Outfall monitoring overview
BACKGROUND:
2012 update

Massachusetts Water Resources Authority

Environmental Quality Department
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2012 Update

prepared for

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

prepared by

Christine Werme
Berkeley, CA 94705

Andrea Rex
Environmental Quality Department
MWRA

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

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1. Introduction

The Massachusetts Water Resources Authority (MWRA) was created by an act of the Massachusetts state legislature in December 1984 to upgrade wastewater treatment facilities serving the greater Boston area. At that time, both sewage biosolids and inadequately treated sewage effluent were discharged into the confined waters of Boston Harbor from outfalls located at Deer Island in the northern part of the harbor and at Nut Island in Quincy Bay, in the southern part of the harbor. In 1985, MWRA embarked upon that mission, what has become known as the Boston Harbor Project.

By 2000, most of the Boston Harbor Project milestones had been completed, and MWRA received a National Pollutant Discharge Elimination System (NPDES) permit to discharge from Deer Island Treatment Plant (DITP) to Massachusetts Bay. The permit was issued jointly by the U.S. Environmental Protection Agency (EPA) and the Massachusetts Department of Environmental Protection (MADEP). The permit had many unique requirements, including an extensive ambient monitoring requirement and a Contingency Plan, which provided for responses and actions should permit violations occur. One requirement was that MWRA prepare an annual report summarizing the year's monitoring results; these reports are the annual outfall monitoring overviews.

A background document to these annual overviews was written in 2008, presenting information on environmental concerns, monitoring design, and Contingency Plan thresholds for effluent, water-column, sea-floor, and fish-and-shellfish monitoring (Werme and Hunt 2008). This current document, the first update of the 2008 background, incorporates changes to the ambient monitoring plan for MWRA's effluent outfall (MWRA 2010), which were approved in December 2010 and implemented in 2011. This introduction briefly describes the Boston Harbor Project, the permit, the monitoring program, the Contingency Plan, data management, reporting, and the contents of the outfall monitoring overviews.

The Boston Harbor Project

The Boston Harbor Project was a complex undertaking to minimize the environmental impacts of MWRA's wastewater discharge. The basic steps to minimize effects of effluent discharge included source reduction to prevent pollutants from entering the waste stream, improved treatment before discharge, and better dilution of effluent entering the marine environment.

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

Improved treatment has been implemented in a series of major milestones (Table 1-1). In 1995, a new primary treatment plant was brought on-line, and disinfection facilities were completed. (Primary treatment is a physical treatment process, which involves removal of solids through settling, followed by disinfection.) Batteries of secondary treatment (which includes microbial decomposition as well as settling and disinfection) went on-line in 1997, 1998, and 2001. Also during 1998, discharge from the Nut Island Treatment Plant into Quincy Bay ceased, and all wastewater was conveyed to DITP for treatment, ending effluent discharge to the southern part of the harbor. In 2005, a cross-harbor tunnel, which connected DITP to the Fore River biosolids pelletizing plant was completed, allowing nutrient-rich waste from the pelletizing plant to be steadily piped to DITP, facilitating a more stable secondary treatment process. The tunnel meant that DITP could treat a greater proportion of its flow during high-flow conditions by full secondary treatment, lessening the need to blend primary-only treated flow into the secondary-treated wastewater. In 2010,

Table 1-1. Timeline of Boston Harbor Project and later milestones for improved treatment and concurrent ambient monitoring activities.

Year	Milestones	Monitoring Activities
1991	Interim repairs to existing treatment plants completed, pumping capacity increased. Sludge discharge into Boston Harbor ceased in December.	Outfall Monitoring Task Force designs Phase I Outfall Monitoring Plan, which formulated monitoring hypotheses to be tested.
1992		MWRA initiates Baseline (Phase I) monitoring.
1995	New primary treatment facility at DITP became operational in January.	Baseline monitoring continues
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. Baseline monitoring continues.
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.	Baseline monitoring continues
2000	Outfall is relocated to Massachusetts Bay, 9.5 miles from DITP, in September.	Regulatory agencies issue NPDES permit in August which incorporates Ambient Monitoring Plan and Contingency Plan by reference. Monitoring changes from baseline to discharge (monitoring design remains consistent).
2001	Secondary Battery C start-up in March.	Contingency Plan revised to reflect new information since 1997.
2004	Inter-island tunnel transport for sludge and improvements to secondary treatment facilities completed.	MWRA completes four years of discharge monitoring, implements Revision 1 of Ambient Monitoring Plan.
2010	Improvements to primary and secondary clarifiers and floatables control completed.	MWRA completes ten years of discharge monitoring, completes draft of Revision 2 of Ambient Monitoring Plan.
2011		MWRA begins monitoring according to Revision 2 of Ambient Monitoring Plan.

MWRA carried out a major repair and upgrade to the primary and secondary treatment facilities, including improved floatables removal.

Better dilution was achieved in 2000, by diverting the effluent discharge from Boston Harbor to a 9.5-mile-long outfall and diffuser system, located offshore in Massachusetts Bay. The Massachusetts Bay site was selected because it had a water depth and current patterns that would promote effective dilution, it was the least likely of the alternative sites to affect sensitive resources, and it was feasible to construct an outfall tunnel to the location.

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

The outfall is but one of many of the uses, both human and natural, now considered to be "ecosystem services" of Massachusetts and Cape Cod bays. Figures 1-1 through 1-4 [1] depict some of the multiple uses of Massachusetts and Cape Cod Bays. Some of these uses, such as the locations of beaches and shellfish beds, were factors considered in the outfall siting process and helped drive the decision to build a long outfall. Other uses, such as ocean sanctuaries and protected whales were considered in the permitting of the treatment plant. And when outfall ambient monitoring data are interpreted, it is helpful to bear in mind the many wastewater sources to the bays and the potential impacts of commercial uses of the bays.

The source reduction and improved treatment components of the Boston Harbor Project were widely recognized as benefiting the marine environment and the people of the region. Moving the effluent outfall from the harbor to Massachusetts Bay raised some concerns, which were expressed as general, continuing questions:

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

These concerns were recognized by MWRA and the NPDES permit for the outfall. The permit established strict limits on the discharge, and the outfall monitoring program, which was already underway, was formally established as a permit condition.

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[1] Maps on following pages were prepared by Peter Ralston and Rita Berkeley of MWRA, based on data from the Massachusetts Ocean Resource Information System, (Massachusetts Office of Coastal Zone Management, Executive Office of Energy and Environmental Affairs).

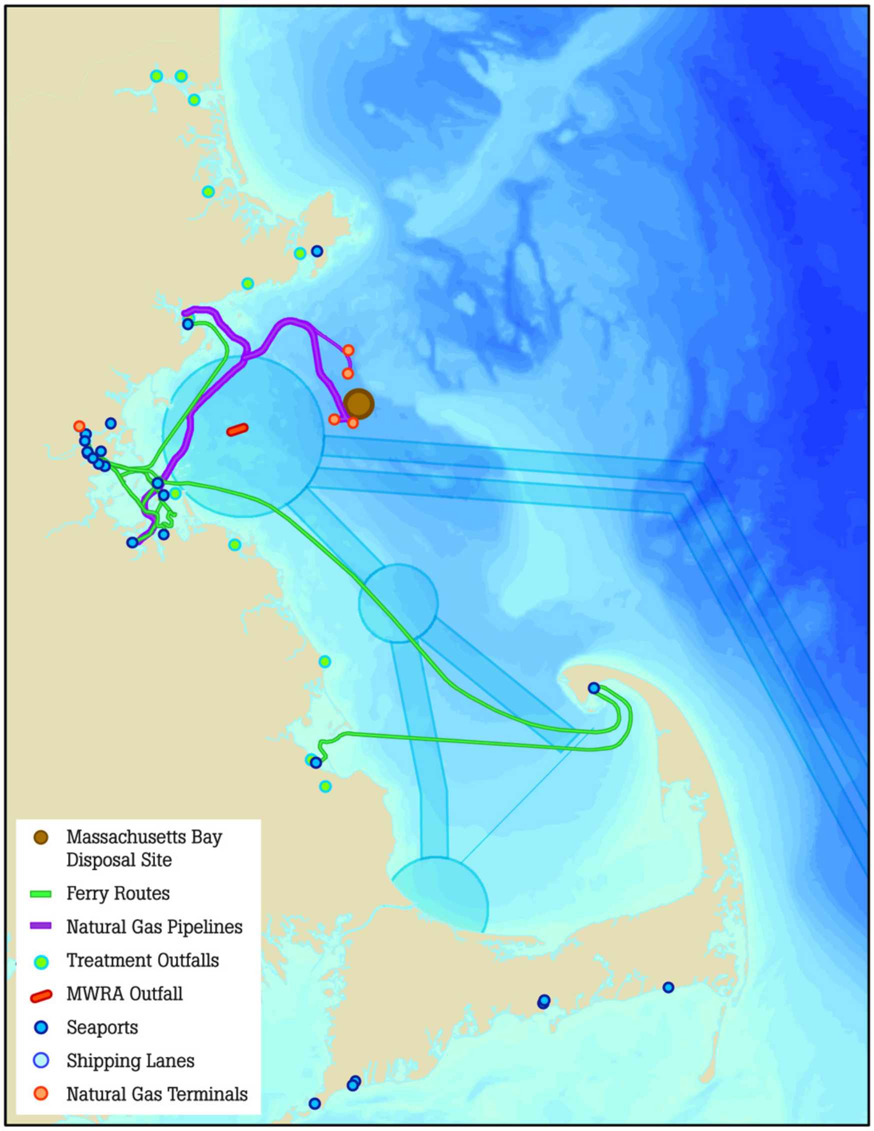

Figure 1-1. Massachusetts and Cape Cod bays municipal, commercial, and industrial uses. Locations of natural gas pipelines and terminals provided by Northeast Gateway and Neptune LNG.

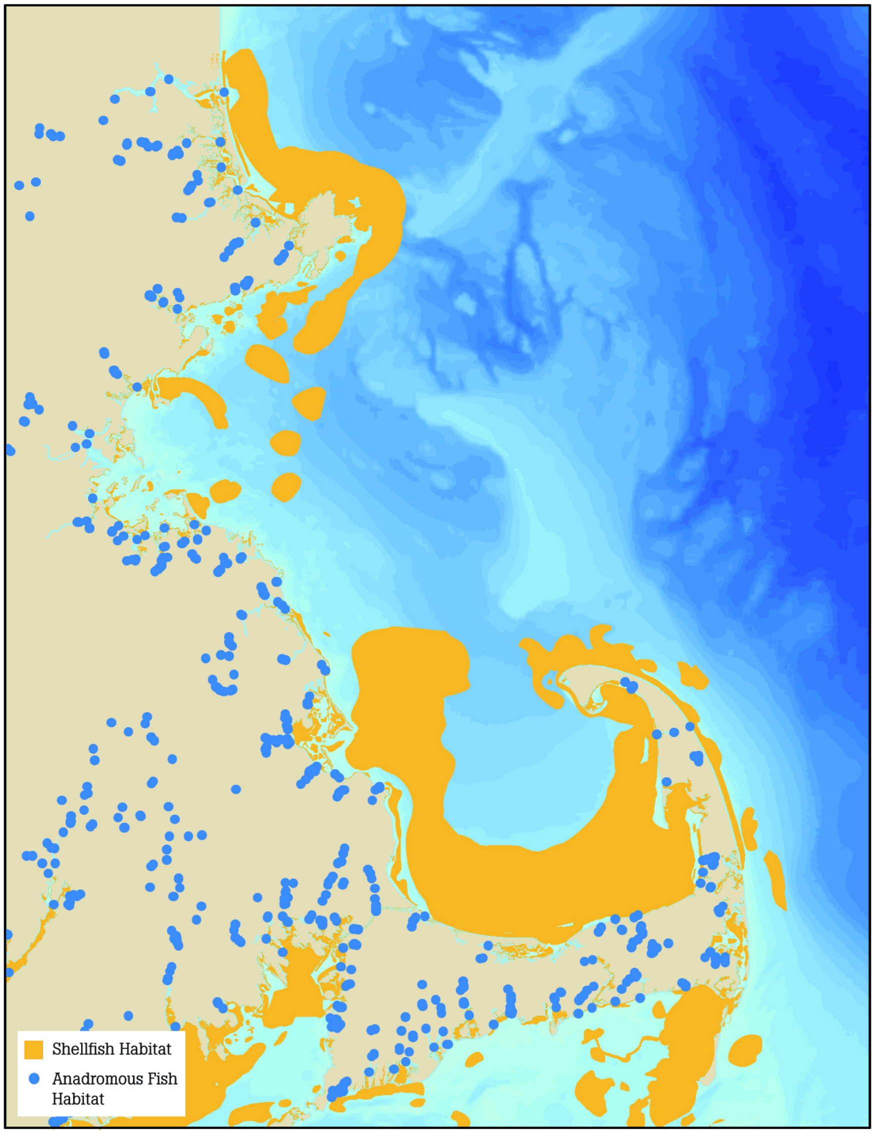

Figure 1-2. Massachusetts and Cape Cod Bays shellfish and anadromous fish habitat.

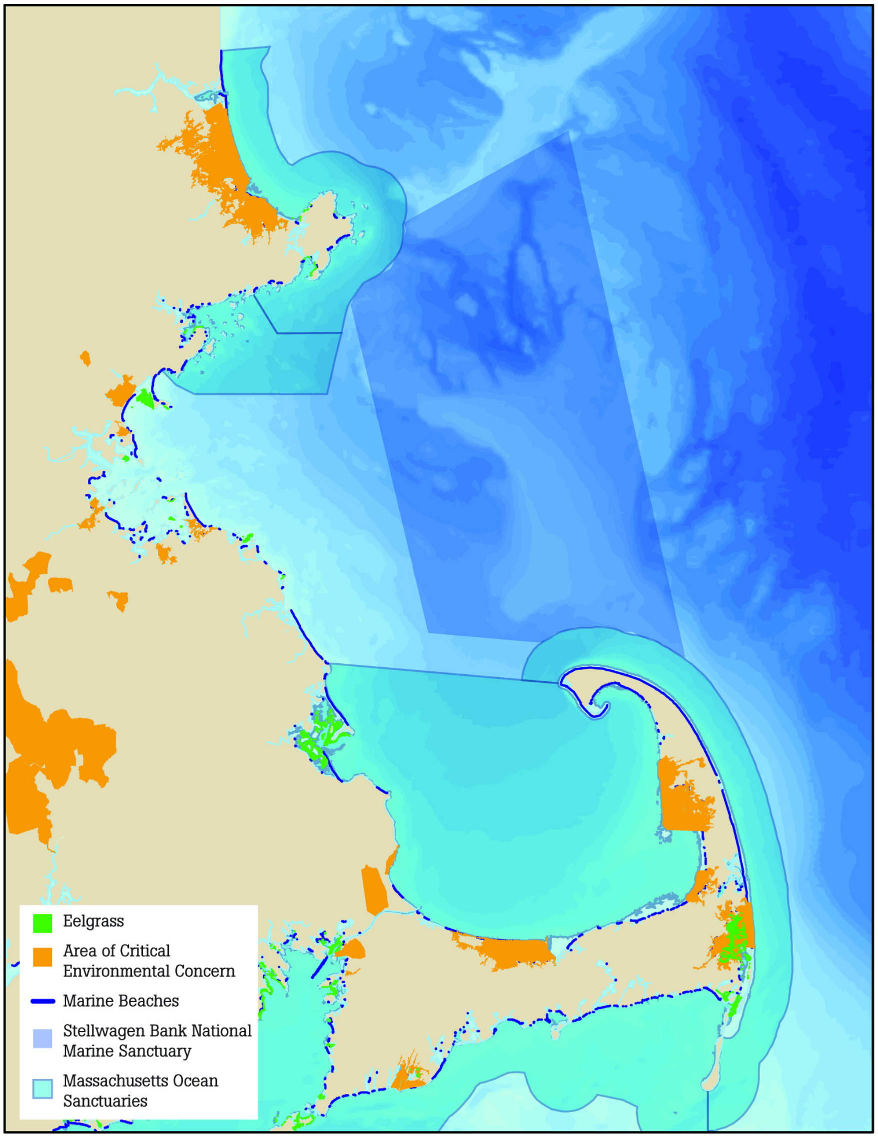

Figure 1-3. Massachusetts ocean special habitats and sanctuaries.

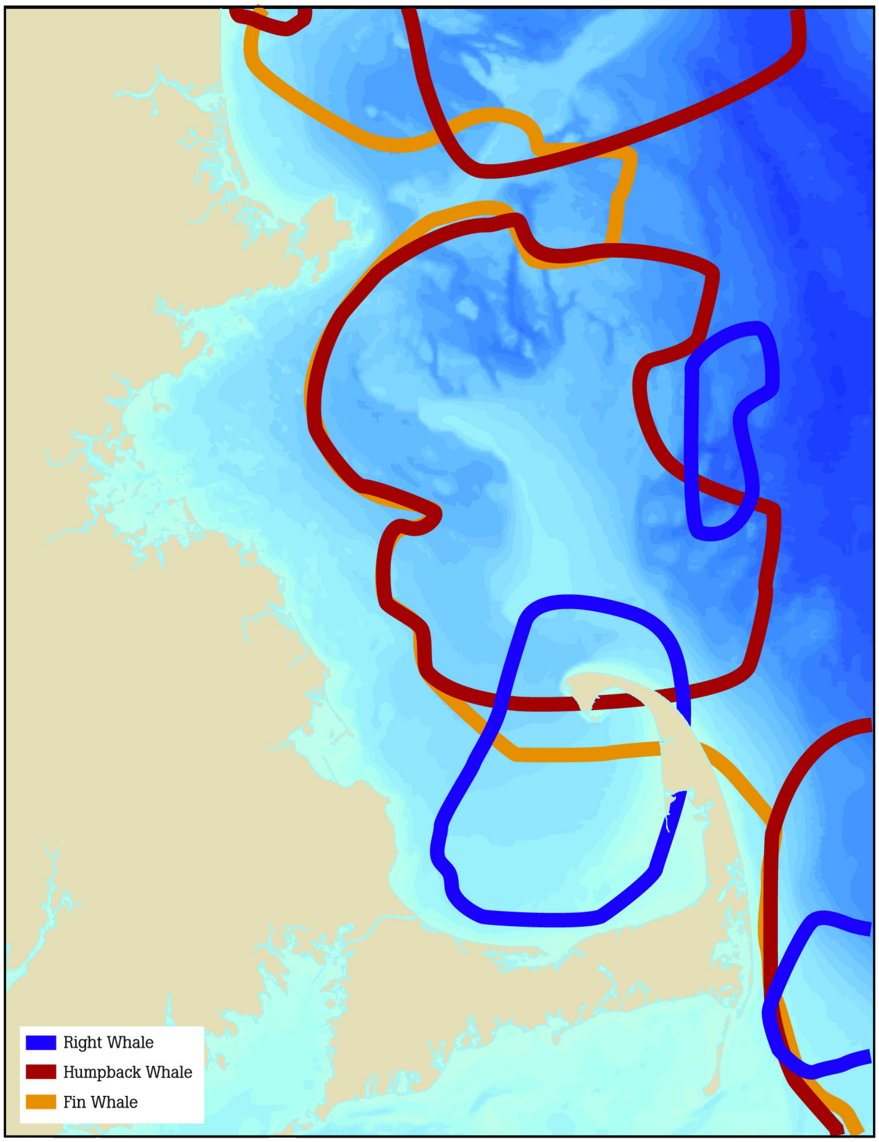

Figure 1-4. Whale habitats in Massachusetts and Cape Cod bays, and offshore. The map is adapted from information on whale sightings/unit effort and shows the approximate boundaries for the top two quartiles of sightings/unit effort for three species, that is, the areas where most sightings of those species occurred. The fin whale habitat encompasses the entire area to the east (right) of the line.

Outfall Permit

The permit issued by EPA and MADEP under NPDES became effective on August 9, 2000. The permit limits discharges of pollutants and requires MWRA to monitor the effluent for compliance with permit limits and to monitor discharges of priority pollutants. Additional requirements include reporting on treatment plant and collection system operation and maintenance, and implementation of best management practices to prevent accidental discharge of pollutants to the environment. There are extensive pollution-prevention requirements, which limit industrial discharges of pollutants to the sewer system. Two unusual requirements are extensive monitoring of ambient receiving waters in accordance with the Effluent Outfall Ambient Monitoring Plan (MWRA 1991, 1997a, 2004, 2010),[2] and implementation of a Contingency Plan (MWRA 1997b, 2001), which identifies relevant environmental quality parameters and thresholds that, if exceeded, would require a response.

EPA and MADEP established an independent panel of scientists to review monitoring data and provide advice on key scientific issues related to the permit. This panel, the Outfall Monitoring Science Advisory Panel (OMSAP, Table 1-2), conducts peer reviews of monitoring reports, evaluates data, and advises EPA and MADEP on scientific issues. OMSAP also provides advice concerning any proposed modifications to the monitoring or contingency plans.

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

[2] The first ambient monitoring plans were developed in response to the EPA Supplemental Environmental Impact Statement (SEIS) prepared as part of the outfall-siting process (EPA 1988).

Table 1-2. Panel and committee organizations that review monitoring data and provide advice.

<table>
<tr><th colspan="2">Outfall Monitoring Science Advisory Panel (OMSAP)</th></tr>
<tr><td colspan="2">Woods Hole Oceanographic Institution
University of Rhode Island
Massachusetts Institute of Technology Sea Grant
University of Massachusetts at Boston
Harvard School of Public Health</td></tr>
<tr><th>Inter-agency Advisory Committee (IAAC)</th><th>Public Interest Advisory Committee (PIAC)</th></tr>
<tr><td>US Geological Survey
MA Coastal Zone Management
US Army Corps of Engineers
Stellwagen Bank National Marine Sanctuary
MA Department of Environmental Protection
MA Division of Marine Fisheries
US Environmental Protection Agency
National Marine Fisheries Service</td><td>Save the Harbor/Save the Bay
Center for Coastal Studies
Wastewater Advisory Committee
Conservation Law Foundation
Massachusetts Audubon Society
New England Aquarium
MWRA Advisory Board
Association for the Preservation of Cape Cod
Safer Waters in Massachusetts
The Boston Harbor Association
Cape Cod Commission</td></tr>
</table>

Monitoring Program

EPA and MADEP require monitoring to ensure compliance with the permit, to assess whether the outfall has effects beyond the area identified in the SEIS as acceptable, and to collect data useful for outfall management. In anticipation of these requirements, MWRA began some studies during 1989–1991 and implemented a broad baseline-monitoring program in 1992. Outfall ambient monitoring plans were originally developed and refined under the direction of an Outfall Monitoring Task Force (OTMF), made up of scientists, regulators, and environmental advocacy groups (MWRA 1991, 1997a). The monitoring program was designed to compare environmental quality of the Massachusetts Bay system, including Boston Harbor and Cape Cod Bay, before and after the outfall re-location from the harbor to the bay. (The OMTF was disbanded upon creation of OMSAP.)

Because the first years of monitoring following diversion of effluent from Boston Harbor to Massachusetts Bay found no unexpected results, changes to the monitoring program were approved by EPA and MADEP, and a new plan (MWRA 2004) was implemented in the 2004 monitoring year. In 2010, the monitoring plan was revised again (MWRA 2010) to focus more on the area most likely to be affected by the discharge, with sufficient reference stations for comparison. The design was made more consistent, and some special studies were ended.

The initial ambient monitoring plan expanded the general questions of public concern by translating them into possible "environmental responses," which were more specific questions directly related to the outfall (Table 1-3). To answer those questions, the monitoring program focused on critical constituents of treatment plant effluent, such as nutrients, organic material, toxic contaminants, pathogens, and solids. Presence and potential effects of these constituents continue to be evaluated within the context of four environmental measurement areas: effluent, water column, sea floor, and fish and shellfish (Table 1-4). The basic program is augmented by special studies, which are conducted in response to specific permit requirements, scientific questions, and environmental concerns.

By 2011, after nine years of baseline monitoring and eleven years of post-diversion monitoring, most or all of the monitoring questions that had been developed at the beginning of the program had been answered. As had been expected, monitoring has been able to detect minimal effects in the immediate vicinity of the outfall, but there has been no indication of unexpected or broad-range changes. The questions posed at the beginning of the monitoring program and their answers are summarized in the back matter at end of this report.

Table 1-3. Public concerns and environmental responses presented in the original monitoring plan (MWRA 1991).

Public Concern: Is it safe to eat fish and shellfish?

- Will toxic chemicals accumulate in the edible tissues of fish and shellfish, and thereby contribute to human health problems?
- Will pathogens in the effluent be transported to shellfishing areas where they could accumulate in the edible tissues of shellfish and contribute to human health problems?

Public Concern: Are natural/living resources protected?

- Will nutrient enrichment in the water column contribute to an increase in primary production?
- Will enrichment of organic matter contribute to an increase in benthic respiration and nutrient flux to the water column?
- Will increased water-column and benthic respiration contribute to depressed oxygen levels in the water?
- Will increased water-column and benthic respiration contribute to depressed oxygen levels in the sediment?
- Will nutrient enrichment in the water column contribute to changes in plankton community structure? (Such changes could include stimulation of nuisance or noxious algal blooms and could affect fisheries.)
- Will benthic enrichment contribute to changes in community structure of soft-bottom and hard-bottom macrofauna, possibly also affecting fisheries?
- Will the water column near the diffuser mixing zone have elevated levels of some contaminants?
- Will contaminants affect some size classes or species of plankton and thereby contribute to changes in community structure and/or the marine food web?
- Will finfish and shellfish that live near or migrate by the diffuser be exposed to elevated levels of some contaminants, potentially contributing to adverse health in some populations?
- Will the benthos near the outfall mixing zone and in depositional areas farther away accumulate some contaminants?
- Will benthic macrofauna near the outfall mixing zone be exposed to some contaminants, potentially contributing to changes in community structure?

Public Concern: Is it safe to swim?

- Will pathogens in the effluent be transported to waters near swimming beaches, contributing to human health problems?

Public Concern: Are aesthetics being maintained?

- Will changes in water clarity and/or color result from the direct input of effluent particles or other colored constituents, or indirectly through nutrient stimulation of nuisance plankton species?
- Will the loading of floatable debris increase, contributing to visible degradation?

Table 1-4. Monitoring program objectives and analyses.

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

Contingency Plan

The Contingency Plan (MWRA 1997b, 2001) describes how, if monitoring results indicate a possible environmental problem, MWRA and the regulatory agencies will respond to determine the cause of the problem and to specify the corrective actions that should be taken if the problem appears to be related to the discharge. The Contingency Plan identifies parameters that represent environmentally significant components of the effluent or the ecosystem and that, if specific threshold levels are exceeded, indicate a potential for environmental risk (Table 1-5). The plan provides a process for evaluating parameters that exceed thresholds and formulating appropriate responses.

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

Table 1-5. Contingency Plan threshold parameters.

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

Exceeding warning levels could, in some circumstances, indicate a need for a response to avoid potential adverse environmental effects. The response would include early notification of EPA and MADEP and, if it appeared that the outfall had contributed to adverse environmental effects, the quick development of a response plan. Response plans are to include a schedule for implementing actions, such as making adjustments in plant operations or undertaking an engineering study to formulate specific corrective activities.

A process for modifying the Contingency Plan to incorporate new scientific information and improved understandings resulting from the monitoring program is set forth in the NPDES permit. Revision 1 of the Contingency Plan was approved in 2001.

Data Management

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

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

Reporting

MWRA’s NPDES permit requires regular reports on effluent quality and extensive reporting on the monitoring program. A variety of reports are submitted to OMSAP and state and federal regulatory agencies for review (Table 1-6). Changes to the monitoring program or the Contingency Plan must be reviewed by regulators and published in the *Environmental Monitor*. Data that exceed Contingency Plan thresholds and corrective actions must also be reported. Data that exceed thresholds must be reported within five days after the results become available, and MWRA must make all reasonable efforts to report all data on thresholds within 90 days of each sampling event.

Table 1-6. Monitoring reports submitted to OMSAP and regulatory agencies.

Reports	Description/Objectives
Outfall Monitoring Plans Phase I—Baseline Studies (MWRA 1991) Phase II—Discharge Ambient Monitoring (MWRA 1997a, 2004, 2010)	Discuss goals, strategy, and design of baseline and discharge monitoring programs.
Contingency Plan (MWRA 1997b, 2001)	Describes development of threshold parameters and values and MWRA's planned contingency measures.
Program Area Summary Reports	Summarize, interpret, and explain annual results for effluent, water column, benthos, and fish and shellfish monitoring areas.
Special Studies Reports	Discuss, analyze, and cross-synthesize data related to specific issues in Massachusetts and Cape Cod bays.
Outfall Monitoring Overviews	Summarize monitoring data and include information relevant to the Contingency Plan.

Reports are posted at http://www.mwra.state.ma.us/harbor/enquad/trlist.html, the MWRA technical reports site, and copies are placed in repository libraries in Boston and on Cape Cod. OMSAP also holds public workshops at which outfall monitoring results are presented.

Outfall Monitoring Overview

Among the many reports that MWRA completes, outfall monitoring overviews have been prepared for most baseline-monitoring years (Galya et al. 1996, 1997a, 1997b; Werme and Hunt 2000a, 2000b) and for each year that the permit has been in place and the outfall has been on-line (Werme and Hunt 2001, 2002, 2003, 2004, 2005, 2006, 2007; Werme et al. 2008, 2009, 2010, 2011, 2012). Overviews for 1994 through 1999 included only baseline information. With the Massachusetts Bay outfall discharge beginning in September 2000, subsequent reports have included information relevant to the Contingency Plan, including threshold exceedances, responses, and corrective actions. When data suggest that monitoring activities, parameters, or thresholds should be changed, the report summarizes those recommendations. Overviews also include information on Stellwagen Bank National Marine Sanctuary, meeting a permit requirement that MWRA report on monitoring results that are relevant to the sanctuary.

Overviews prepared through the 2006 monitoring year included the background information as well as results. A separate background document (Werme and Hunt 2008) was prepared in conjunction with the 2007 Outfall Monitoring Overview for the monitoring years through 2010.

This updated background document presents information that will not change substantially from year-to-year beginning in monitoring year 2011. It describes the environmental concerns that have driven the monitoring program, monitoring designs, and Contingency Plan thresholds for effluent, water-column, sea-floor, and fish-and-shellfish monitoring. It also includes sections on special studies and on the Stellwagen Bank National Marine Sanctuary.

2. Effluent

Background

Pollution Prevention

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

The MWRA Toxic Reduction and Control (TRAC) program sets and enforces limits on the types and amounts of pollutants that industries can discharge into the sewer system and works to encourage voluntary reductions in the use of toxic chemicals. TRAC has also implemented programs to reduce mercury from dental facilities and to educate the public about proper disposal of hazardous wastes. A booklet, *A Healthy Environment Starts at Home* identifies household products that could be hazardous and recommends alternatives. The booklet is available through the MWRA website, at http://www.mwra.state.ma.us/03sewer/trac/athome.htm.

Secondary treatment further reduces the concentrations of contaminants of concern, except for nutrients, which are not significantly affected by the secondary treatment process. DITP removes approximately 85–90% of the suspended solids and biochemical oxygen demand (BOD), 50–90% of the toxic chemicals, and about 15% of the nitrogen from the influent.

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

Environmental Concerns

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

Table 2-1. Monitoring questions related to effluent.

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

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

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

Toxic contaminants include heavy metals, such as copper and lead, and organic compounds, such as polychlorinated biphenyls (PCBs), pesticides, polycyclic aromatic hydrocarbons (PAHs), and petroleum hydrocarbons. Toxic contaminants can lower survival and reproduction rates of marine organisms. Some toxic contaminants can accumulate in marine life, potentially affecting human health through seafood consumption.

Organic material, a major constituent of untreated sewage, consumes oxygen as it decays. Even under natural conditions, oxygen levels decline in bottom waters during the late summer, so any effluent component that might further decrease oxygen levels is a concern. Too much organic material could also disrupt animal communities on the sea floor.

Suspended solids, small particles in the water column, decrease water clarity and consequently affect growth and productivity of algae and other marine plants. Excess suspended solids also detract from people's aesthetic perception of the environment.

In marine waters, nitrogen is the limiting **nutrient** that controls growth of algae and other aquatic plants. Excess nitrogen can be detrimental, leading to eutrophication and low levels of dissolved oxygen, excess turbidity, and nuisance algal blooms. Nutrients, particularly dissolved forms, are the only components of sewage entering the treatment plant that are not substantially reduced by secondary treatment.

Oil and grease slicks and floating debris known as **floatables** pose aesthetic concerns. Plastic debris can be harmful to marine life, as plastic bags are sometimes mistaken for food and clog the digestive systems of turtles and marine mammals. Plastic and other debris can also entangle animals and lead to infection or drowning.

Sewage effluent is disinfected by addition of a form of **chlorine**, sodium hypochlorite, which is the active ingredient in bleach. While sodium hypochlorite is effective in destroying pathogens, at high enough concentrations, it is harmful to marine life. Consequently, MWRA dechlorinates the effluent with sodium bisulfite before discharge.

State water quality standards dictate that effluent discharges not change the **pH** of the ambient seawater more than 0.5 standard units on a scale of 1 to 14. Consequently, the outfall permit sets both upper and lower values for pH of the effluent.

Monitoring Design

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

The permit includes numeric limits (Table 2-2) for suspended solids, fecal coliform bacteria, pH, chlorine, PCBs, and carbonaceous biochemical oxygen demand (cBOD). In addition, state water quality standards establish limits for 158 pollutants, and the permit prohibits any discharge that would cause or contribute to exceeding any of those limits. Allowable concentrations of contaminants were based on the predicted dilution at the outfall and verified by field studies of outfall plumes in 2001.

Table 2-2. Permit and Contingency Plan monitoring requirements.

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

The permit also prohibits discharge of nutrients in amounts that would cause eutrophication, and it requires MWRA to test the toxicity of the effluent as a whole on sensitive organisms and establishes limits based on those tests.

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

The Contingency Plan also sets limits for overall plant performance, annual nitrogen load, floatables, and oil and grease. The MWRA monitoring plan also includes special studies of toxic contaminants using sensitive methods, and nutrients (Table 2-3 and Table 2-4). These measurements are made to better interpret field-monitoring results.

Table 2-3. Special study effluent toxic contaminant monitoring.

Parameter	Sample Type	Frequency
Acid base neutrals	24-hr composite	Bimonthly
Volatile Organic Compounds	Grab	
Low detection limit analyses		
Cadmium	24-hr composite	4 times/month
Copper		
Chromium		
Mercury		
Lead		
Molybdenum		
Nickel		
Silver		
Zinc		
17 chlorinated pesticides		
Extended list of PAHs		
20 PCB congeners		

Table 2-4. Special study effluent nutrient monitoring.

Parameter	Sample Type	Frequency
Total Kjeldahl nitrogen	24-hr composite	Weekly
Ammonia		
Nitrate		
Nitrite		
Total phosphorus		
Total phosphate		

Contingency Plan Thresholds

Contingency Plan thresholds for effluent monitoring include warning levels for all parameters and caution levels for PCBs, plant performance, and nitrogen loads (Table 2-5). Floatable debris is present in low amounts in the effluent (Rex et al. 2008, Rex and Tyler, 2011), and one change to the monitoring plan in 2010 was the ending of sampling for effluent floatables.

Table 2-5. Contingency Plan threshold values for effluent monitoring.

Parameter	Caution Level	Warning Level
pH	None	<6 or >9
Fecal coliform bacteria	None	14,000 fecal coliforms/100 ml (monthly 90th percentile, weekly geometric mean, maximum daily geometric mean, and minimum of 3 consecutive samples)
Chlorine, residual	None	631 µg/L daily, 456 µg/L monthly
Total suspended solids	None	45 mg/L weekly 30 mg/L monthly
cBOD	None	40 mg/L weekly, 25 mg/L monthly
Toxicity	None	Acute: effluent LC50 <50% for shrimp and fish Chronic: effluent NOEC for fish survival and growth and sea urchin fertilization <1.5% effluent
PCBs	Aroclor=0.045 ng/L	
Plant performance	5 violations/year	Noncompliance >5% of the time
Flow	None	Flow >436 for annual average of dry days
Total nitrogen load	12,500 mtons/year	14,000 mtons/year
Oil and grease	None	15 mg/L weekly

3. Water Column

Background

Circulation and Water Properties

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

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

As in many coastal waters, during the winter, the water column is well-mixed from top to bottom, and nutrient levels are high. As light levels increase in the early spring, phytoplankton populations often begin a period of rapid growth known as a spring bloom. Contrary to popular wisdom, however, strong spring blooms do not occur every year. During the years in which they occur, spring blooms begin in the shallowest waters of Cape Cod Bay, with blooms in the deeper Massachusetts Bay waters following two to three weeks later. Spring phytoplankton blooms are typically followed by an increase in zooplankton abundance. These zooplankton populations are food for many animals, including the endangered North Atlantic right whale (*Eubalaena glacialis*), a seasonal visitor to the region, which feeds on large zooplankton species on Stellwagen Bank and in Cape Cod Bay during the winter and spring.

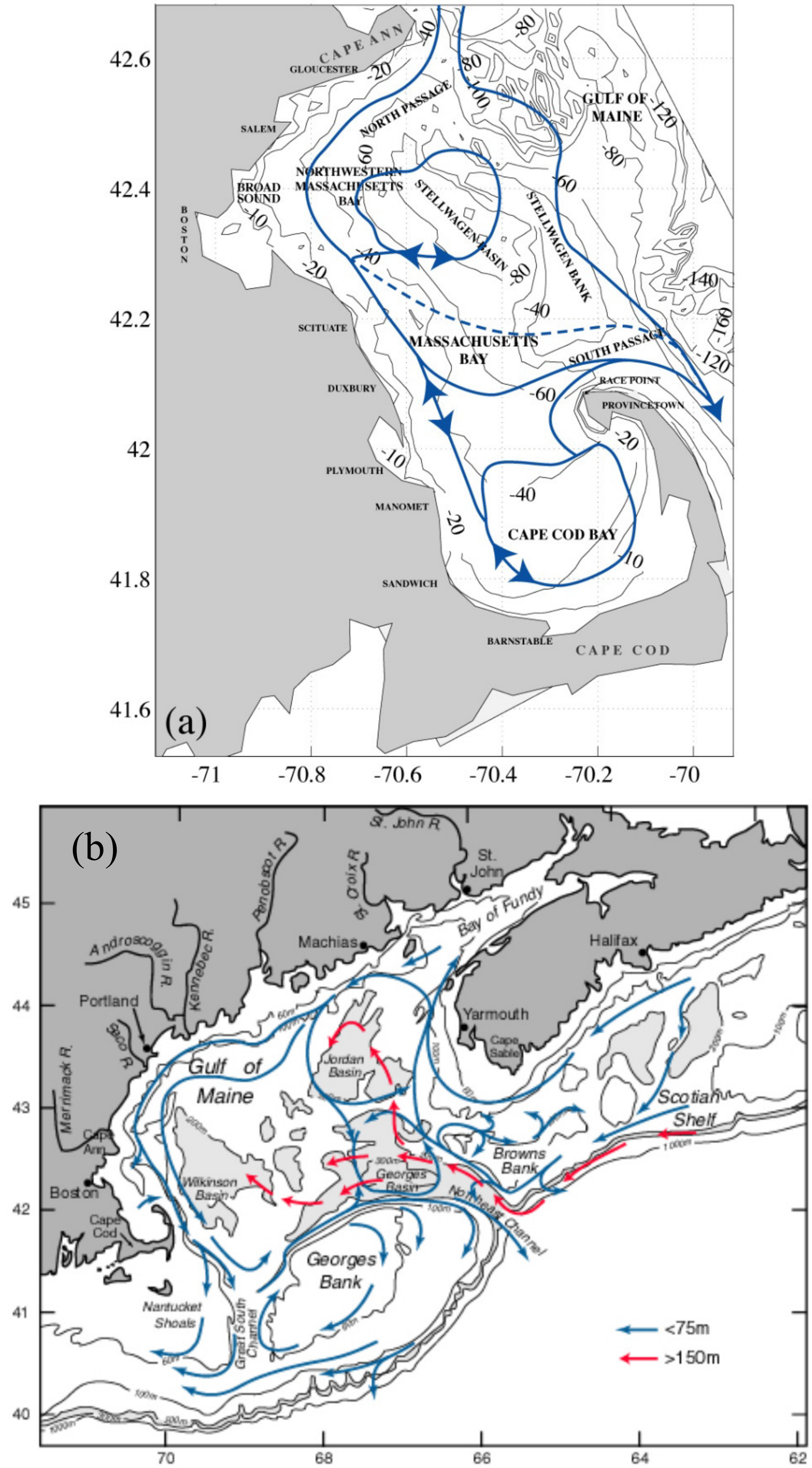

Figure 3-1. (a) General circulation within Massachusetts Bay. Reprinted from Journal of Marine Systems, Vol. 29, Author: PFJ Lermusiaux, "Evolving the subspace of the three-dimensional multiscale ocean variability: Massachusetts Bay," pp 385-422 © 2001 with permission from Elsevier. **(b) General circulation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

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

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

Environmental Concerns

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

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

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

Is it safe to eat fish and shellfish?

Will pathogens in the effluent be transported to shellfishing areas where they could accumulate in the edible tissues of shellfish and contribute to human health problems?

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

Are natural/living resources protected?

Will nutrient enrichment in the water column contribute to an increase in primary production?

Will nutrient enrichment in the water column contribute to changes in plankton community structure?

- Have nutrient concentrations changed in the water near the outfall; have they changed at farfield stations in Massachusetts Bay or Cape Cod Bay, and, if so, are they correlated with changes in the nearfield?
- Has the phytoplankton biomass changed in the vicinity of the outfall or at selected farfield stations in Massachusetts Bay or Cape Cod Bay, and, if so, can changes be correlated with effluent or ambient water nutrient concentrations, or can farfield changes be correlated with nearfield changes?
- Have the phytoplankton production rates changed in the vicinity of the outfall or at selected farfield stations, and, if so, can these changes be correlated with effluent or ambient water nutrient concentrations, or can farfield changes be correlated with nearfield changes?
- Has the abundance of nuisance or noxious phytoplankton species changed in the vicinity of the outfall?
- Has the species composition of phytoplankton or zooplankton changed in the vicinity of the outfall or at selected farfield stations in Massachusetts Bay or Cape Cod Bay? If so, can these changes be correlated with effluent or ambient water nutrient concentrations, or can farfield changes be correlated with nearfield changes?

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

- Do the concentrations (or percent saturation) of dissolved oxygen in the vicinity of the outfall and at selected farfield stations meet the state water quality standard?
- Have the concentrations (or percent saturation) of dissolved oxygen in the vicinity of the outfall or at selected farfield stations in Massachusetts Bay or Cape Cod Bay changed relative to pre-discharge baseline or a reference area? If so, can changes correlated with effluent or ambient water nutrient concentrations, or can farfield changes be correlated with nearfield changes?

Is it safe to swim?

Will pathogens in the effluent be transported to waters near swimming beaches, contributing to human health problems?

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

Are aesthetics being maintained?

Will changes in water clarity and/or color result from the direct input of effluent particles or other colored constituents, or indirectly through nutrient stimulation of nuisance plankton species?

Will the loading of floatable debris increase, contributing to visible degradation?

- Has the clarity and/or color of the water around the outfall changed?
- Has the amount of floatable debris around the outfall changed?

Information on transport and fate necessary to answer all the questions

- Are model estimates of short-term (less than 1 day) effluent dilution and transport accurate?
- What are the nearfield and farfield water circulation patterns?
- What is the farfield fate of dissolved, conservative, or long-lived effluent constituents?

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

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

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

Monitoring Design

Water-column monitoring includes assessments of physical conditions, water quality, phytoplankton, and zooplankton. Regular monitoring includes four components: Massachusetts Bay monitoring surveys; Cape Cod Bay and Stellwagen Bank National Marine Sanctuary surveys; continuous recording; and remote sensing. Plume-tracking studies conducted in 2001 verified the expected dilution at the outfall and confirmed predictions that concentrations of bacteria and toxic contaminants in the discharged effluent are very low. Additional, rapid-response surveys may be conducted during *Alexandrium fundyense* red tide blooms or in response to wet weather and high flows, when floatable debris may be present.

The water-column monitoring program was redesigned in 2010, with changes implemented in 2011. Nine Massachusetts Bay outfall monitoring surveys at eleven stations provide vertical and horizontal profiles of physical, chemical, and biological characteristics of the water column in the area around the outfall (the nearfield), where some effects of the effluent were expected and have been observed, and at reference stations. Similar measurements at three stations assess the health of Cape Cod Bay and the Stellwagen Bank National Marine Sanctuary. Every effort is made to collect all samples within two days. Figure 3-2 shows the locations of monitoring stations for regular surveys and Figure 3-3 shows locations for special surveys in response to *Alexandrium fundyense* blooms. Tables 3-2 through 3-7 present the components of monitoring, sampling schedule, stations, and parameters measured.

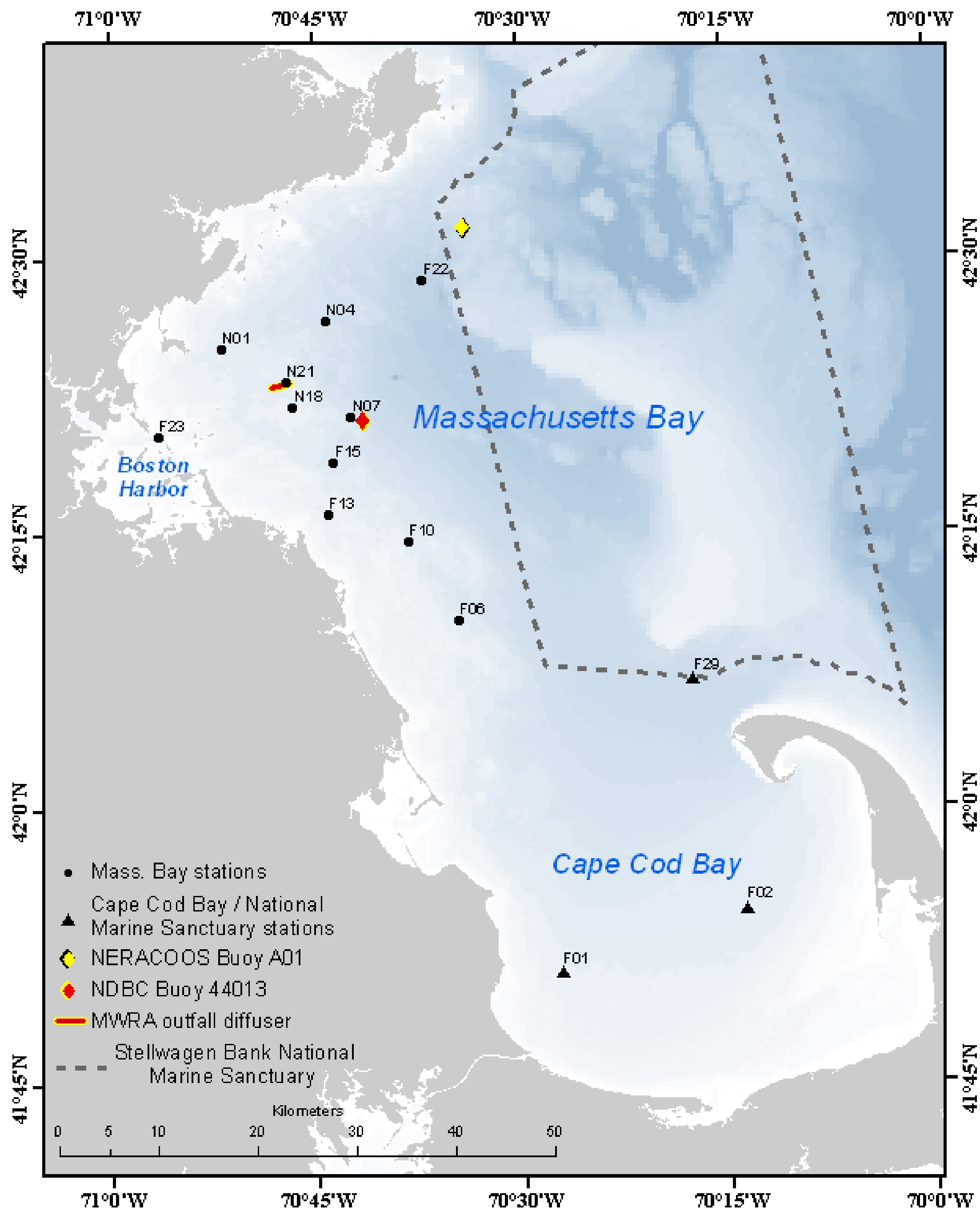

Figure 3-2. Water-column monitoring stations. Also shown are two instrumented buoys, one operated by the Northeastern Regional Association of Coastal and Ocean Observing Systems (NERACOOS) and the other by the National Oceanic and Atmospheric Administration National Data Buoy Center (NDBC); the MWRA outfall diffuser; and the Stellwagen Bank National Marine Sanctuary.

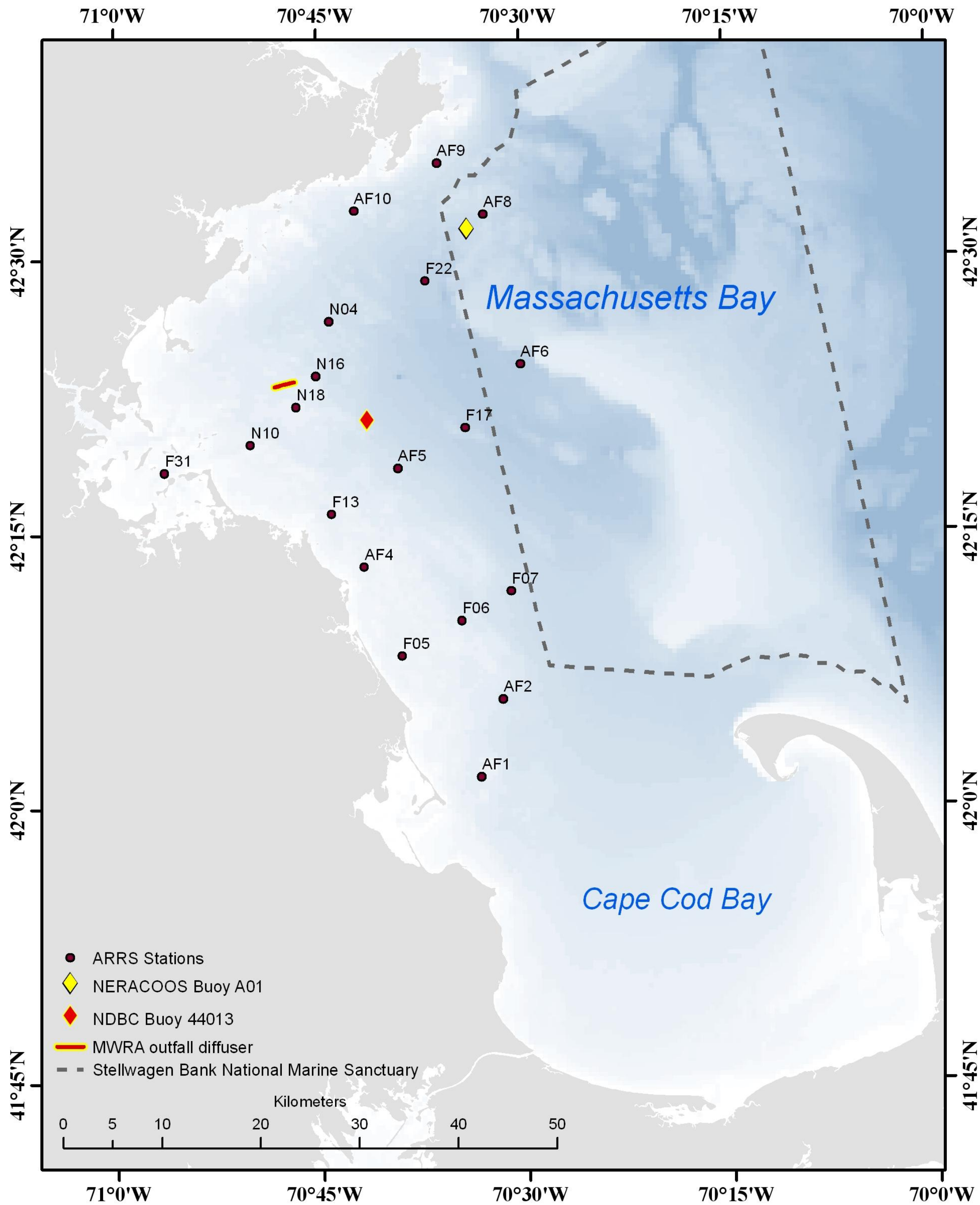

Figure 3-3. *Alexandrium* Rapid Response Survey (ARRS) stations. Also shown are two instrumented buoys, one operated by the Northeastern Regional Association of Coastal and Ocean Observing Systems (NERACOOS) and the other by the National Oceanic and Atmospheric Administration National Data Buoy Center (NDBC); the MWRA outfall diffuser; and the Stellwagen Bank National Marine Sanctuary.

Parameters measured in the water column include physical conditions, dissolved oxygen, dissolved inorganic and organic nutrients, particulate forms of nutrients, chlorophyll, total suspended solids, phytoplankton abundance and species composition, and zooplankton abundance and species composition. Nutrients measured include the major forms of nitrogen, phosphorus, and silica. The measurements focus on the dissolved inorganic forms, which are most readily used by phytoplankton. The surveys also include visual observations in the outfall area to assess the presence of floatable debris. The presence of debris is assessed visually in the vicinity of the outfall site during water-column surveys and twice a year by net tows after DITP blending events. Fat particles collected during net tows are analyzed for PCBs, PAHs, pesticides, and mercury.

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

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

Task	Objective
Massachusetts Bay monitoring surveys	Collect water quality and plankton data near the outfall and at reference stations
Cape Cod Bay and Stellwagen Bank surveys	Collect water quality and plankton data in Cape Cod Bay and Stellwagen Bank National Marine Sanctuary
Moorings	Provide continuous oceanographic data near outfall and off Cape Ann
Remote sensing	Provides oceanographic data on a regional scale through satellite imagery

Table 3-3. Water-column survey schedule.

When	Target Week	Purpose
Early February	6	Nutrient conditions near start of spring bloom
March	12	Spring bloom
Early April	15	Capture *Phaeocystis pouchetii* bloom. Late winter/spring bloom nutrients
Mid-May	20	Nutrient/water column conditions at end of winter-spring, *Alexandrium fundyense*
Mid-June	25	Early summer stratification and nutrients. Mid-late red tide season
Mid-July	30	Mid-summer stratification and nutrients
Mid-August	34	Mid-summer stratification and nutrients
September	36	Nutrients, etc. prior to overturn.
Late October	43	Mid-fall bloom nutrients, dissolved oxygen minima

Table 3-4. Massachusetts Bay water-column monitoring stations.

Station	Water Depth (meters)	Location Relative to Outfall	Purpose
F22	80	17 km NE	Northern reference station Gulf of Maine influence Regional physical forcing relates to nearfield Dissolved oxygen Link between buoy and sampling data “Upstream” sentinel station in winter-spring
N04	50	7.1 km NE	Nearfield station Evaluate extent of plume northeast
N01	31	6.3 km NW	Nearfield station Evaluate extent of plume northwest
N21	35	60 m	Nearfield station Evaluate water quality at effluent zone of initial dilution Close to outfall Ammonium signature Primary “impact” station for comparison to other stations
N18	27	2.5 km S	Nearfield station. Close to outfall Ammonium signature Primary “impact” station for comparison to other stations
N07	50	7 km SE	Nearfield station Near NDBC buoy MWRA instruments-data comparison
F23	25	12 km E	Boston Harbor
F15	38	9 km S	Evaluate southward extent of plume
F13	25	14 km S	Near coastal (model, *Alexandrium fundyense*)
F10	33	20 km S	Furthest expected southern expression of effluent plume
F06	33	29 km SE	Southern reference station

Table 3-5. Water-column parameters measured in Massachusetts Bay. (Plankton are not sampled at station N21, because nearfield plankton is adequately characterized by data collected at the other four nearfield stations.)

Analyte	Depth	Parameter
Hydrographic vertical profile	Downcast data continuous, with upcast data at any sampled depths	Temperature Salinity Dissolved oxygen Chlorophyll fluorescence Transmissometry Irradiance Depth of sensors
Water chemistry	Five depths. Surface, bottom, and three intermediate depths which includes the chlorophyll maximum	Ammonium Nitrate Nitrite Total dissolved nitrogen Particulate nitrogen Phosphate Total dissolved phosphorus Particulate phosphorus Silicate Particulate carbon
Alexandrium	Two depths	Gene probe
Phytoplankton Zooplankton	Near surface Net tow for zooplankton	Identification, enumeration

Table 3-6. Cape Cod Bay–Stellwagen Bank National Marine Sanctuary water-column monitoring stations.

Station	Water Depth (meters)	Location Relative to Outfall	Purpose
F29	65	50 km SE	Evaluate nutrients and plankton in Stellwagen Bank National Marine Sanctuary
F02	32	70 km SE	Evaluate nutrients and plankton in Cape Cod Bay
F01	26	66 km SE	

Table 3-7. Water-column parameters in Cape Cod Bay and Stellwagen Bank National Marine Sanctuary.

Analyte	Depth	Parameter
Hydrographic vertical profile	Continuous downcast data from within 1m of surface to within 5m of bottom.	Temperature Salinity Dissolved oxygen Depth of sensor Chlorophyll fluorescence Irradiance
Water chemistry	Two depths Near-surface and Near-bottom	Nitrate + nitrite Ammonium Phosphate Total nitrogen Total phosphorus Extracted chlorophyll
Phytoplankton	Near-surface	Identification and enumeration
Zooplankton	Net tow	

Contingency Plan Thresholds

Threshold parameters for water-column monitoring include minimum dissolved oxygen concentrations and percent saturation in nearfield and Stellwagen Bank bottom waters, dissolved oxygen depletion rate in nearfield bottom waters, chlorophyll levels, abundance of nuisance algal species, and geographic extent of PSP toxin (Table 3-8). Oxygen concentrations and percent saturation are compared to background levels rather than to the caution and warning levels. Beginning in 2011, Contingency Plan thresholds and/or background levels for the water column were recalculated based on the revised sampling design (MWRA 2010).

Table 3-8. Contingency Plan threshold values for water-column monitoring. DO = dissolved oxygen

	Specific Parameter	Baseline	Caution Level	Warning Level
Bottom water nearfield	Dissolved oxygen concentration	Background 5th percentile 6.05 mg/L	Lower than 6.5 mg/L for any survey (June–October) unless background conditions are lower	Lower than 6.0 mg/L for any survey (June–October) unless background conditions are lower
	Dissolved oxygen percent saturation	Background 5th percentile 65.3%	Lower than 80% for any survey (June–October) unless background conditions are lower	Lower than 75% for any survey (June–October) unless background conditions are lower
Bottom water Stellwagen Basin	Dissolved oxygen concentration	Background 5th percentile 6.23 mg/L	6.5 mg/L for any survey (June–October) unless background conditions lower	Lower than 6.0 mg/L for any survey (June–October) unless background conditions are lower
	Dissolved oxygen percent saturation	Background 5th percentile 67.2%	Lower than 80% for any survey (June–October) unless background conditions	Lower than 75% for any survey (June–October) unless background conditions are lower
Bottom water nearfield	DO depletion rate (June-October)	0.024 mg/L/day	0.037 mg/L/day	0.049 mg/L/day
Chlorophyll nearfield	Annual	72 mg/m^2	108 mg/m^2	144 mg/m^2
	Winter/spring	50 mgml^2	199 mg/m^2	None
	Summer	51 mg/m^2	89 mg/m^2	None
	Autumn	90 mg/m^2	239 mg/m^2	None
Nuisance algae nearfield *Phaeocystis pouchetii*	Winter/spring	622,000 cells/L	2,860,000 cells/L	None
	Summer	72 cells/L	357 cells/L	None
	Autumn	370 cells/L	2,960 cells/L	None
Nuisance algae nearfield *Pseudo-nitzschia* spp.	Winter/spring	6,735 cells/L	17,900 cells/L	None
	Summer	14,635 cells/L	43,100 cells/L	None
	Autumn	10,050 cells/L	27,500 cells/L	None
Nuisance algae nearfield *Alexandrium fundyense*	Any nearfield sample	Baseline maximum = 163 cells/L	100 cells/L	None
Massachusetts shellfish resources	PSP toxin extent	Not applicable	New incidence	None

4. Sea Floor

Background

Bottom Characteristics and Sediment Transport

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

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

Environmental Concerns

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

If diversion of the nutrient loads to offshore were to cause eutrophication, the depressed levels of dissolved oxygen that were also a concern in water-column monitoring could adversely affect bottom-dwelling animals. An increase in the amounts of particles and organic matter to the bottom could disrupt normal benthic community structure in the vicinity of the discharge.

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

Are natural/living resources protected?

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

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

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

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

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

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

Although source control and treatment plant performance are designed to keep effluent contaminant concentrations too low to affect the sediments, concerns over the efficacy of treatment and early projections that primary-only treated effluent would be discharged for the first five years after the outfall came on-line led to questions about the potential for contaminant build-up. (Construction of the outfall tunnel took longer than initially projected; by the time the outfall discharge began in September 2000, about 80% of the effluent flow received secondary treatment.) Similarly, concentrations of particulate matter were expected to be low, but there remained some concern that bottom communities near the outfall could be affected by deposition.

Monitoring Design

Sea-floor monitoring includes several components: measurements of physical characteristics, sewage effluent tracers, and contaminant concentrations in sediments; sediment-profile imaging to provide a rapid assessment of sediment quality and benthic communities; studies of nearfield and farfield soft-bottom communities; and studies of hard-bottom communities. In 2011, MWRA implemented a revised monitoring plan for benthic monitoring (MWRA 2010). Eleven nearfield and three farfield stations were selected as a representative subset of stations for measurements of sediment characteristics, sediment chemistry, and benthic infauna (Figure 4-1). Sediment-profile imaging is done at the 23 nearfield stations monitored historically (Figure 4-2). Hard-bottom monitoring is conducted at the same locations as historically (Figure 4-3), but the frequency of surveys has been reduced from yearly to every three years, including 2011.

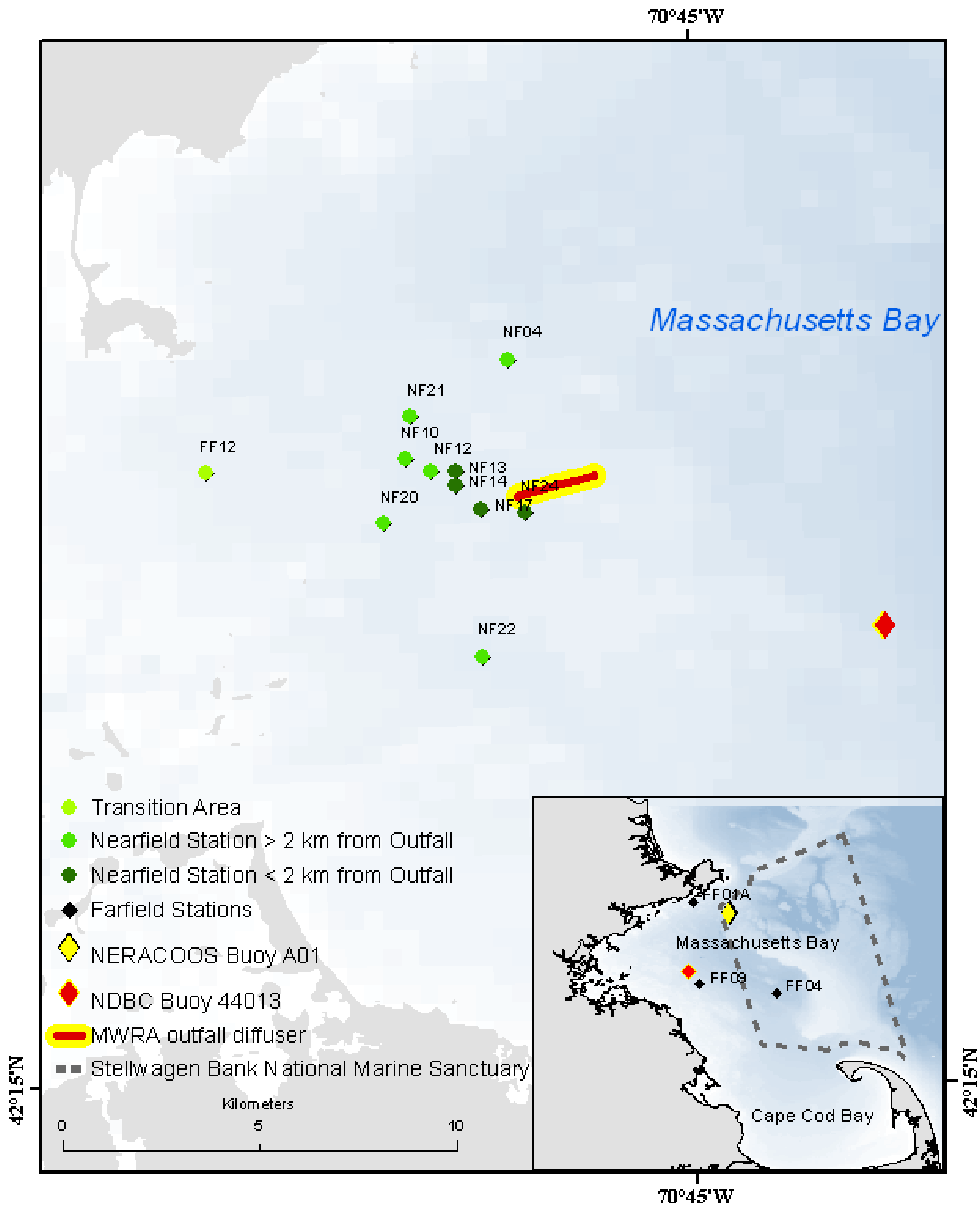

Figure 4-1. Soft-bottom monitoring stations. Also shown are two instrumented buoys, one operated by the Northeastern Regional Association of Coastal and Ocean Observing Systems (NERACOOS) and the other by the National Oceanic and Atmospheric Administration National Data Buoy Center (NDBC); the MWRA outfall diffuser; and the Stellwagen Bank National Marine Sanctuary.

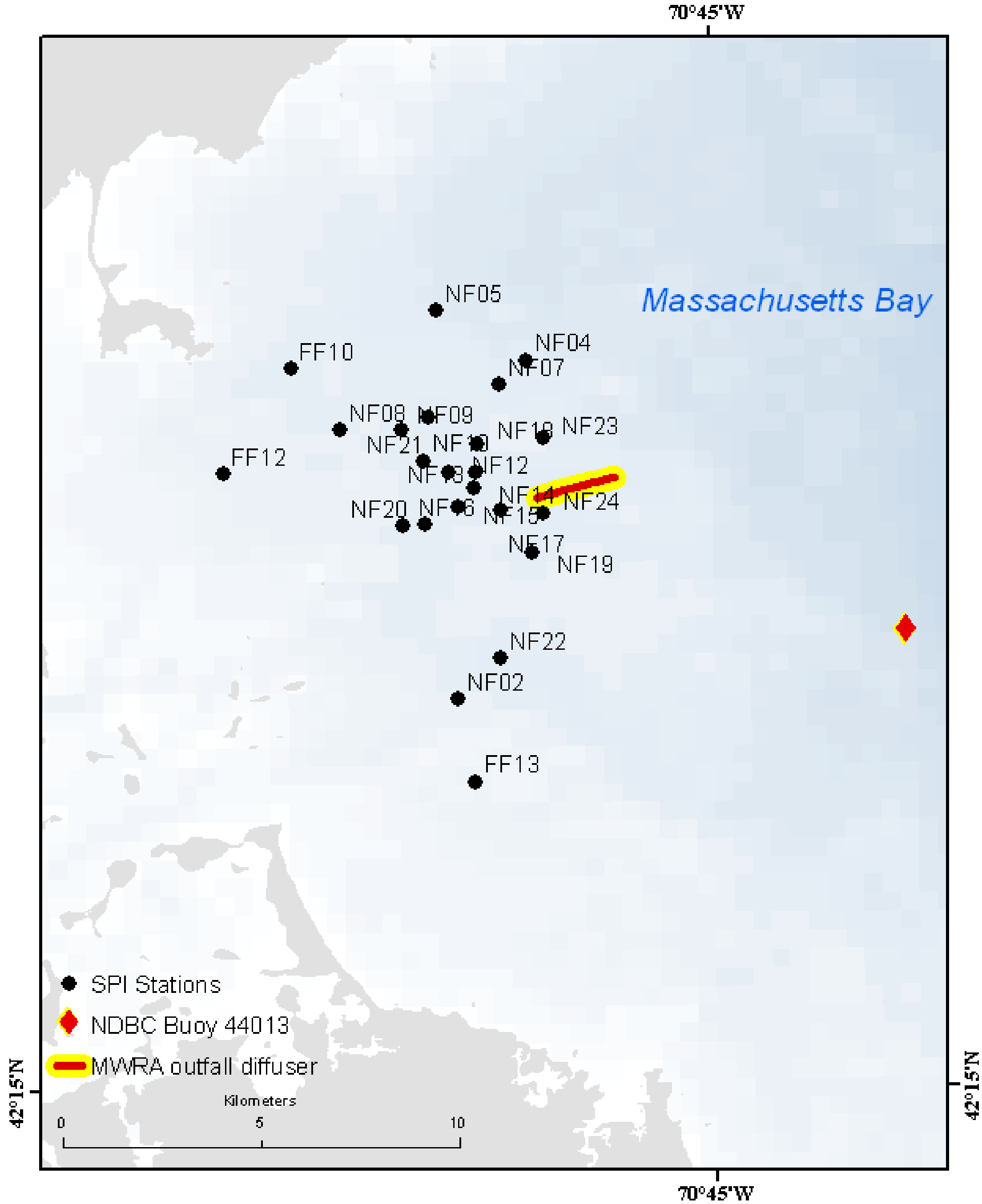

Figure 4-2. Sediment-profile imaging (SPI) stations. Also shown are two instrumented buoys, one operated by the Northeastern Regional Association of Coastal and Ocean Observing Systems (NERACOOS) and the other by the National Oceanic and Atmospheric Administration National Data Buoy Center (NDBC); and the MWRA outfall diffuser.

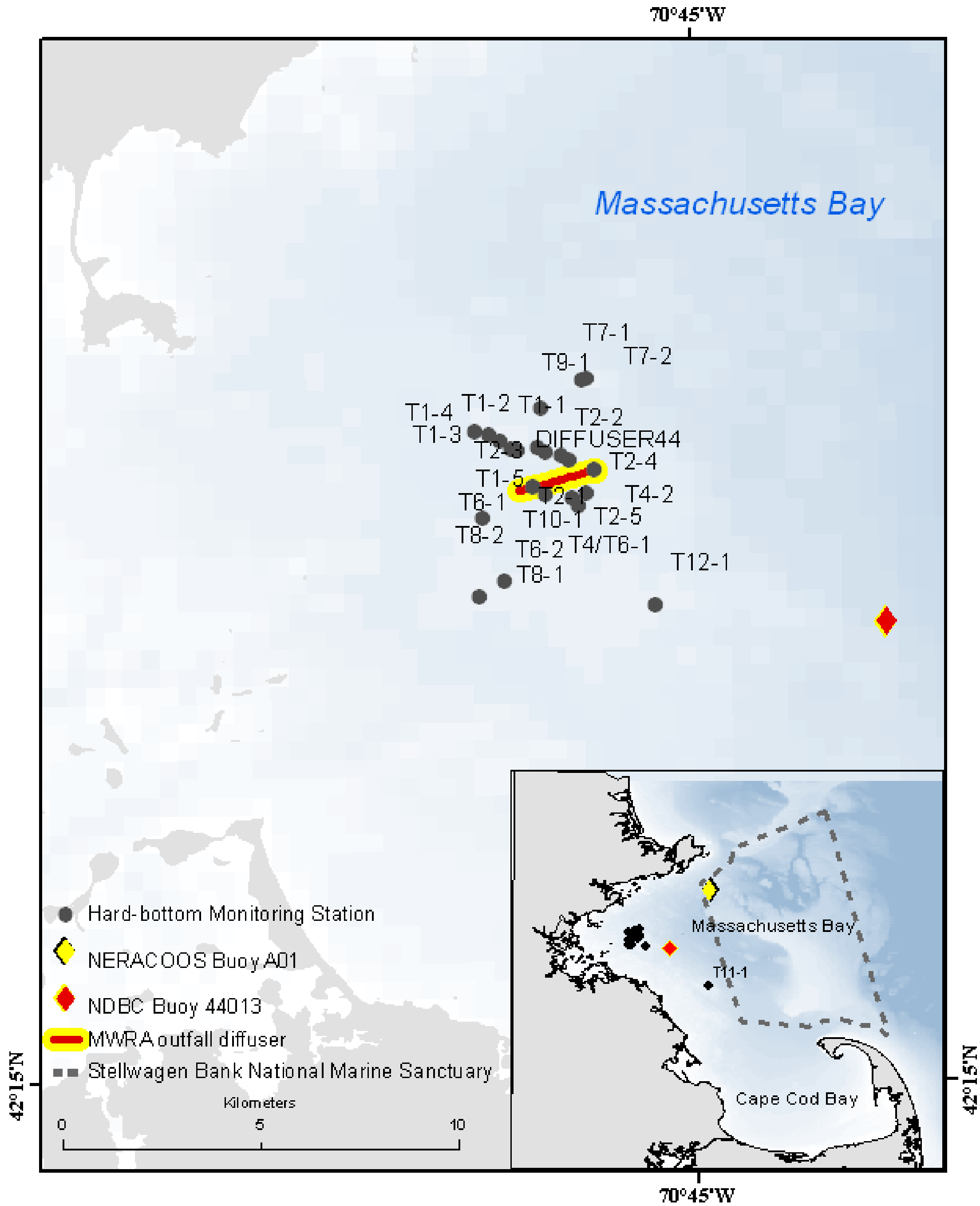

Figure 4-3. Hard-bottom stations. Video and still photographs are collected at 17 stations distributed among six transects and at six additional waypoints, including one active diffuser and one diffuser that has not been opened. Also shown are two instrumented buoys, one operated by the Northeastern Regional Association of Coastal and Ocean Observing Systems (NERACOOS) and the other by the National Oceanic and Atmospheric Administration National Data Buoy Center (NDBC); and the MWRA outfall diffuser.

Sediment grain size, total organic carbon (TOC), and the sewage tracer *Clostridium perfringens* spores are measured annually. Concentrations of contaminants in sediments, including PAHs, PCBs, chlorinated pesticides, and metals, are measured every third year, including 2011. Sediment-contaminant monitoring has also been complemented by special studies, primarily in association with the U.S. Geological Survey (USGS) (for example, Bothner and Butman 2007).

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

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

Most pollutant-effect monitoring studies of benthic communities, including the MWRA monitoring program, focus on the soft-bottom areas with finer-grained sediments, but such depositional areas are few in the vicinity of the outfall. Therefore, MWRA also conducts video and photographic surveys of the hard-bottom habitats found on the tops and flanks of drumlins in western Massachusetts Bay (Figure 4-4). Video and still photographs are taken at a series of stations or waypoints, including diffuser head #44 of the outfall (which was not opened) and diffuser head #2 (which is active). Photographs are examined for substrate type (top or flank of the drumlin, with relief defined by presence of boulders and cobbles), amount of sediment drape (the degree to which a layer of fine material covers the hard surface), and biota (taxa identified to species or species groups and counted). These surveys are conducted in June; beginning in 2011, they are conducted every third year, in the same year that sediment contaminants are studied.

Contingency Plan Thresholds

The Contingency Plan minimum threshold for RPD is set as half the baseline mean depth (Table 4-2). Thresholds for toxic contaminants in sediments are based on NOAA effects range median criteria, the median concentrations at which toxicity has been observed in laboratory tests (Wolf et al. 1994, Long et al. 1998.)

Table 4-2. Contingency Plan threshold values for RPD depth and sediment toxic contaminants.

Location	Parameter	Caution Level	Warning Level
Nearfield sediments	RPD depth	<1.18 cm	None
Nearfield PAHs (ng/g or parts per billion, dry weight)	Acenaphthene	None	500
	Acenaphylene		640
	Anthracene		1,100
	Benzo(a)anthracene		1,600
	Benzo(a)pyrene		1,600
	Chrysene		2,800
	Dibenzo(a,h)anthracene		260
	Fluoranthene		5,100
	Fluorene		540
	Naphthalene		2,100
	Phenanthrene		1,500
	Pyrene		2,600
	Total HMW PAH		9,600
	Total LMW PAH		3,160
	Total PAHs		44,792
Nearfield other organics (ng/g dry weight)	p,p'-DDE	None	27
	Total DDTs		46.1
	Total PCBs		180
Nearfield metals (µg/g or parts per million, dry weight)	Cadmium	None	9.6
	Chromium		370
	Copper		270
	Lead		218
	Mercury		0.71
	Nickel		51.6
	Silver		3.7
	Zinc		410

The thresholds for community parameters were recalculated beginning in 2011 based on the new sampling design (Table 4-3). Caution levels are set for benthic community parameters, and there are both caution and warning levels for percent opportunists.

Table 4-3. Contingency Plan threshold values for benthic community parameters.

Location	Parameter	Caution Level	Warning Level
Nearfield benthic community	Species per sample	<42.99 or >81.85	None
	Fisher's log-series alpha	<9.42 or >15.8	None
	Shannon diversity	<3.37 or >3.99	None
	Pielou's evenness	<0.57 or >0.67	None
Nearfield benthic opportunists	Percent opportunists	>10%	>25%

5. Fish and Shellfish

Background

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

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

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

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

Monitoring Design

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

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

Winter Flounder

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

Since 2004, chemical analyses for flounder are completed every third year, including 2006 and 2009, to determine tissue burdens and to evaluate whether contaminant burdens approach human health consumption limits. Chemical analyses (Table 5-2) of composite samples of fillets and livers include PCBs, pesticides, mercury, and lipids. Liver samples are also analyzed for PAHs, lead, silver, cadmium, chromium, copper, nickel, and zinc.

Lobster

Commercial lobstermen collect lobsters for the monitoring program. Since 2004, lobsters have been studied every third year, including 2006 and 2009. All lobsters are examined for external conditions, and chemical analyses are performed on composite samples. Meat (from the tail and claw) and hepatopancreas are analyzed for lipids, PCBs, pesticides, and mercury. Hepatopancreas samples are also analyzed for PAHs, lead, silver, cadmium, chromium, copper, nickel, and zinc.

Blue Mussel

Mussels are collected from a clean reference site (such as Stover's Point, Maine). They are placed in cages and deployed in replicate arrays at Cape Cod Bay, Boston Inner Harbor, Deer Island Light and the outfall site. Since 2004, mussel deployments and analyses have been carried out every third year, including 2006 and 2009.

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

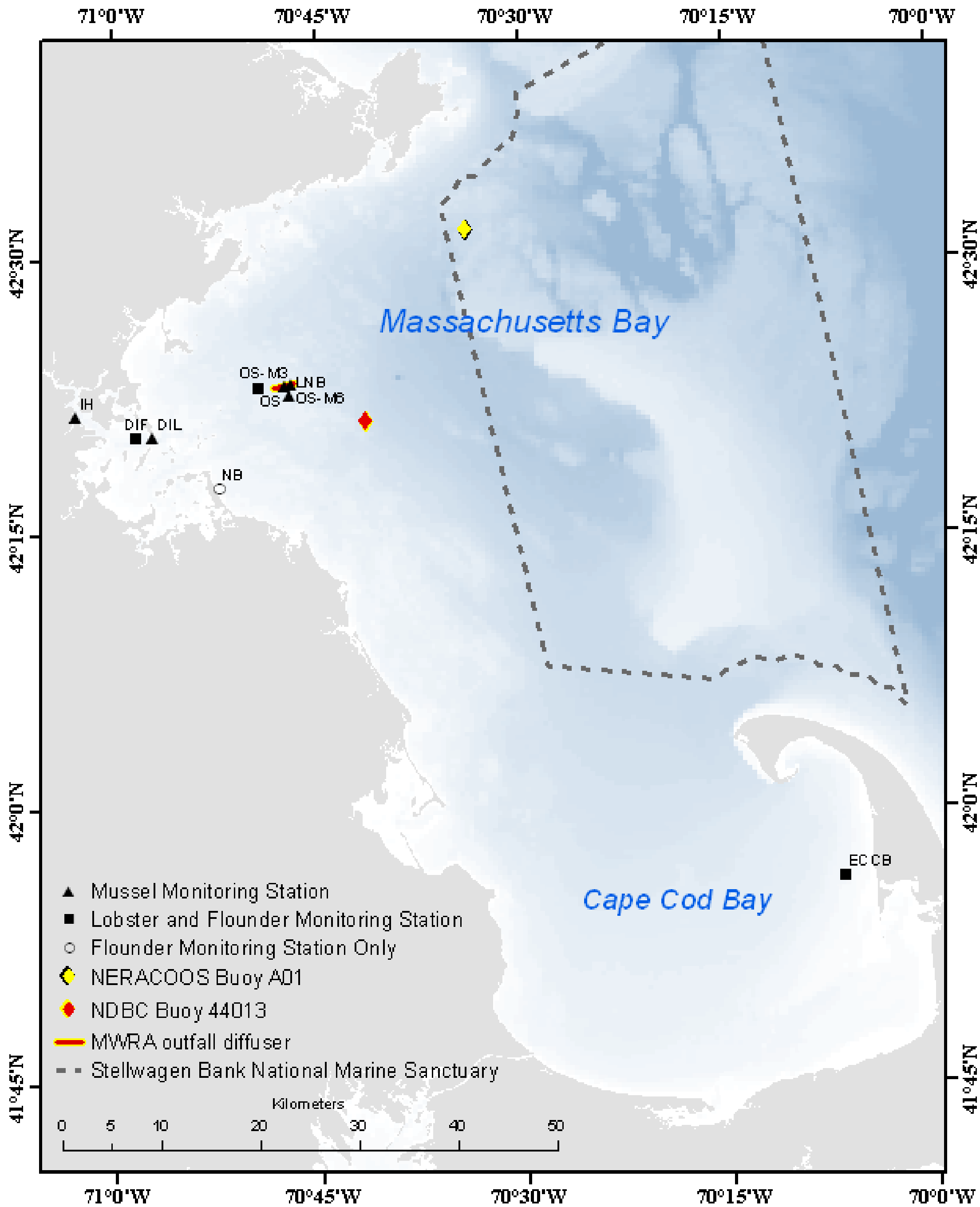

Figure 5-1. Fish-and-shellfish monitoring stations. Also shown are two instrumented buoys, one operated by the Northeastern Regional Association of Coastal and Ocean Observing Systems (NERACOOS) and the other by the National Oceanic and Atmospheric Administration National Data Buoy Center (NDBC); the MWRA outfall diffuser; and the boundaries of the Stellwagen Bank National Marine Sanctuary.

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

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

Contingency Plan Thresholds

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

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

Location/ Parameter Type	Parameter	Caution Level	Warning Level
Flounder tissue nearfield	PCB	1 ppm wet weight	1.6 ppm wet weight
	Mercury	0.5 ppm wet weight	0.8 ppm wet weight
Flounder tissue, lipid normalized, nearfield	Chlordane	484 ppb	None
	Dieldrin	127 ppb	None
	DDT	1552 ppb	None
Flounder nearfield	Liver disease (CHV)	44.9%	None
Lobster tissue nearfield	PCB	1 ppm wet weight	1.6 ppm wet weight
	Mercury	0.5 ppm wet weight	0.8 ppm wet weight
Lobster tissue, lipid normalized, nearfield	Chlordane	150 ppb	None
	Dieldrin	322 ppb	None
	DDT	683 ppb	None
Mussel tissue nearfield	PCB	1 ppm wet weight	1.6 ppm wet weight
	Lead	2 ppm wet weight	3 ppm wet weight
	Mercury	0.5 ppm wet weight	0.8 ppm wet weight
Mussel tissue, lipid normalized, nearfield	Chlordane	205 ppb	None
	Dieldrin	50.1 ppb	None
	DDT	483 ppb	None
	PAH	2160 ppb	None

6. Special Studies

Besides monitoring the effluent and the water column, sea floor, and fish and shellfish in Massachusetts Bay and the surrounding area, MWRA conducts special studies in response to specific permit requirements, scientific questions, and public concerns. Some studies were conducted over many years and ended with the monitoring plan revisions. For example, studies of primary productivity and nutrient flux at the sediment-water interface were conducted each year until the studies ended at the end of 2010.

Other long-term studies continue. Since 1995, MWRA has included endangered species observers on monitoring surveys. Besides providing observational data, the presence of observers trained to identify marine mammals addresses a request by the National Marine Fisheries Service that MWRA take active steps to minimize the chances of a collision of one of its survey vessels with a right whale.

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

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

7. Stellwagen Bank National Marine Sanctuary

Background

The Gerry E. Studds Stellwagen Bank National Marine Sanctuary comprises 842 square miles located at the boundary between Massachusetts Bay and the rest of the Gulf of Maine. Its landward boundaries lie approximately 25 miles east of Boston, three miles north of Provincetown, and three miles south of Gloucester. Stellwagen Basin, which is partially within the sanctuary, is the deepest part of Massachusetts Bay with water depths of about 260 feet. It is a long-term sink for fine-grained sediments. Stellwagen Bank, a sand-and-gravel plateau, lies to the east of Stellwagen Basin and has water depths of about 65 feet. Tidal mixing of nutrients throughout the relatively shallow water column creates a rich habitat for marine life on Stellwagen Bank.

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

The sanctuary issued a Management Plan and Environmental Assessment in 2010 which listed concerns for the sanctuary (U.S. Department of Commerce 2010, available at http://stellwagen.noaa.gov/management/fmp/fmp2010.html.) Concerns include commercial fishing, commercial shipping, whale-watch boat collisions with whales, invasion by exotic species, harmful algal blooms, and the potential for degraded water quality associated with population growth in the region, offshore industrialization such as liquefied natural gas (LNG) ports, and underwater noise. Climate change and ocean acidification are also concerns. While noting that the MWRA discharge (as well as legacy contaminants exported from Boston Harbor) was a potential source of contamination, the report summarized water quality analyses conducted by MWRA and the sanctuary, and found “no evidence of increased eutrophication or unacceptable contaminant loads in the sanctuary relative to outfall start-up.”

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

Monitoring Design

MWRA's regular water-column and sea-floor monitoring efforts include stations within and near the sanctuary. Beginning in 2011, based on the findings of outfall monitoring from 2000–2010, most of the water-column boundary stations that were within the sanctuary were eliminated from the monitoring program. However, the frequency of sampling the remaining farfield stations, including stations between the outfall and the sanctuary, increased from six to nine times per year. In addition, plankton is now monitored at all stations. Generally, if there were effects of the MWRA outfall, they would be expected to be detected first at stations closer to the discharge (N04, N07, F15, see Figure 3-2). Within the sanctuary boundary, station F29 is used to assess water quality off Provincetown, and the NERACOOS Buoy A01 gathers water quality at the north-west corner of the sanctuary. Station F22 is used to assess water quality in Stellwagen Basin, just to the west of the sanctuary's western boundary.

The seafloor design has been modified as well beginning in 2011. One MWRA sea-floor station is within the sanctuary, in Stellwagen Basin (FF04, see Figure 4-1). Station FF09 is adjacent to the basin, southeast of the diffuser. A third sea-floor station (FF01A) is just northwest of the sanctuary boundary.

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List of Acronyms

ARRS	*Alexandrium* Rapid Response Survey
BOD	Biochemical oxygen demand
cBOD	Carbonaceous biochemical oxygen demand
CHV	Centrotubular hydropic vacuolation
DDE	Dichlorodiphenyldichloroethylene
DDT	Dichlorodiphenyltrichloroethane
DITP	Deer Island Treatment Plant
DO	Dissolved oxygen
EPA	U.S. Environmental Protection Agency
HMW	High molecular weight
IAAC	Inter-agency Advisory Committee
LC50	50% mortality concentration
LMW	Low molecular weight
LNG	Liquefied natural gas
MADEP	Massachusetts Department of Environmental Protection
MGD	Million gallons per day
MWRA	Massachusetts Water Resources Authority
NCCOS	National Centers for Coastal Ocean Science
NE	Northeast
NDBC	National Data Buoy Center
NERACOOS	Northeastern Regional Association of Coastal and Ocean Observing Systems
NOAA	National Oceanic and Atmospheric Administration
NOEC	No observable effect concentration
NPDES	National Pollutant Discharge Elimination System
NW	Northwest
OMSAP	Outfall Monitoring Science Advisory Panel
OMTF	Outfall Monitoring Task Force
PAH	Polycyclic aromatic hydrocarbon
PCB	Polychlorinated biphenyl
PIAC	Public Interest Advisory Committee
RPD	Redox potential discontinuity
PSP	Paralytic shellfish poisoning
S	South
SE	Southeast
SEIS	Supplemental Environmental Impact Statement
SBNMS	Stellwagen Bank National Marine Sanctuary
SPI	Sediment-profile imaging
TOC	Total organic carbon
TRAC	Toxic Reduction and Control Program
TSS	Total suspended solids
USGS	U.S. Geological Survey

Monitoring Questions and Answers

Monitoring Question	Answer
Do effluent pathogens exceed the permit limits?	No. Secondary treatment and disinfection effectively remove pathogens. In thousands of tests, daily fecal coliform limits have been exceeded twice, both times during storms.
Does acute or chronic toxicity of effluent exceed the permit limit?	No. In more than 600 tests, there have been four exceedances of permit limits.
Do effluent contaminant concentrations exceed permit limits?	No. Discharges of priority pollutants are well below predictions and in most cases meet receiving water quality criteria even before dilution.
Do conventional pollutants in the effluent exceed permit limits?	No. Discharges of solids and BOD have decreased by 87% compared to the old treatment plant. In more than 600 tests, there have been three exceedances of suspended solids limits, which occurred during an upset of the secondary treatment process by an industrial discharge.
What are the concentrations of contaminants in the influent and effluent and their associated variability?	There has been great success in reducing contaminants in the influent and a high degree of removal of contaminants by the treatment system, with consistently low concentrations since secondary treatment was implemented.
Do levels of contaminants in water outside the mixing zone exceed water quality standards?	No. Water quality standards are not exceeded. The projected degree of mixing was confirmed by plume studies conducted in 2001. Ongoing effluent monitoring assures that standards are not violated.
Are pathogens transported to shellfish beds at levels that might affect shellfish consumer health?	No. Dilution is sufficient for pathogens to reach background concentrations before reaching shellfish beds. Dilution rates were confirmed by plume studies conducted in 2001.
Are pathogens transported to beaches at levels that might affect swimmer health?	No. Dilution is sufficient for pathogens to reach background concentrations before reaching beaches. Dilution rates were confirmed by plume studies conducted in 2001.
Has the clarity and/or color of the water around the outfall changed?	No. Although clarity and color have not changed, there are occasional observations of tiny bits of fat, similar to samples collected at the treatment plant.
Has the amount of floatable debris around the outfall changed?	Floatable debris of concern is rare in the effluent. Signs of effluent can occasionally be detected in the field.
Are the model estimates of short-term (less than one day) effluent dilution and transport accurate?	Yes. Model estimates were confirmed by plume studies conducted in 2001.

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

Monitoring Question	Answer
Has the species composition of phytoplankton or zooplankton changed in the vicinity of the outfall or at selected farfield stations in Massachusetts Bay or Cape Cod Bay? If so, can these changes be correlated with effluent of ambient water nutrient concentrations, or can farfield changes be correlated with nearfield changes?	The increase in frequency of *Phaeocystis* blooms is the most marked change in the phytoplankton community, and the region appears to be entering a period of frequent red tides. Those changes have not been attributed to the outfall. There have been no changes in the zooplankton community beyond normal ecological fluctuations.
What is the level of sewage contamination and its spatial distribution in Massachusetts and Cape Cod bays sediments before discharge through the new outfall?	The effects of historic inputs from Boston Harbor and other sources can be detected, particularly in coastal stations.
Has the level of sewage contamination or its spatial distribution in Massachusetts and Cape Cod bays sediments changed after discharge through the new outfall?	An effluent signal can be detected only in *Clostridium perfringens* spores, the most sensitive sewage tracer, and is only detectable within a few kilometers of the outfall.
Has the concentration of contaminants in sediments changed?	There has been no general increase in contaminants. An effluent signal can be detected as *Clostridium perfringens* spores within 2 km of the diffuser.
Has the soft-bottom community changed?	Changes have occurred but are the result of natural variation. The changes are not significant and are not attributed to the outfall.
Have the sediments become more anoxic; that is, has the thickness of the sediment oxic layer decreased?	No. The sediment RPD has been deeper during post-diversion years rather than shallower; that is, the sediments are more rather than less oxic.
Are any benthic community changes correlated with changes in levels of toxic contaminants (or sewage tracers) in sediments?	There have been no changes detected, even within 2 km of the outfall.
Has the hard-bottom community changed?	There have been no changes that can be attributed to the outfall. There have been decreases in coralline algae at some stations, but the geographic pattern does not suggest an outfall effect.
How do the sediment oxygen demand, the flux of nutrients from the sediment to the water column, and denitrification influence the levels of oxygen and nitrogen in the water near the outfall? Have the rates of these processes changed?	These conditions were described by baseline monitoring. Conditions have improved in Boston Harbor and have not changed in Massachusetts Bay.
Has the level of contaminants in the tissues of fish and shellfish around the outfall changed since discharge began?	There has been no substantial change in flounder or lobster contaminant body burdens, with concentrations remaining very low. There have been detectable increases in concentrations of some contaminants in mussel arrays deployed within the mixing zone at the outfall.

Monitoring Question	Answer
Do the levels of contaminants in the edible tissue of fish and shellfish around the outfall represent a risk to human health?	There have been no changes that would pose a threat to human health. Regional patterns have persisted since the baseline period, and there appears to be a general long-term downward trend for most contaminant levels.
Are the contaminant levels in fish and shellfish different between the outfall, Boston Harbor, and a reference site?	Differences were documented during baseline monitoring. Regional patterns have persisted since the diversion, with concentrations being highest in Boston Harbor and lowest in Cape Cod Bay.
Has the incidence of disease and/or abnormalities in fish or shellfish changed?	There have been no increases in disease or abnormalities in response to the outfall; there has been a long-term downward trend in liver disease in fish from near Deer Island and near the outfall.

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