will be made for 50 fish per station.

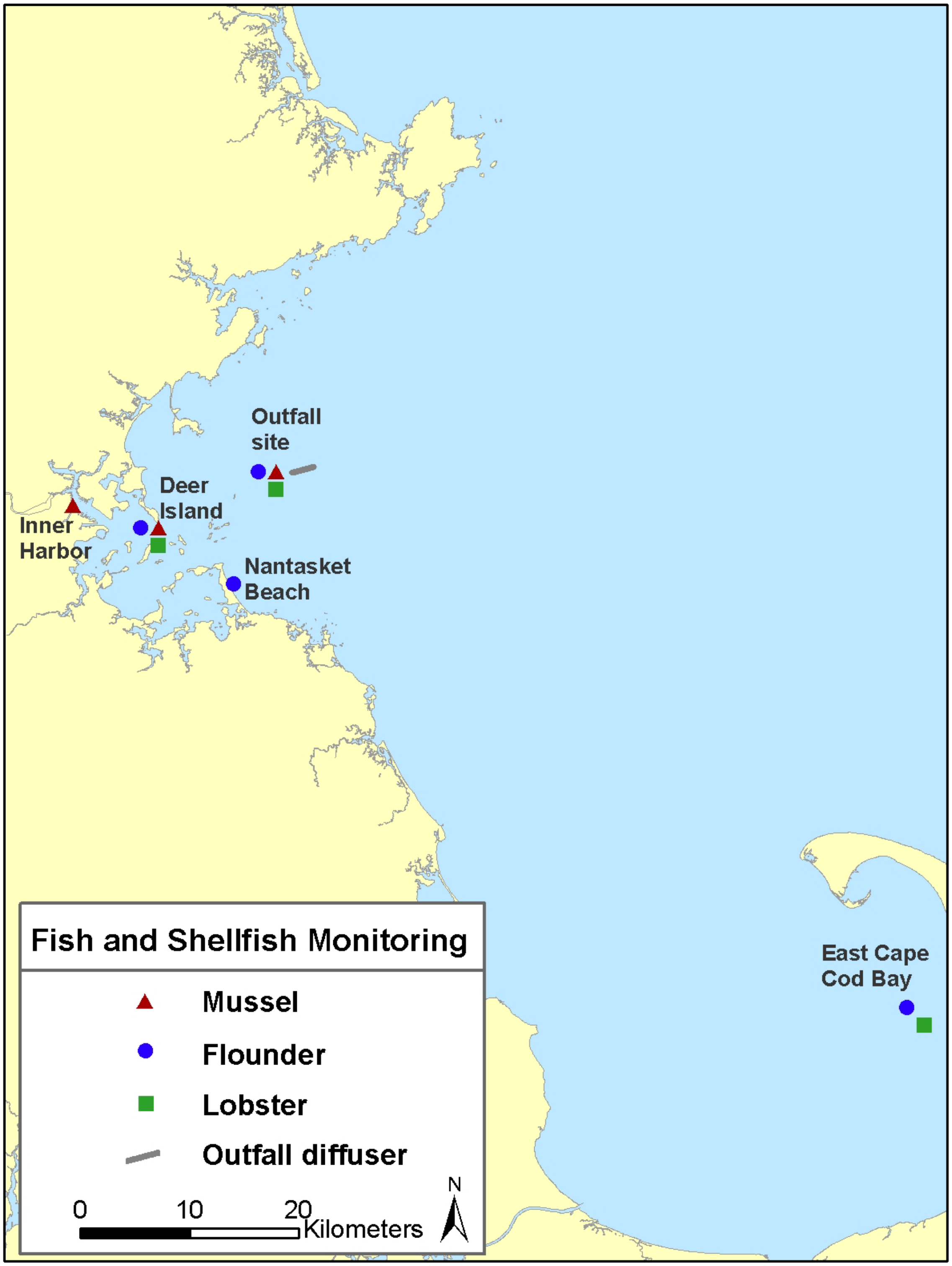

Figure 5-1 Sampling Stations for Winter Flounder, Lobster and Mussels

Table 5-1 Chemistry analyses for fish and shellfish monitoring

Organism	Number of stations	Number of samples of each type per station	Parameters
Flounder	4	3 composites (fillet from 5 flounder)	Mercury PCB Chlorinated pesticides Lipids
Flounder	4	3 composites (liver from 5 flounder)	Trace metals PAH PCB Chlorinated pesticides Lipids
Lobster	3	3 composites (meat from 5 lobster)	Mercury PCB Chlorinated pesticides Lipids
Lobster	3	3 composites (hepatopancreas from 5 lobster)	Trace metals PAH PCB Chlorinated pesticides Lipids
Mussel	1 predeployment and 3 postdeployment	6 composites (soft tissue from 10 mussels)	Mercury Lead PAH PCB Chlorinated pesticides Lipids

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.

Frequency: Every third year, for example skipping 2004 and 2005. 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 40 days in case storms prevent the 60-day retrieval. For each station, biological material from 50 mussels is pooled to form five composite samples (10 specimens per sample) for chemical analyses.

Special studies to enhance mussel bioaccumulation monitoring

Since 1998, MWRA has deployed mussels at a reference station in Cape Cod Bay. In 2001-2003, MWRA deployed an extra set of mussels in the vicinity of the Boston “B”-buoy, ~1 km SE of the outfall.

In 2002, MWRA carried out enhanced effluent contaminant monitoring during the mussel deployments, and analyzed mussels deployed along the outfall from both the 40 and 60-day retrievals to determine if an intervening treatment plant upset led to increased mussel bioaccumulation (it did not) (Pala et al. 2003).

Special study of flounder blind side lesions

At its October, 2003 meeting, OMSAP recommended that MWRA continue its special study investigating recent observations of an apparent increased prevalence of blind side flounder lesions in Boston Harbor and Massachusetts Bay, coordinating with other agencies. An important aspect of the study is developing, with fisheries agencies, a lesion identification protocol to insure consistency. Also, for this study, the Broad Sound location would be sampled for extrernal lesion identification and other evaluations to be determined (e.g. liver histopathology) as the study design is developed.

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.

6 REFERENCES

Anderson DM, Keafer BA, Churchill JH, Loder TC. 2002. Post-outfall surveys of toxic *Alexandrium fundyense* populations in Massachusetts Bay, 2001. Boston: Massachusetts Water Resources Authority. Report 2002-08. 36 p.

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. U.S.G.S. 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.

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.

Darling S, Wu D. 2001. NPDES compliance summary report, fiscal year 2001. Boston: Massachusetts Water Resources Authority. Report 2001-08. 196 p.

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 ENQUAD. 20 p.

GoMOOS. 2003. Website " Gulf of Maine Ocean Observing System: Up-to-date information on weather and oceanographic conditions in the Gulf of Maine", http://www.gomoos.org.

Hunt CD, Abramson S, Lefkovitz L, Neff J, Durell G, Keay K, Hall M. 2002a. Evaluation of 2001 mussel tissue contaminant threshold exceedance. MWRA. ENQUAD Report 2002-05. 48 p.

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

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.

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

Lefkovitz LF, Abramson SL, Moore MJ. 2002a. Combined work/quality assurance project plan (CW/QAPP) for fish and shellfish monitoring: 2002-2005. Boston: Massachusetts Water Resources Authority. Report ms-078. 71 p.

Lefkovitz L, Abramson S, Hillman R, Moore M, Field J. 2002b. 2001 Annual Fish and Shellfish Report. MWRA. ENQUAD Report 2002-14. 175 p.

Libby PS, Gagnon C, Albro CS, Mickelson MJ, Keller AA, Borkman D, Turner JT, Oviatt CA. 2002a. Combined work/quality assurance plan (CWQAPP) for water column monitoring 2002 - 2005 - tasks 9, 10, 12, 13, 14, 15. Boston: Massachusetts Water Resources Authority. Report ms-074. 79 p.

Libby PS, Keller AA, Turner JT, Borkman DG, Mickelson MJ, Hunt CD, Oviatt CA. 2002b. 2001 annual water column monitoring report. Boston: Massachusetts Water Resources Authority. Report 2002-22. 100 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 ENQUAD 2003-09. 111 p.

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. Draft report.

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

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

MWRA. 2002. Massachusetts Water Resources Authority Industrial Waste Report, No. 18. Boston: Massachusetts Water Resources Authority. October 2002.

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.

NASA. 2003. Website "SeaWiFS Project, NASA Goddard Space Flight Center", http://seawifs.gsfc.nasa.gov/SEAWIFS.html

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. Minutes of Outfall Monitoring Science Advisory Panel meeting, September 24 2002, Boston, MA. http://www.epa.gov/region01/omsap/omsapm.html

OMSAP. 2003a. Minutes of Outfall Monitoring Science Advisory Panel 2003 monitoring review workshop #1, March 31-April 1, 2003, Woods Hole, MA.

OMSAP. 2003b. Minutes of Outfall Monitoring Science Advisory Panel 2003 monitoring review workshop #2, June 18-19, 2003, Woods Hole, MA.

OMSAP. 2003c. Minutes of Outfall Monitoring Science Advisory Panel 2003 Monitoring review workshop #3, July 24, 2003, Boston, MA.

OMSAP. 2003d. Draft summary, OMSAP mussel tissue contaminant focus group meeting, Wednesday, March 5, 2003, MADEP Boston.

OMSAP. 2003e. [draft] Minutes of Outfall Monitoring Science Advisory Panel 2003 meeting, October 21, 2003, Woods Hole, MA.

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.

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. http://www.sfei.org

Tucker J, Kelsey S, Giblin AE, Hopkinson CS Jr. 2002. Benthic metabolism and nutrient cycling in Boston Harbor and Massachusetts Bay: Summary of baseline data and observations after one year of Harbor-to-Bay Diversion of Sewage Effluent. Boston: Massachusetts Water Resources Authority. Report 2002-13. 83 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. Website "Boston sewage outfall: the fate of sediments and contaminants in Massachusetts Bay", http://woodshole.er.usgs.gov/project-pages/bostonharbor

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

Williams IP, Maciolek NJ, Boyle JD, Dahlen DT, Baptiste-Carpenter EM. 2002. Combined work/quality assurance plan for benthic monitoring: 2002-2005. Boston: Massachusetts Water Resources Authority. Report ms-076. 109 p.

Wu D, Paleti N. 2003. NPDES compliance summary report, fiscal year 2002. Boston: Massachusetts Water Resources Authority. Report 2002-12. 144 p.

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